NASA CR-111891
MDC G2282

TEST REPORT

TEST RESULTS

OPERATIONAL NINETY-DAY MANNED TEST OF A REGENERATIVE LIFE SUPPORT SYSTEM

MAY 1971



02 N71-28877 (ACCESSION NUMBER) (THRU)
FACILIT

Prepared under Contract No. NAS1-8997

by Advance Biotechnology and Power Department
McDonnell Douglas Astronautics Company
Huntington Beach, California

for

LANGLEY RESEARCH CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

150

NASA CR-111881
MDC G2282

TEST REPORT

TEST RESULTS

OPERATIONAL NINETY-DAY MANNED TEST OF A REGENERATIVE LIFE SUPPORT SYSTEM

Prepared under Contract No. NAS1-8997

by Advance Biotechnology and Power Department
McDonnell Douglas Astronautics Company
Huntington Beach, California

for

LANGLEY RESEARCH CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOREWORD

An Operational 90-Day Manned Test of a Regenerative Life Support System was completed in a Space Station Simulator (SSS) on September 11, 1970. This test was conducted by the Advance Biotechnology and Power Department of the McDonnell Douglas Astronautics Company (MDAC), Huntington Beach, California, under Contract NAS1-8997. This project was performed for the NASA-Langley Research Center under the direction of Mr. A. O. Pearson of the Space Systems Division, under the technical cognizance of Walton L. Jones, M. D., Director of the Biotechnology and Human Research Division of the Office of Advanced Research and Technology, NASA Headquarters, and his staff.

A NASA Resident Technical Director was assigned to monitor the 5 and 90-day manned tests. The following Resident Technical Directors participated in this program on a rotational basis:

D. C. Grana
R. W. Johnson
C. W. McKee
D. C. Popma

The program was supervised by K. H. Houghton, M. D., Chief Technology Engineer of the Advance Biotechnology and Power Department, MDAC. J. K. Jackson was the Program Manager for McDonnell Douglas. Assisting him were J. R. Wamsley, M. D., Test Medical Director; M. S. Bonura, Test Engineering Director, and J. S. Seeman, Test Man/Machine Director. Preparation of the test facility was accomplished under capital expenditures AFE No. 1410-758 and the MDAC Independent Research and Development program.

This report was prepared under the direction of J. K. Jackson with major assistance from:

M. S. Bonura
J. R. Wamsley, M. D.
J. S. Seeman
G. E. Allen
L. G. Barr
J. F. Harkee
P. P. Mader, Ph. D.
T. J. Linzey
M. V. McLean
N. A. Jones
A. A. Kelton, Ph. D.
D. J. Myers
K. J. Levinson
E. S. Mills
M. M. Okanes, Ph. D.
D. F. Putnam
E. R. Regis
R. E. Shook
M. Sofios
E. C. Thomas
R. F. Gabriel
S. S. Viglione

Preceding page blank

Several sections of this report have relied heavily on contributions from principal investigators outside the MDAC organization. Among these are Section 3.8, Glycerol Drink, which was prepared by Jacob Shapira, Ph. D., of NASA-Ames Research Center, and Section 3.10, Critical Task Tester, which was prepared by R. Wade Allen and Henry R. Jex of Systems Technology, Inc., for NASA-Ames Research Center. These documents have been included herein to present as complete a picture as possible of the test results.

Contributions were also made by many other engineers and scientists at the NASA agencies, the Air Force and Navy laboratories, other Government offices, the MDAC staff, and the many industrial organizations who participated in the accomplishment of this test. Appendix A is a listing of these participants.

The complete test report consists of the following parts:

NASA CR-1835 Program Operational Summary—This volume presents a brief review of the program objectives, procedures and results. It summarizes the conclusions and recommendations for future studies. It is intended to give an overview of the program and to serve as a reference guide to the details which are presented in the other two volumes.

NASA CR-111881 Test Results—This volume provides the results, conclusions and recommendations from the test. This volume is divided into three major sections covering the Life Support System, the Man/Machine Results, and the Biomedical operations.

NASA CR-111882 Final Test Plan and Procedure—This is an update of the Master Test Plan and Procedure used as a controlling document during the 90-Day Test. The original release of this report was in July 1969. As planned, frequent changes were made to adapt the program as the study reached more detailed levels. The final version includes a detailed description of test equipment and procedures as they were during the test. Also included is a summary of the implementation of the document with recommendations to improve its overall effectiveness.

CONTENTS

Section 1	INTRODUCTION		1
	1.1	Program Objectives	1
	1.2	Program Description	2
	1.3	International System of Units	5
Section 2	LIFE SUPPORT SYSTEM		9
	2.1	Operational Summary	17
	2.1.1	Maintenance and Repair Operations	17
	2.1.2	Mass Balance	25
	2.1.3	Thermal Balance	35
	2.1.4	Electrical Power Usage	37
	2.1.5	Trace Contaminants	42
	2.2	Water Management	63
	2.2.1	Subsystem Description	63
	2.2.2	Qualification and Certification Procedures	75
	2.2.3	Subsystem Performance	92
	2.3	Atmosphere Purification	130
	2.3.1	Carbon Dioxide Concentrators	144
	2.3.2	Thermal Control	156
	2.3.3	Humidity Control	162
	2.4	Atmosphere Supply and Pressurization	165
	2.4.1	Integrated Sabatier Reactor/Toxin Control	166
	2.4.2	Water Electrolysis	177
	2.4.3	Two-Gas Controller	202

2.5	Food Management	210
2.5.1	Description	210
2.5.2	Food Evaluation	215
2.5.3	Microwave Oven Evaluation	220
2.6	Waste Management	230
2.6.1	Commode	230
2.6.2	Urine Collector	237
2.6.3	Waste Storage and Disposal	239
2.6.4	Maintenance and Repair	243
2.7	Conclusions and Recommendations	243
2.7.1	Life Support System Operation	245
2.7.2	Water Management	249
2.7.3	Atmosphere Purification	250
2.7.4	Atmosphere Supply and Pressurization	252
2.7.5	Food Management	253
2.7.6	Waste Management	254
2.7.7	Program Aspects	255
Section 3	MAN-SYSTEMS INTEGRATION	257
3.1	Crew Selection, Training, and Performance	258
3.1.1	Selection	258
3.1.2	Training Program	263
3.1.3	Crew Performance	270
3.1.4	Conclusions and Recommendations	275
3.2	Staff Selection, Training, and Certification	277
3.2.1	Staff Selection	278
3.2.2	Training and Certification Program	279
3.2.3	Conclusions and Recommendations	280
3.3	Habitability Evaluation	284
3.3.1	Procedures	284
3.3.2	Results	284
3.3.3	Summary and Conclusions	295

3.4	Behavioral Program	297
3.4.1	Procedures	298
3.4.2	Results	300
3.4.3	Discussion	320
3.4.4	Conclusions	325
3.5	Manned Mission Activity Analysis	327
3.5.1	Mathematical Model Description	328
3.5.2	Pretest Documentation	331
3.5.3	Crew and Observer Training	350
3.5.4	Test Monitoring	351
3.5.5	Data Analysis and Results	356
3.5.6	Conclusions	374
3.5.7	Recommendations	375
3.6	Behavioral Acoustics	376
3.6.1	Test Equipment and Methods	376
3.6.2	Procedures	382
3.6.3	Results	384
3.6.4	Discussion	406
3.6.5	Conclusions and Recommendations	407
3.7	EEG Monitoring and Sleep Studies	409
3.7.1	Instrumentation	410
3.7.2	Selection and Training of Participants	410
3.7.3	Baseline Recording Session	412
3.7.4	Data Collection	412
3.7.5	Data Analysis	412
3.7.6	Results	414
3.7.7	Conclusions	420
3.8	Glycerol Food Supplement	426
3.8.1	Materials and Methods	428
3.8.2	Results	429
3.8.3	Discussion	430
3.8.4	Recommendations	432
3.9	Non-Interference Performance Assessment (NIPA)	432
3.9.1	Experimental Methods	433

	3.9.2	Results	443
	3.9.3	Discussion	443
	3.9.4	Conclusions and Recommendations	487
	3.10	Critical Task Tester	489
	3.10.1	Control Tasks	489
	3.10.2	Test Setup and Equipment	492
	3.10.3	Training	492
	3.10.4	General Protocol	495
	3.10.5	Results	495
	3.10.6	Conclusions	500
Section 4	BIOMEDICINE		501
	4.1	Pretest Procedures and Baseline Data	502
	4.1.1	Physical Examination	502
	4.1.2	Clinical Chemistries	502
	4.1.3	Radiological Health	503
	4.1.4	Pulmonary Function	511
	4.2	Test Procedures/Operations	512
	4.2.1	Medical Monitors	512
	4.2.2	Medical Station	512
	4.2.3	Onboard Medical Kit	512
	4.2.4	Medical Interview	512
	4.2.5	Basal Vital Signs and Skin Folds	513
	4.2.6	Clinical Chemistries	513
	4.2.7	Radiological Monitoring	515
	4.2.8	Electrocardiogram	516
	4.2.9	Pulmonary Spirometry	516
	4.3	Post-Test Procedures	517
	4.3.1	Physical Examination	517
	4.3.2	Clinical Chemistries	518
	4.3.3	Pulmonary Function	518
	4.4	Special Studies	521

4.4.1	Carbon Dioxide Exposure Studies	521
4.4.2	NMRI Blood Studies	524
4.4.3	Automated Visual Sensitivity Tester	526
4.4.4	Isotope Studies	528
4.4.5	Physical Conditioning Program	529
4.5	Test Results	533
4.5.1	Operations	533
4.5.2	Basal Signs and Skin Fold Measurements	535
4.5.3	Clinical Blood Chemistry, Urine Analysis and Hematology	538
4.5.4	Radiological Monitoring	544
4.5.5	Electrocardiography	553
4.5.6	Pulmonary Spirometry	554
4.5.7	Contingency Samples	555
4.5.8	Special Studies	556
4.6	Microbiology	596
4.6.1	Collection and Passout of Samples	596
4.6.2	Laboratory Processing of Samples	596
4.6.3	Results	607
4.6.4	Discussion	629
4.6.5	Conclusions	631
4.7	Conclusions and Recommendations	631
4.7.1	Medical Operations	632
4.7.2	Basal Signs and Skin Fold Measurements	633
4.7.3	Clinical Blood Chemistry and Hematology	634
4.7.4	Routine Urinalysis and Urine Chemistry	635
4.7.5	Radiological Monitoring	635
4.7.6	Electrocardiography (ECG)	637
4.7.7	Pulmonary Spirometry	637
4.7.8	Contingency Samples	638
4.7.9	Special Studies	638
4.7.10	Microbiology Program	642

	REFERENCES	645
Appendix A	PARTICIPANTS	655
Appendix B	CREW TRAINING—FINAL EXAMINATION	657
Appendix C	HABITABILITY INVENTORY QUESTIONNAIRE	661
Appendix D	CREW OPERATING GROUND RULES	673
Appendix E	NOISE QUESTIONNAIRE	679
Appendix F	NIPA DATA COLLECTION EXHIBITS	683
Appendix G	NIPA DATA REDUCTION EXHIBITS	689
Appendix H	GLOSSARY OF NIPA INDICES	701
Appendix I	BLOOD CHEMISTRY RESULTS	709
Appendix J	URINE CHEMISTRY RESULTS	711
Appendix K	USNSMC VENOUS BLOOD GAS AND ELECTROLYTE DATA	715

FIGURES

1-1	Space Station Simulator	5
1-2	Space Station Simulator Interior Arrangement	6
2-1	Life Support System Block Diagram	10
2-2	SSS Interior Equipment Area—Looking Forward	11
2-3	SSS Interior Equipment Area—Looking Aft	12
2-4	Life Support Instrumentation Data Management System	15
2-5	SSS Operations Control Area	16
2-6	Life Support System Operation Summary	18
2-7	Overall Water Mass Balance	26
2-8	Potable Water Mass Balance—Days 5 through 12	27
2-9	Potable Water Mass Balance—Days 46 through 53	28
2-10	Potable Water Mass Balance—Days 81 through 90	29
2-11	Wash Water Mass Balance	30
2-12	Gaseous Mass Balance	33
2-13	Average Crew Input/Output Data	35
2-14	Overall Thermal Balance—Typical for Day 33	38
2-15	Overall Thermal Balance—Typical for Day 50	38
2-16	Overall Thermal Balance—Typical for Day 58	39
2-17	Overall Thermal Balance—Typical for Day 83	39
2-18	Power System Block Diagram	41
2-19	Summary of Power Load Profile	42
2-20	Power Load Profile for Day 67, Circuit WIR-D2	46
2-21	Power Load Profile for Day 67, Circuit WIR-D3	46
2-22	Power Load Profile for Day 67, Circuit WIR-D4	47
2-23	Power Load Profile for Day 67, Circuit WIR-D5	47
2-24	Power Load Profile for Day 67, Circuit WIR-D6	48

2-25	Power Load Profile for Day 67, Circuit WIR-D7	48
2-26	Freon 113 and Acetone Concentration	56
2-27	Toluene and Ethyl Alcohol Concentration	57
2-28	Dichloroethane and MEK Concentration	57
2-29	2-Ethyl Hexanol and 2-Ethyl Butanol Concentration	58
2-30	Methane and Carbon Monoxide Concentration	58
2-31	Integrated Potable H_2O and Humidity Control Subsystem Schematic	64
2-32	Potable Water Distribution Unit Schematic	65
2-33	Wash Water Recovery Unit Schematic	66
2-34	VD-VF Movable Radiation Shield	67
2-35	VD-VF Water Recovery Unit Installation—Urine Accumulator and Condensate Tanks	68
2-36	Cooled Water Isotope Storage Installation	69
2-37	Wick Evaporator Module	71
2-38	Potable Water Recovery and Humidity Control Unit—Air Evaporation Unit, VD-VF Unit, Water Control Panel	72
2-39	Detoxification-Multifiltration Unit Schematic	73
2-40	Potable Water Dispensing Unit	74
2-41	Wash Water Recovery Unit—Multifiltration Columns and Sink	76
2-42	Procedures for Quantification and Identification of Microorganisms in Water Sample	80
2-43	Identification Scheme for Gram Negative Organisms	81
2-44	Checkoff Sheet	91
2-45	Potable Water Tank Status Card	92
2-46	System Status Board	93
2-47	Potable Water Daily Inventory	95
2-48	Reclaimed Potable Water Analysis	95
2-49	VD-VF Product Water Analyses and Boiler Temperature at Condenser	104
2-50	VD-VF Boiler 2 Prior to Assembly	107
2-51	VD-VF Boiler 2 After Disassembly	108
2-52	VD-VF Boiler 2 Interior View	108

2-53	VD-VF Membrane Filter	109
2-54	VD-VF Expended Catalyst	109
2-55	Disassembled Wick Package	113
2-56	Reclaimed Wash Water Analysis	119
2-57	Used Wash Water Filters	122
2-58	Crew Total Urine Output	126
2-59	Urine Production by Shift	127
2-60	Crew Number of Micturitions per Day	128
2-61	Urine Volume per Micturition	129
2-62	Total Dissolved Solids of Urine	131
2-63	Specific Conductivity of Urine	132
2-64	Specific Conductivity vs Total Dissolved Solids of Urine	133
2-65	Total Organic Carbon of Urine	134
2-66	Total Organic Carbon vs Total Dissolved Solids of Urine	135
2-67	Measured Specific Gravity of Urine	136
2-68	Measured Specific Gravity vs Total Dissolved Solids of Urine	137
2-69	pH of Urine	138
2-70	pH vs Total Dissolved Solids of Urine	139
2-71	Refractive Index of Urine	140
2-72	Refractive Index vs Total Dissolved Solids of Urine	141
2-73	Solute Concentration of Urine	142
2-74	Solute Concentration vs Total Dissolved Solids of Urine	143
2-75	CO_2 Concentrator–Solid Amine Unit	145
2-76	Solid Amine CO_2 Concentrator Unit	146
2-77	CO_2 Concentrator–Molecular Sieve Unit	147
2-78	Molecular Sieve CO_2 Concentrator Unit	148
2-79	Carbon Dioxide Partial Pressure	150
2-80	Solid Amine CO_2 Concentrator Performance (Day 53, 14:24:01 to 14:49:01)	152
2-81	Molecular Sieve Temperature Performance (Day 17–1, 000 Hours)	153

2-82	Molecular Sieve CO_2 Partial Pressure Performance (Day 17–1, 000 Hours)	154
2-83	Molecular Sieve Pressure Performance (Day 17–1, 000 Hours)	155
2-84	Thermal Balance of Solid Amine Unit	159
2-85	Thermal Balance of Molecular Sieve Unit	159
2-86	Thermal Conditioning Unit Schematic	160
2-87	Average Test Day Simulator Temperature	161
2-88	Thermal Conditioning Unit Coarse Particle Filters at Test Completion	164
2-89	Humidity Control Schematic	164
2-90	Dew Point Levels	165
2-91	Integrated Sabatier and Toxin Control	167
2-92	Integrated Sabatier Reactor/Toxin Control	168
2-93	Sabatier Water Production	172
2-94	Hydrogen Utilization	172
2-95	Carbon Dioxide Utilization	173
2-96	Sabatier Exhaust Products	174
2-97	Sabatier Mixture Ratio	176
2-98	On-Line Hydrocarbon Analysis	178
2-99	Water Electrolysis Unit–Allis Chalmers	180
2-100	Water Electrolysis Unit–Lockheed	182
2-101	Simplified Gas Flow Schematic	184
2-102	Oxygen Generation	185
2-103	Time History of System Pressures	186
2-104	Module Position No. 2 Temperature Performance	187
2-105	Module Position No. 3 Temperature Performance	188
2-106	Module Position No. 2 Electrical Performance	189
2-107	Module Position No. 3 Electrical Performance	190
2-108	Cell Voltage Variations	191
2-109	Modules 2A and 2B of Electrolysis Unit (Lockheed) Performance–Days 1 through 30	195
2-110	Modules 2A and 2B of Electrolysis Unit (Lockheed) Performance–Days 31 through 60	196

2-111	Modules 2A and 2B of Electrolysis Unit (Lockheed) Performance—Days 61 through 90	197
2-112	Modules 4A and 4B of Electrolysis Unit (Lockheed) Performance—Days 1 through 30	198
2-113	Modules 4A and 4B of Electrolysis Unit (Lockheed) Performance—Days 31 through 60	199
2-114	Modules 4A and 4B of Electrolysis Unit (Lockheed) Performance—Days 61 through 90	200
2-115	Two-Gas Control and Onboard Water Electrolysis Unit	203
2-116	Electronic Interface Connections	204
2-117	Block Diagram of Oxygen and Nitrogen Channels of the Two-Gas Atmosphere Control Unit	205
2-118	Oxygen Partial Pressure	208
2-119	Nitrogen Partial Pressure	208
2-120	Total Atmosphere Pressure	209
2-121	Food Preparation Area—Oven Installation	221
2-122	Outgassing Test Setup	224
2-123	Waste Management Subsystem	231
2-124	Commode/Urine Collector Units	232
2-125	Commode Schematic	233
2-126	Commode Uses per Day	234
2-127	Slinger Assembly After Test	236
2-128	Schematic Diagram of Urine Collector	237
2-129	Food Preparation Area	240
2-130	Waste Liquid Overboard Dump Installation	242
3-1	Instructor Utilization	268
3-2	Distribution of Trainee Hours	268
3-3	Sample Work Rest Cycle	272
3-4	Habitability Inventory	285
3-5	Acoustic Spectra and Criteria	292
3-6	Acoustic Noise Background Recorded in the Crew Quarters with Equipment On	293
3-7	Hostility (Directed Toward Onboard Crew) Scale Results for Crewman 1	301
3-8	Hostility (Directed Toward Onboard Crew) Scale Results for Crewmen 2	301

3-9	Hostility (Directed Toward Onboard Crew) Scale Results for Crewman 3	302
3-10	Hostility (Directed Toward Onboard Crew) Scale Results for Crewman 4	302
3-11	Hostility (Directed Toward Outside Personnel) Scale Results for Crewman 1	303
3-12	Hostility (Directed Toward Outside Personnel) Scale Results for Crewman 2	304
3-13	Hostility (Directed Toward Outside Personnel) Scale Results for Crewman 3	304
3-14	Hostility (Directed Toward Outside Personnel) Scale Results for Crewman 4	305
3-15	Subjective Stress Scale Results for Crewman 1	305
3-16	Subjective Stress Scale Results for Crewman 2	306
3-17	Subjective Stress Scale Results for Crewman 3	306
3-18	Subjective Stress Scale Results for Crewman 4	307
3-19	Sociometry Results	308
3-20	Sleep Durations for Crewman 1	309
3-21	Sleep Durations for Crewman 2	309
3-22	Sleep Durations for Crewman 3	310
3-23	Sleep Durations for Crewman 4	310
3-24	Sleep Questionnaire Responses. Smoothed Curve Based on 10-Day Segments	311
3-25	Isolation Symptomatology Questionnaire Results for Crewman 1	312
3-26	Isolation Symptomatology Questionnaire Results for Crewmen 2	313
3-27	Isolation Symptomatology Questionnaire Results for Crewmen 3	313
3-28	Isolation Symptomatology Questionnaire Results for Crewman 4	314
3-29	Group Confinement Inventory Results for Crewman 1	314
3-30	Group Confinement Inventory Results for Crewman 2	315
3-31	Group Confinement Inventory Results for Crewman 3	316
3-32	Group Confinement Inventory Results for Crewman 4	316
3-33	Primary Affect Scale Results for Crewman 1	317
3-34	Primary Affect Scale Results for Crewman 2	317
3-35	Primary Affect Scale Results for Crewman 3	318

3-36	Primary Affect Scale Results for Crewman 4	319
3-37	LRC-CC Daily Scores for Crewman 1	320
3-38	LRC-CC Daily Scores for Crewman 2	321
3-39	LRC-CC Daily Scores for Crewman 3	321
3-40	LRC-CC Daily Scores for Crewman 4	322
3-41	Model Concept and Utilization Sequence	329
3-42	Mission Activity Analysis Overview	331
3-43	Mission Analysis Monitoring	352
3-44	Crew Activity Schedule Comparison	366
3-45	90-Day Manned Test Event Times— Scheduled vs Crew Performance (Crew Mean Time)	368
3-46	Exercise—Mean Time per Crewman	371
3-47	Water Samples/Tests for Crewman 2	373
3-48	Meals—Mean Time per Crewman	373
3-49	Sleep—Mean Time per Crewman	374
3-50	Audio Circuit	378
3-51	Pushbutton Response Circuit	378
3-52	Calibration System	379
3-53	Audiometric Calibration Data	380
3-54	Ambient Noise	381
3-55	Pink Noise Test Stimuli	382
3-56	Background Noise Spectra	383
3-57	Weekly Audiometric Data	386
3-58	Audiometric Data in Summary Categories	395
3-59	Ambient Acceptability Data	397
3-60	Average Ambient Acceptability Data	399
3-61	Mixed Word Set Speech Comprehension Data	402
3-62	Repeated Word Set Speech Comprehension Data	403
3-63	Hostility Scale Crew Mean Values	404
3-64	Biotelemetry System	411
3-65	Automatic Sleep Scoring and Sleep Performance Analysis	413
3-66	Computer Printout—Automatic Sleep Scoring	415
3-67	Unaltered Sleep Cycle—Automatic Scoring for Night 1	416

3-68	Sleep Parameters	417
3-69	19-Day Summary Chart—Sleep Parameters, Altered Sleep Cycle	418
3-70	Delta Activity (0.2 to 2 Hz) and Sleep Stages vs Sleep Time Subject 02S Baseline	419
3-71	Sleep Print—Unaltered Sleep Cycle	421
3-72	Sleep Print and Delta Plot, Automatic Scoring—Unaltered Sleep Cycle for Night 42	422
3-73	20-Day Summary Chart—Sleep Parameters, Unaltered Sleep Cycle	423
3-74	19-Day Summary Chart—Sleep Parameters, Altered Sleep Cycle	424
3-75	Trend Plot—Total Waking Time	425
3-76	Space Station Simulator Floor Plan Labeled for NIPA Observations	436
3-77	Flow Diagram of Data Collection, Reduction, and Analysis	441
3-78	Positive Affect Ratio for Crewman 1	444
3-79	Positive Affect Ratio for Crewman 2	445
3-80	Positive Affect Ratio for Crewman 3	446
3-81	Positive Affect Ratio for Crewman 4	447
3-82	Number of Positive Statements by Crewman 1	448
3-83	Number of Positive Statements by Crewman 2	449
3-84	Number of Positive Statements by Crewman 3	450
3-85	Number of Positive Statements by Crewman 4	451
3-86	Psychological Dispersion from Others for Crewman 1	452
3-87	Psychological Dispersion from Others for Crewman 2	453
3-88	Psychological Dispersion from Others for Crewman 3	454
3-89	Psychological Dispersion from Others for Crewman 4	455
3-90	Physical Dispersion from Others for Crewman 1	456
3-91	Physical Dispersion from Others for Crewman 2	457
3-92	Physical Dispersion from Others for Crewman 3	458
3-93	Physical Dispersion from Others for Crewman 4	459
3-94	Psychological Distance per Unit Time for Crewman 1	460
3-95	Psychological Distance per Unit Time for Crewman 2	461
3-96	Psychological Distance per Unit Time for Crewman 3	462

3-97	Psychological Distance per Unit Time for Crewman 4	463
3-98	Statistical Correlation of NIPA Measures	466
3-99	Comparison of Observers by Total Number of Positives Recorded	482
3-100	NIPA Results as Conventionally Plotted	485
3-101	NIPA Results Cumulatively Plotted Showing Operational Utility	486
3-102	Tracking Tasks, Data Measurements, and Analysis	491
3-103	Control Task Apparatus and Experimental Setup for the 90-Day Confinement Study	493
3-104	Training Data	494
3-105	Weekly Mean Critical Instability Scores During the 90-Day Confinement Period	496
3-106	Comparison of Tracking-Session Data for the 90-Day Test	498
3-107	Correlation Between Critical Instability Line and Steady Tracking Data	499
4-1	Space Station Simulator, Simplified Interior Layout	505
4-2	Typical Volume—Flow Loop and Subdivisions	517
4-3	Spirometer Setup	518
4-4	Subject Taking Automated Visual Sensitivity Test	527
4-5	Exercise Program Worksheet	531
4-6	Calculation of Aerobic Capacity During Submaximal Work	532
4-7	Basal Biomedical Data—Oral Temperature (°C)	536
4-8	Basal Biomedical Data—Body Weight	537
4-9	Skin Fold	537
4-10	Blood Urea Nitrogen and Alkaline Phosphatase	538
4-11	Serum Albumin and Albumin-Globulin Ratio	539
4-12	Serum Enzymes—SGOT and LDH	540
4-13	Urinary Excretion Patterns, Na^+/K^+ Ratios	542
4-14	Hematology Summary for Crewmen 1 and 2	543
4-15	Hematology Summary for Crewmen 3 and 4	544
4-16	Radiation Survey Near VD-VF Unit with Retracted Shield	545
4-17	Radiation Survey Near Isotope Storage Container (Chill box)	545

4-18	Exposure to Ionizing Radiation During Handling of Pu-238 Capsules	549
4-19	Measurement of Radioactivity on Daily Filters from the Air Monitor Daily Reading of Air-Monitor Ratemeter	549
4-20	Measurement of Radioactivity from the Air Monitor Measurement from Isotope Analysis Unit	550
4-21	Measurement of Water and Smear Samples for Radioactive Contamination with the Isotope Analysis Unit	551
4-22	Typical Volume Flow Loops at Sea Level and Altitude	555
4-23	CO_2 Exposure History Related to Sample Pass-out	557
4-24	Frequency Distribution of Pco_2 Recorded Observations (90 Days)	558
4-25	Frequency Distribution of Pco_2 Recorded Observations, Days 1-46 and Days 47-90	559
4-26	Sleeping Respiratory and Pulse Rates	561
4-27	Summary of Pulse Versus Respiratory Rate— 2 Hours into Sleep	563
4-28	Hydrogen Ion Excretion (mEq/24 Hours)	564
4-29	Venous Plasma pH	566
4-30	Venous Plasma and RBC Bicarbonate	567
4-31	Red Blood Cell Sodium	569
4-32	Serum Calcium	570
4-33	Serum and Urine Calcium Trends	571
4-34	Serum Inorganic Phosphorus Trends	572
4-35	Serum Calcium and Inorganic Phosphorus Trends	572
4-36	Calcium-Phosphorous Trends	573
4-37	Serum Levels of Creatine Phosphokinase Activity	576
4-38	Serum Levels of Amylase Activity	577
4-39	Serum Levels of Sphingomyelin	578
4-40	Serum Levels of Cholesterol	579
4-41	Crew Carboxyhemoglobin % Saturation, Mean and Standard Deviation	581
4-42	Simulator Carbon Monoxide Concentration	582
4-43	Results of Visual Sensitivity Test for Crewman 1	586
4-44	Total Aerobic Capacity (Maximal O_2 Consumption)	593

4-45	Aerobic Capacity (Maximal O_2 Consumption) in Relation to Body Weight	594
4-46	Balke Optimal Work Capacity Test	595
4-47	Identification Schemes for Primary Throat and Nasal Isolates	600
4-48	Identification Schemes for Dermal Isolates on Primary Isolation Media	601
4-49	Bench Test Setup Bacterial Sensor Experiment	605
4-50	Onboard Setup Bacterial Sensor Experiment	606
4-51	Counts of SSS Surface Contaminants Before and During the 90-Day Test	612
4-52	Location of Post-Test Surface Samples	615
4-53	Potable and Wash Water Multifiltration Units	621

TABLES

1-1	Comparison of Planned and Accomplished Program Objectives	3
1-2	Dimensional Notation	7
2-1	Space Station Simulator Life Support System	13
2-2	SSS Environmental Design Requirements	13
2-3	Weight and Volume of Life Support Equipment	14
2-4	Summary of LSS Operation	19
2-5	LSS Maintenance and Repair Summary	22
2-6	Miscellaneous Maintenance and Repair Summary	23
2-7	Major Onboard Spares Usage	24
2-8	Life Support Equipment Involved in Thermal Balance	36
2-9	Significant Power System Events	43
2-10	Power Usage for Space Station Simulator (60 Hz, 115 vac, Single Phase)	44
2-11	Power Usage for Space Station Simulator (400 Hz and 28 vdc)	45
2-12	Major Atmospheric Contaminant Guidelines in SSS	50
2-13	Atmospheric Contaminants	52
2-14	Atmospheric Trace Contaminants During 90-Day Test	52
2-15	Constituents of Freeze-Out Samples	60
2-16	Constituents of Weekly Freeze-Out Samples	61

Preceding page blank

2-17	Constituents of Weekly Freeze-Out Samples	62
2-18	Potable Water Chemical Pretest and Biweekly Analysis	77
2-19	Pretest Qualification Microbiological Results	78
2-20	Comparison of COD and TOC Determinations (Solution of Potassium Acide Phthalate)	83
2-21	Comparison of COD and TOC Determinations (Different Sample Sources of Reclaimed Water)	83
2-22	Results of First Water Acceptability Test	85
2-23	Results of Second Water Acceptability Test	87
2-24	Results of Third Water Acceptability Test	89
2-25	Potable Water Subsystems Summary Water Balance (4 Men, 90 Days)	94
2-26	Potable Water Chemical Analysis	96
2-27	Summary of Potable Water Analysis	98
2-28	Water Management Subsystem Microbiological Data	100
2-29	VD-VF Boiler 1 Mass and Energy Balance	102
2-30	VD-VF Boiler 2 Mass and Energy Balance	103
2-31	VD-VF Condensate Chemical Analysis	105
2-32	Wick Evaporator Mass and Energy Balance 31 Days of Operation	111
2-33	Wick Performance Summary	112
2-34	Potable Water Detoxification-Multifiltration Unit 85 Days of Operation	114
2-35	Detoxification-Multifiltration Unit Input Chemical Analysis	115
2-36	Data on Iodine Dissipation in Backup Potable Water Storage Tank	116
2-37	Wash Water System Summary Water Balance and Expendables (4 Men, 90 Days)	118

2-38	Wash Water Chemical and Microbiological Analysis	120
2-39	Wash Water Post-Test Chemical Analysis	121
2-40	Wash Water Filter Residue	123
2-41	Water Management Subsystem Power Consumption	124
2-42	Water Management Subsystem Maintenance and Repair Activity	125
2-43	Crew Urine Data Summary	130
2-44	CO_2 Concentrator Maintenance Summary	157
2-45	Thermal Conditioning Design and Operational Data	163
2-46	Sabatier Reactor/Toxin Control Maintenance Activity	170
2-47	Sabatier Reactor Material Balance	177
2-48	Allis-Chalmers Maintenance Summary	194
2-49	Lockheed Maintenance Summary Outside Activity	201
2-50	Menu	211
2-51	Food Consumption	216
2-52	90-Day Freeze-Dry Food Acceptance	217
2-53	Frozen Food (8 of each)	218
2-54	Outgassed Products Measured	225
2-55	Thermal Map of Three Microwave Ovens	227
2-56	Commode Usage Summary	236
2-57	Overboard Dump Summary	242
2-58	Waste Summary	244
2-59	Waste Management Maintenance Summary	246
3-1	Screening Questionnaires and Origins	260

3-2	Information on Crewmen	262
3-3	SSS Crewmen Training Curriculum	264
3-4	Training Instructors	265
3-5	Manpower Utilization—90-Day Values	273
3-6	LSS Maintenance and Repair Time Summary	274
3-7	Miscellaneous Unscheduled Maintenance and Repair Summary	275
3-8	Staff Training Courses	281
3-9	SSS Facilities Operation Training and Certification Record	282
3-10	Habitability Inventory Item Ranks (90-Day Group Mean Values)	286
3-11	"Nasadent" Constituents	289
3-12	Recreational Provisions	290
3-13	Illumination Results	294
3-14	Questionnaire Definition and Use Schedule	299
3-15	Mean Sleep Duration and Sigma Values	311
3-16	Crew Skill Matrix	332
3-17	Crew Event Matrix	334
3-18	Water Sample Matrix	341
3-19	Mission Event Profile	344
3-20	Guidelines for Mission Analysis Monitor Data Collection	354
3-21	Guidelines for Communications Monitor Data Collection	355
3-22	Monday, Day 45, Manual Activity Schedule	357
3-23	Monday, Day 45, Computer Activity Schedule	360
3-24	Monday, Day 45, Actual Crew Schedule	363
3-25	Event Mean Time per Day per Crewman (for Days: 31-35, 41-45)	369

3-26	Speech Peak Levels Used During Speech Comprehension Tests	380
3-27	Audiometry Significance Test Results	390
3-28	Audiometric Data Comparing Loss and No-Loss Groups	394
3-29	Audiometry Significance Test Results Comparing Loss and No-Loss Groups	394
3-30	Acceptability Significance Test Results	398
3-31	Speech Comprehension Significance Test Results for Individual Crewmen	400
3-32	Speech Comprehension Significance Test Results for Averaged Data	401
3-33	Noise-Related Habitability Data	404
3-34	Acceptability of Glycerol as a Food Additive	430
3-35	Serum and Urine Free Glycerol	431
3-36	Other Observer Judgments	437
3-37	Paper-and-Pencil Tests and NIPA Measures Used During the Study	438
3-38	Observed Correlations Among On-Line NIPA Measures Significant at the One Percent Level	465
3-39	Definitions of Selected NIPA Indices	467
3-40	Partial Correlations of Selected Indices with Positive Affect to Show Their Independence of Run Day	469
3-41	Correlations Between Paper-and-Pencil Tests and NIPA Measures	470
3-42	Correlation of NIPA Measures with Selected Independent Variables	474
3-43	Correlation of Intrusive Measures with Selected Independent Variables	477
4-1	Screening Test Results, Raw Data	504
4-2	Federal Radiation Council Radiation Protection Guide	507
4-3	Maximum Integral Dose for the 90-Day Test	508

4-4	Radiological Tolerances of ^{238}Pu	510
4-5	Pretest and Post-Test Physical Examination Summary	519
4-6	Pulmonary Function	520
4-7	Onboard Medication Used in 90-Day Test	534
4-8	Personnel Dosimetry Film Badge Readings	547
4-9	Record of Capsule Handling and Surveys for Radioactive Contamination	548
4-10	Carboxyhemoglobin, % Saturation	584
4-11	Number of Test Presentations	585
4-12	Plasma and Blood Volumes of Subjects in the 90-Day Test of a Space Station Simulator	587
4-13	Measurement of Whole-Body Potassium in Subject by Counting K-40 with the UCLA Total-Body Counter	588
4-14	Total Body Water of Crewmen During the 90-Day Test of an SSS	590
4-15	Exercise Program Data	592
4-16	Summary of Microbiological Sampling Procedures	597
4-17	Primary Cultural Conditions for Crew and Surface Microflora	598
4-18	Primary Cultural Conditions for Post-Test Samples of Hardware Component Surfaces and Subsystem Components	603
4-19	Recovery of S. Aureus, Beta-Hemolytic Streptococci, N. Meningitidis, and D. Pneumoniae from the Nose and Throat	608
4-20	Recovery of Aerobic Bacteria from Dermal Sites	610
4-21	Number of Different Types of Obligate Anerobes from Dermal Sites	611
4-22	Recovery of Bacteria from SSS Surfaces	613
4-23	Post-Test Surface Contamination Levels	616

4-24	Microbial Types Recovered from SSS Surfaces Post-Test	617
4-25	Post-Test Recovery of Microbial Contaminants from the Potable and Wash Water Multifiltration Units	619
4-26	Post-Test Recovery of Microbial Contaminants from Potable and Wash Water Subsystem Components	620
4-27	Post-Test Recovery of Microbial Contaminants from SSS Fecal Collection System	623
4-28	Post-Test Recovery of Microbial Contaminants from Stored Waste	624
4-29	Number of Viable Particles per 0.028 m^3 (1 ft^3) in the SSS Atmosphere	625
4-30	Types of Bacteria Recovered from SSS Atmosphere	626

NOMENCLATURE

A-C	Allis-Chalmers
AFE	Authority for expenditure
A/G	Albumin/globulin
AMRL	Aerospace Medical Research Laboratory
APSS	Association for the Psychophysiological Study of Sleep
ARC	Ames Research Center
AVST	Automated Visual Sensitivity Tester
ASO	Antistreptolysin O
BTPS	Body temperature, ambient pressure and saturated with water
BUN	Blood urea nitrogen
CEC	Controlled element computer
CM	Crew member (Crewman identified by number)
CM	Communications monitor
COD	Chemical oxygen demand
COHb	Carboxyhemoglobin
CPE	Cytopathogenic effect
CPK	Creatine phosphkinase
CPM	Count per minute
CRT	Cathode ray tube
CTT	Critical Task Tester (Human Describing Function)
DFA	Describing function analyzer
ECG	Electrocardiogram

EDTA	Ethylene diamine tetra acetic acid
EEG	Electroencephalogram
EM	Engineering monitor
EMT	Electrical/mechanical technician
EOG	Electro-oculogram
ERV	Expiratory reserve volume
FAA	Federal Aeronautics Administration
FES	Forced expiratory spirogram
FFT	Fast Fourier Transform
FIRO-B	Fundamental Interpersonnel Relationships Orientation (B Form)
FMECA	Failure mode, effect and criticality analysis
GAC	Gas analysis console
GCI	Group Confinement Inventory
GFE	Government-furnished equipment
Hct	Hematocrit
H. Ep. 2	Human Epidermoid Carcinoma-2/Heteroploid
Hgb	Hemoglobin
IBR	Institute of Behavioral Research
IC	Inspiratory capacity
ILSS	Integrated Life Support System
IRAD	Independent Research and Development
IRIG-B	Inter Range Instrumentation Group-B
IRV	Inspiratory reserve volume
ISQ	Isolation Symtomatology Questionnaire
LDH	Lactic acid dehydrogenase
LIRA	Luft Infrared Analyzer

LMSC	Lockheed Missiles and Space Company
LRC	Langley Research Center
LRC-CC	Langley Research Center-Complex Coordinator (Psychomotor tester)
LSDS	Low speed digital subsystem
LSM	Life support monitor
LSS	Life support system
MAA	Mission Activity Analysis
MAT	Motivational Analysis Test
MBC	Maximum breathing capacity
MCH	Mean corpuscular hemoglobin
MCHC	Mean corpuscular hemoglobin concentration
MCV	Mean corpuscular volume
MDAC	McDonnell Douglas Astronautics Company
MF	Multifilter
MM	Medical monitor
MMF	Maximum midexpiratory flow
MMPI	Minnesota Multiphasic Personality Inventory
MPC	Maximum permissible concentration
MPLM	Maximum permissible lung burden
MSC	Manned Spacecraft Center
MSFC	Manned Space Flight Center
NAS-NRC	National Academy of Science - National Research Council
NCA	Noise criteria - A scale
NIPA	Non-Interference Performance Assessment
NIH	National Institute of Health
NMRI	Naval Medical Research Institute

NMNRU	Naval Medical Neurophychiatric Research Unit
ODM	One Day Model
PAS	Primary Affect Scale
PBI	Polybenzimidazole (nonflammable material)
PBI	Protein bound iodine
PF	Personality Factors
PM	Planning Model
PPS	Personal Preference Schedule
PRMK	Primary Rhesus Monkey Kidney
PV	Plasma volume
PVC	Premature ventricular contractions
RATER	Response Analysis Tester
RBC	Red blood cells
REM	Rapid eye movement
RISA	Radioiodated serum albumin
RQ	Respiratory quotient
SAM	School of Aerospace Medicine
SDS-930	Scientific Data System - Model 930 (Computer)
SGOT	Serum glutamic acid oxalacetic transaminase
SMC	Submarine Medical Center
SSS	Space Station Simulator
SSMM	Space Station Mathematical Model
TA	Titratable acidity
TBC	Thyroxine binding capacity
TBW	Total body water
TBV	Total blood volume
TC	Test conductor

$TCID_{50}$	Tissue Culture Infective Dose 50
TDS	Total dissolved solids
TGAS	Two-gas atmosphere sensor (mass spectrometer)
TOC	Total organic carbon
TSCL	Time share computer link (acoustical data link)
TSCT	Time share computer terminal
TV	Tidal volume
USPHS	United States Public Health Service
$\dot{V}_E$	Expiratory volume flow
$\dot{V}_I$	Inspiratory volume flow
$\dot{V}$-V	Forced vital capacity volume - Flow
VC	Vital Capacity
VDRL	Venereal Disease Research Laboratory
VD-VF	Vacuum Distillation–Vapor Filtration
WHR	Watt hour recorder
WI-38	Human embryonic lung (diploid)
WIR	Watt recorder
WBC	White blood cells
XDS-940	Xerox Data System - Model 940 (computer)

Section 1
INTRODUCTION

Future manned space missions will involve the extension of mission duration to periods of years, with crew duty tours from 28 days in the initial Skylab mission, to 180 days or longer in the space station of the future. This extension from previous durations of 14 days or less requires the establishment of a technological base which will ensure the support, well being, and efficiency of the crew. One key element in establishing this base is the performance of ground-based integrated operational manned tests simulating orbiting conditions. Such a test is reported herein.

The Operational 90-Day Manned Test of a Regenerative Life Support System was planned to provide data in a closed ecology such as that of an orbiting spacecraft to determine the performance of subsystems under continuous operating conditions, to demonstrate the ability of the crew to operate and maintain them, and to evaluate the requirements of the crew for maintenance of their physiological and psychological health to efficiently perform mission objectives.

Previous tests of complete, manned life support systems have been performed by McDonnell Douglas Astronautics Company (MDAC) for a period of 60 days in the Space Station Simulator (SSS) (References 1-1, 1-2, and 1-3) and by the NASA for 28 days in the Integrated Life Support System (ILSS) (Reference 1-4). The experience gained in performing these tests, and others of shorter duration, was applied in planning for the 90-day test. Features that were incorporated included advanced criteria for selection and design of subsystems, selection of the test crew, design of crew quarters, logistics planning, and data acquisition.

1.1 PROGRAM OBJECTIVES

In order to meet these general goals, the following objectives were established (Reference 1-5):

A. To demonstrate a capability to operate a multi-man life support system in a continuous regenerative mode for a 90-day period without resupply. The system must provide a habitable atmosphere, food and water for nutritional support, and personal accommodations consistent with man's needs in the areas of personal hygiene, waste management, comfort, and health. The system will include regenerative oxygen and water loops. It will be a goal to minimize the amount of stored, expendable materials required for the test.

B. To obtain total life support system and subsystem performance characteristics which include a material balance, a thermal balance, and power requirements.

C. To operate with no materials passed into or out of the test chamber for the maximum duration possible to permit the chemical and microbiological characteristics of the atmosphere, processes and hardware to reach operating equilibrium under man-loaded conditions and to determine the capability of the system and crew to operate without resupply. If resupply is required, it will continue to be an objective to hold the passing in and out of materials to a minimum and whenever feasible, materials to be passed into the chamber will be sterilized.

D. To demonstrate man's capability to perform in-flight maintenance as a means of increasing system reliability and to demonstrate the capability for in-flight monitoring of the necessary human, environmental, and systems parameters.

E. To obtain through skillful planning, timelining, conducting and analyzing pertinent onboard crew work activities, data which will assist in determining the precise role of man in performing in-flight experiments; assist in determining the practical benefits of manned activity in space; and assist in validating mathematical models of space missions.

F. To obtain data on physiological and psychological effects of long-duration exposure of the crew to confinement in the cabin atmosphere; on long-term group dynamics; and on crew work rest cycles.

G. To evaluate a number of advanced life support subsystems, using the proven subsystems of the SSS as backup, obtaining operating experience and performance data under continuous testing and realistic conditions of manned loads and subsystem interaction.

A summary of these objectives and how they were met by this program is shown in Table 1-1. The section numbers in parenthesis in this table refer to the sections of this report which explain the accomplishments in detail.

1.2 PROGRAM DESCRIPTION

The 90-day test was performed with a crew of four men. A two-gas atmosphere was selected, at a design pressure of 68.9 kN/m^2 (10 psia) with oxygen partial pressure to be held at 21.0 ± 0.35 kN/m^2 (3.05 ± 0.05 psia) and nitrogen as a diluent. The design level for CO_2 partial pressure was 0.507 kN/m^2 (3.8 mm Hg).

All crew equipment and expendables were stored onboard at the start of the mission to eliminate the need for pass-in operations. Pass-out operations were conducted in an autoclave-airlock and were limited to once each week to provide the required samples to verify the health of the crew, obtain basic medical data, and insure potability of the reclaimed water. Some routine

Table 1-1

COMPARISON OF PLANNED AND ACCOMPLISHED PROGRAM OBJECTIVES

Planned Program Objectives	Accomplished Program Objectives
Operate regenerative life support systems for 90 days without resupply.	The regenerative life support systems were operated for 90 days with all maintenance accomplished onboard and no resupply (Section 2. 1. 1).
Obtain a material balance, thermal balance, and power requirements.	A complete mass and energy balance was obtained on equipment and crew (Sections 2. 1. 2, 2. 1. 3, and 2. 1. 4).
Reach microbial and chemical equilibrium in a closed environment.	90 days were completed without pass-ins, thereby assuring the microbial and chemical isolation of the test chamber and crew (Sections 4. 6 and 2. 1. 5).
Determine crew's ability to operate, maintain, and repair equipment.	The performance of the crew was outstanding in accomplishing the normal operation of the systems and in the successful completion of the many repair and maintenance tasks (Sections 2. 1. 1 and 3. 1. 3).
Determine the precise role of man in performing in-flight experiments.	A computerized method for planning mission activities was evaluated and found to be a practical operational tool, providing the necessary flexibility to adapt to changing program requirements. The crew used an average of approximately 2 hours/man-day for operational tasks and during the balance of their work day demonstrated a capacity for performing useful in-flight experiments (Section 3. 5).
Obtain data on physiological and psychological effects of long-duration confinement.	A nonintrusive method of evaluating crew behavior and performance (NIPA) was implemented for comparison with conventional methods of psychological assessment and was found to be a practical operational tool (Section 3. 9). 90 days of confinement caused no perceptible physiologic alterations and the test environment was medically benign (Sections 4. 5 and 4. 6).
Evaluate advanced life support systems.	The advanced life support units evaluated were: VD-VF potable water recovery (Section 2. 2. 3. 1). Solid amine CO_2 concentrator (Section 2. 3. 1). Water electrolysis (Section 2. 4. 2). Two-gas controller and mass spectrometer sensor (Section 2. 4. 3). Microwave oven (Section 2. 5. 3). Commode (2. 6. 1).

tests of blood, urine, and potable water were performed in an onboard laboratory to achieve mission realism and minimize the requirements for passout operations.

The four-man crew was selected from eight candidates who had under gone extensive screening and detailed training in performance of the mission tasks. These crew members were selected because of physical and intellectual similarity to scientist-astronauts who will undertake orbiting missions later in the 1970's. These men were required (1) to be physically fit; (2) to be undertaking a graduate study in a technological field related to the task they performed in the SSS; and (3) to be well adjusted, mature individuals who appeared able to withstand the stress of confinement and small group interaction.

Proper acquisition and handling of data were important in meeting the test objectives. Instrumentation was provided for the crew to operate the equipment onboard the SSS and manage their use of expendables. Automatic totalizers measured oxygen and water consumption, urine and CO_2 production, and nitrogen usage. Food consumption data were logged each day. The crewmen were responsible for collection of data and running a mass-balance calculation each day, as well as maintaining an up-to-date inventory of food stores, spare parts, and water reserves. In these tasks, they use an onboard computer link to simulate an operational data management system.

Data for evaluation of life support system (LSS) performance was presented on an engineering life support monitor and recorded by a 200-channel analog-digital converter system on magnetic tape for periodic processing on an SDS 930 computer. This provided temperatures, pressures, flow rates, and power consumptions and determined the equipment performance, thermal balances, and power requirements of the LSS.

Important to the evaluation of the life support system was the collection of man/system data. Tasks related to this effort included mission task analysis, crew behavior evaluations, data on habitability and crew acceptance of accommodations, and evaluation of the physiological and psychological effects of the confinement.

The SSS in which the test was conducted (Figure 1-1) is a double-walled horizontal cylinder, 3.66 meters (12 ft) in diameter and 12.2 m (40 ft) in length. The 116 m^3 (4, 100 cu ft) chamber is normally operated at reduced atmospheric pressure to duplicate proposed space station cabin atmosphere composition. The annular space between the inner and outer walls, as well as the airlock and small pass-through ports, is usually evacuated to 1.24 kN/m^2 (5 in. H_2O) below cabin pressure, ensuring that all leakage is outboard to provide realistic testing and evaluation of environmental control and life support equipment. The chamber is provided with 4 in. of thermal insulation to minimize thermal and acoustic transmission.

Figure 1-2 shows the configuration of the chamber used during the 90-day test. This arrangement featured an equipment room and crew living area separated by an acoustic barrier. The equipment room included all the mechanical equipment of the environmental control system and its operating instrumentation. A command center was located at the "front" of this room

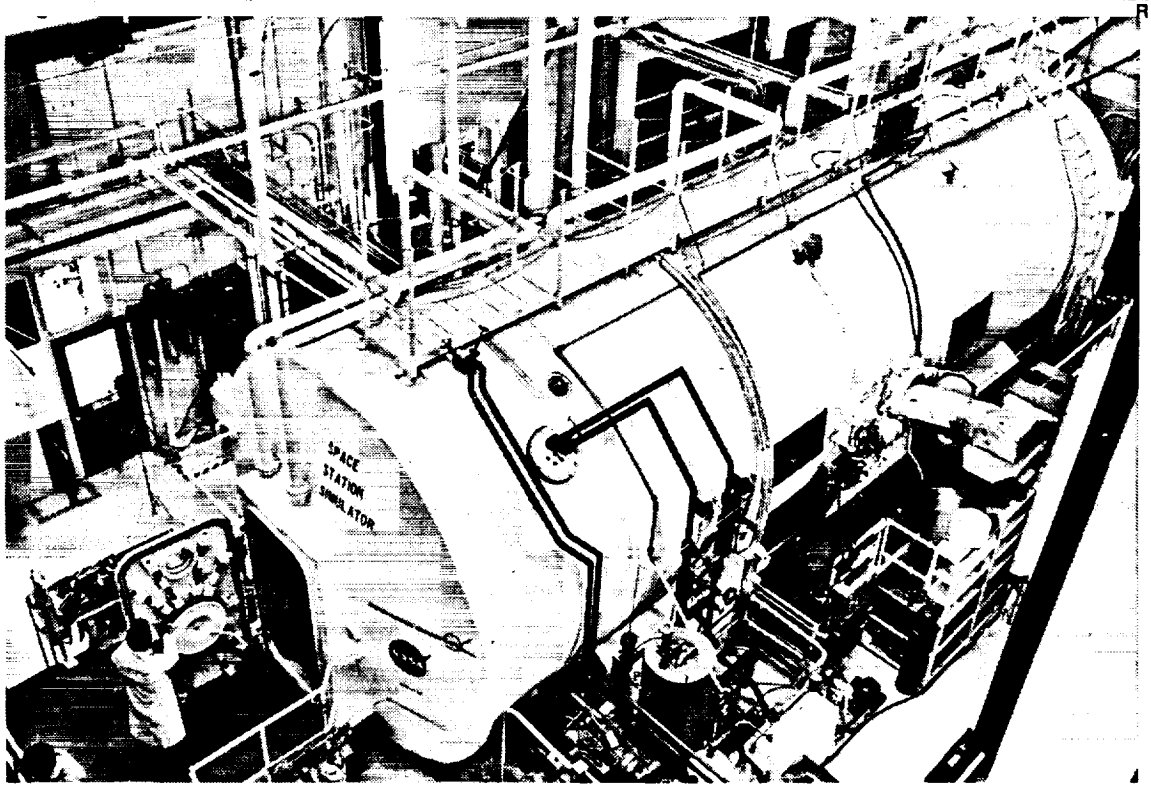
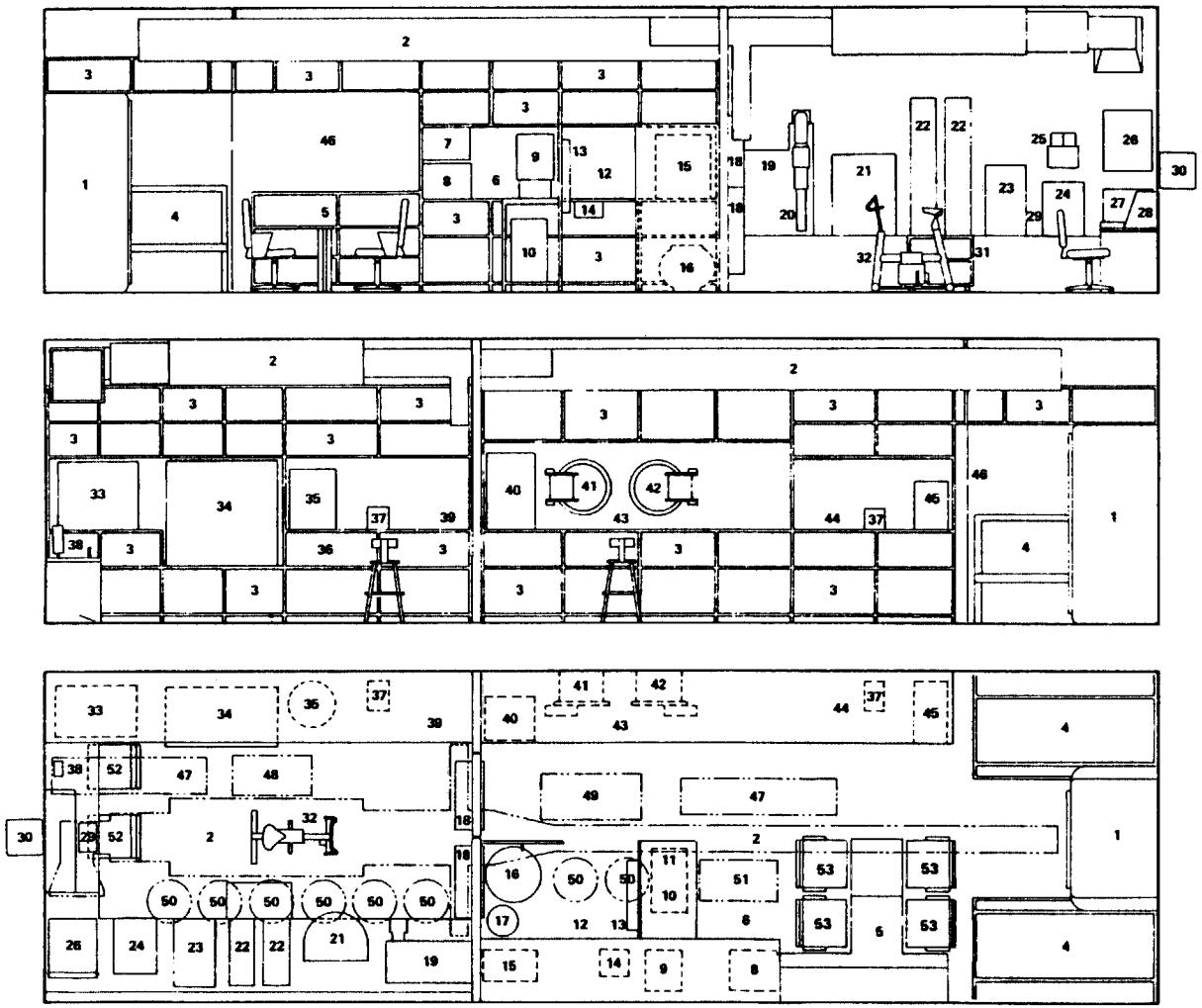


Figure 1-1. Space Station Simulator

including the crew life support monitor, a psychomotor test console, and the computer-link keyboard. Computer input and output were displayed on a large video monitor visible through the forward view port, but outside the chamber for ease of installation and maintenance. The crew living area included space for food preparation, a folding table for eating and recreation, an onboard laboratory area, and the enclosed waste management area. Two bunks were located on each side of the airlock and were isolated from the main area by nonflammable draperies. Much of the design of this installation was influenced by previous test experience which indicated equipment and living areas should be separated and that efficient noise control is very important. The design goals for noise levels are NCA 60 in the living-working areas and NCA 50 in the sleeping quarters (Reference 1-6).

1.3 INTERNATIONAL SYSTEM OF UNITS

This report has been prepared using the International System of Units as a basis for dimensional information. Application of this system in a uniform manner to a document covering a variety of technologies in which many dimensional conventions have been developed has resulted in the necessity for a number of decisions on style and usage. Unfortunately, there does not exist an adequate body of precedents in this area. As usage of the International System increases, conventions will develop in its application which may not be consistent with tentative terminology herein.



LEGEND

1. AIRLOCK
2. THERMAL CONTROL
3. STORAGE
4. BUNKS (4)
5. DINING/RECREATION
6. FOOD PREPARATION
7. WATER DISPENSER
8. MICROWAVE OVEN
9. ELECTRICAL OVEN
10. WASHER
11. CANNER
12. PERSONAL HYGIENE/WASTE MANAGEMENT
13. WASH WATER RECOVERY
14. SINK
15. DRYER
16. COMMODE
17. URINE COLLECTOR
18. AIRCOUSTAT (2)
19. POTABLE WATER RECOVERY AND HUMIDITY CONTROL
20. O-G WATER SEPARATOR
21. VD-VF WATER RECOVERY
22. CO_2 CONCENTRATOR
23. SABATIER/TOXIN CONTROL
24. ELECTROLYSIS
25. FLIGHT WEIGHT TWO-GAS CONTROL
26. FOUR-GAS MASS SPECTROMETER
27. TWO-GAS CONTROL
28. CREW LIFE SUPPORT MONITOR
29. COMPUTER KEYBOARD
30. COMPUTER CART
31. MAINTENANCE CART
32. ERGOMETER
33. LITHIUM HYDROXIDE CO_2 CONTROL (BACKUP)
34. SOLID AMINE CO_2 CONTROL
35. WASTE MANAGEMENT STORAGE VESSEL
36. ISOTOPE STORAGE
37. TV MONITOR (2)
38. PSYCHOMOTOR TESTER
39. MAINTENANCE COUNTER
40. REFRIGERATOR
41. PASSTHROUGH AIRLOCK (STANDBY)
42. PASSTHROUGH AIRLOCK (AUTOCLAVE)
43. ONBOARD LAB
44. CRITICAL TASK TESTER
45. PERIPHERAL VISION TESTER
46. DRAPE
47. WATER TANK, BACKUP (2)
48. OXYGEN TANK
49. HYDROGEN TANK
50. O-G WATER TANK (8)
51. CARBON DIOXIDE TANK
52. CHAIR (2)
53. ARMCHAIR (4)

Figure 1-2. Space Station Simulator Interior Arrangement

An introductory word is in order on the conventions which have been applied in this report. These conventions are intended to be consistent with Reference 1-7, and in particular with Resolution No. 12 on pages 2 through 4 of this reference. The abbreviations for dimensions and for prefixes are in accordance with this resolution, and dimensional units which are not included have been avoided. In accordance with this policy, the basic unit of mass is the kilogram (kg), not gram (g).

Table 1-2 lists some of the dimensional nomenclature which has been used in this report. In the style used, the SI nomenclature has been used basically, followed by conventional units in parenthesis.

Table 1-2

DIMENSIONAL NOTATION

Abbreviation	Dimension	Equivalent
m	meter	feet x 0.3048
cm	centimeter	
m^3	cubic meter	
l	liter	
ml	milliliter	cubic centimeter
cm^3	cubic centimeter	
N	Newton (force)	pounds x 4.448
N/m^2	Newtons per square meter (pressure)	pounds per sq in. x 6,894
kN/m^2	kilonewtons per square meter	
°K	Degrees Kelvin (temperature)	(°F + 459.67) x 1.8
J	Joules (work, energy, heat)	Calories x 4.184; Btu x 1,056
MJ	Megajoule	
W	Watt	
Hz	Hertz (frequency)	Cycles per second

Section 2
LIFE SUPPORT SYSTEM

A block diagram of the regenerative life support system (LSS) evaluated during the 90-day manned test is shown in Figure 2-1. This LSS was installed inside the SSS as shown in Figures 2-2 and 2-3 and maintained without resupply by the SSS crew. The LSS installed in the SSS includes advanced subsystem units being evaluated for the first time in a manned test and baseline LSS units whose design has been proved in previous manned tests. In the operation of the LSS during the 90-day test, the prime function was to evaluate the performance of the advanced subsystem units. A list of the advanced units, baseline units, and backup units of the LSS is shown in Table 2-1.

The design requirements of the LSS included providing the SSS environmental conditions shown in Table 2-2.

In addition to the requirements noted in Table 2-2, design of the LSS involved consideration of the requirement for compact installation with ready accessibility for maintenance and repair. The installation of the advanced subsystems required extensive integration with the previously tested backup systems. This ensured continuation of the test when a malfunction caused temporary or permanent shutdown of one or more of the advanced subsystems, without compromising the remaining test objectives.

A breakdown of weights and volumes of major items of life support equipment used in the 90-day test is included in Table 2-3. Generally, these units were not designed to meet flight-weight, reliability, or structural requirements. These values may serve as a general guide, although they are usually larger than would be found in a flight type design.

The data utilized in this section in reporting the operational performance of the LSS was acquired from the program instrumentation and data management system. This system is described more fully in NASA CR-111882. Its operation and application may be explained briefly as follows: Instrumentation was provided on all units and supporting equipment to allow for evaluation of their performance throughout the 90-day test. In acquiring the data, the major portion of the SSS/LSS instrumentation signals were conditioned and displayed on the life support monitor (LSM). In addition to display on the LSM, the conditioned signals were collected automatically on the low-speed digital subsystem (LSDS) at least once each 1/2-hour period during the 90-day test. These data, recorded on magnetic tape, were processed by a SDS 930 computer once each day, analyzed, then filed for the post-test reporting cycle.

Preceding page blank

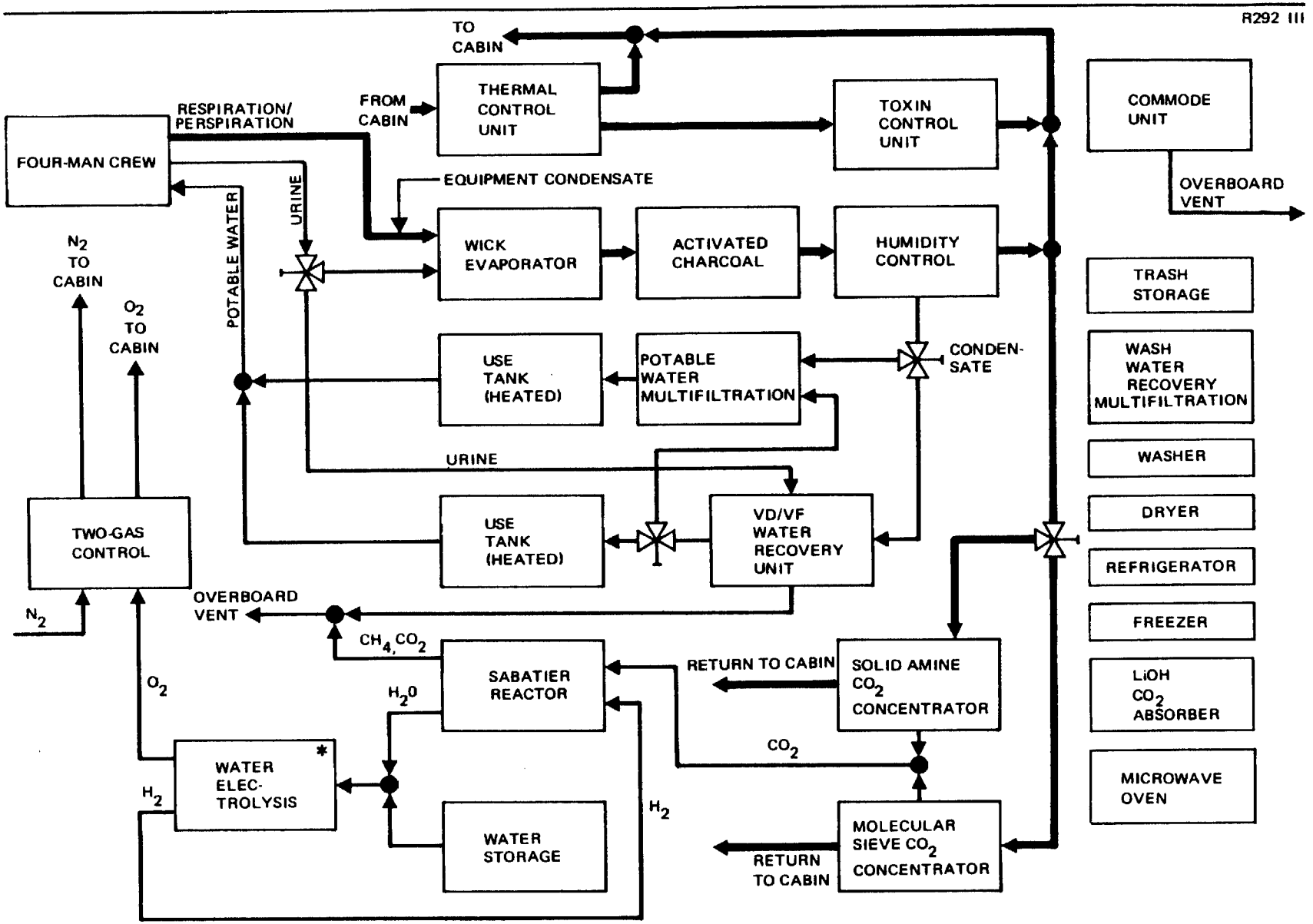


Figure 2-1. Life Support System Block Diagram

*SCHEMATIC IDENTICAL FOR ALLIS CHALMERS AND LMSC UNITS

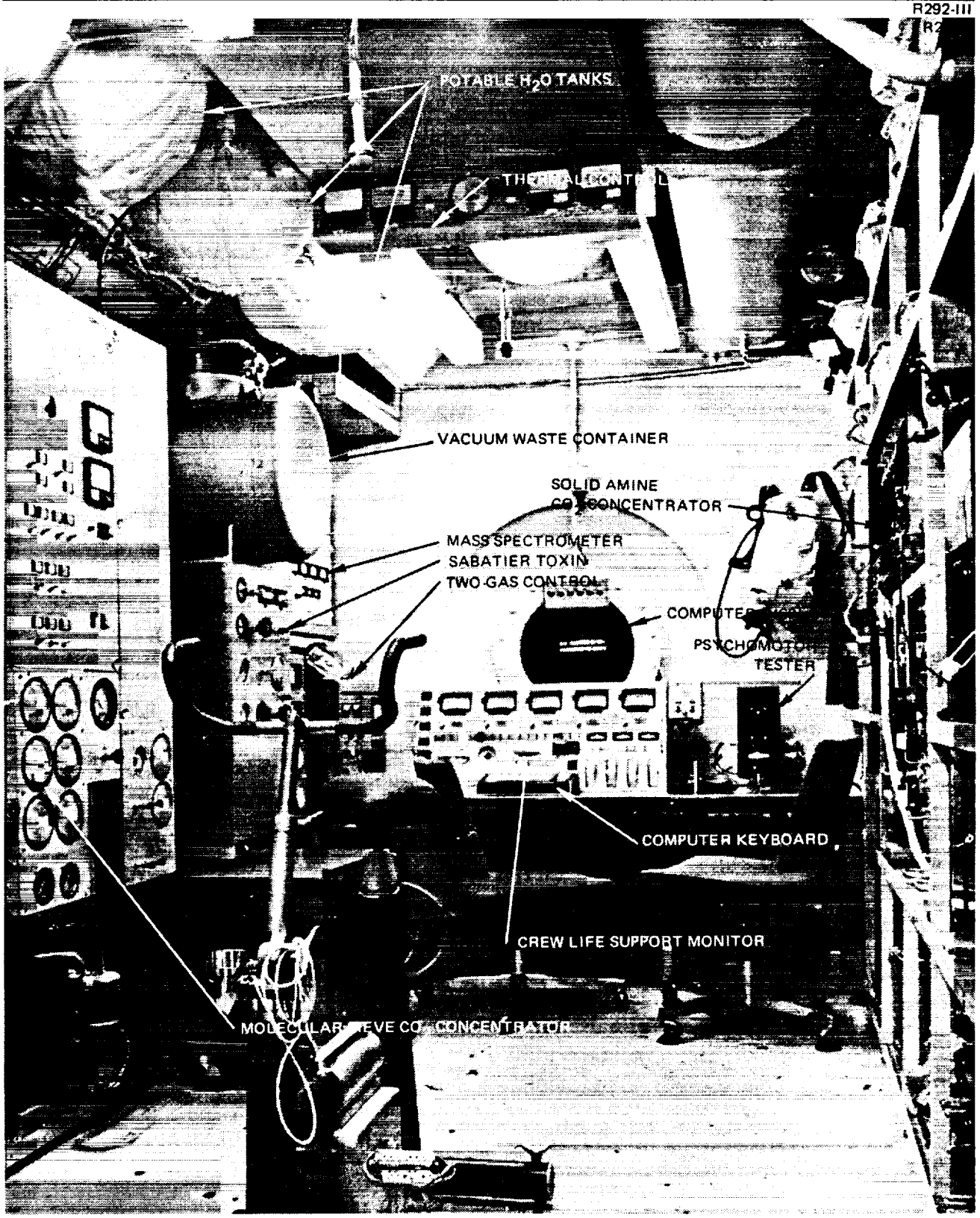


Figure 2-2. SSS Interior Equipment Area—Looking Forward

NOT REPRODUCIBLE

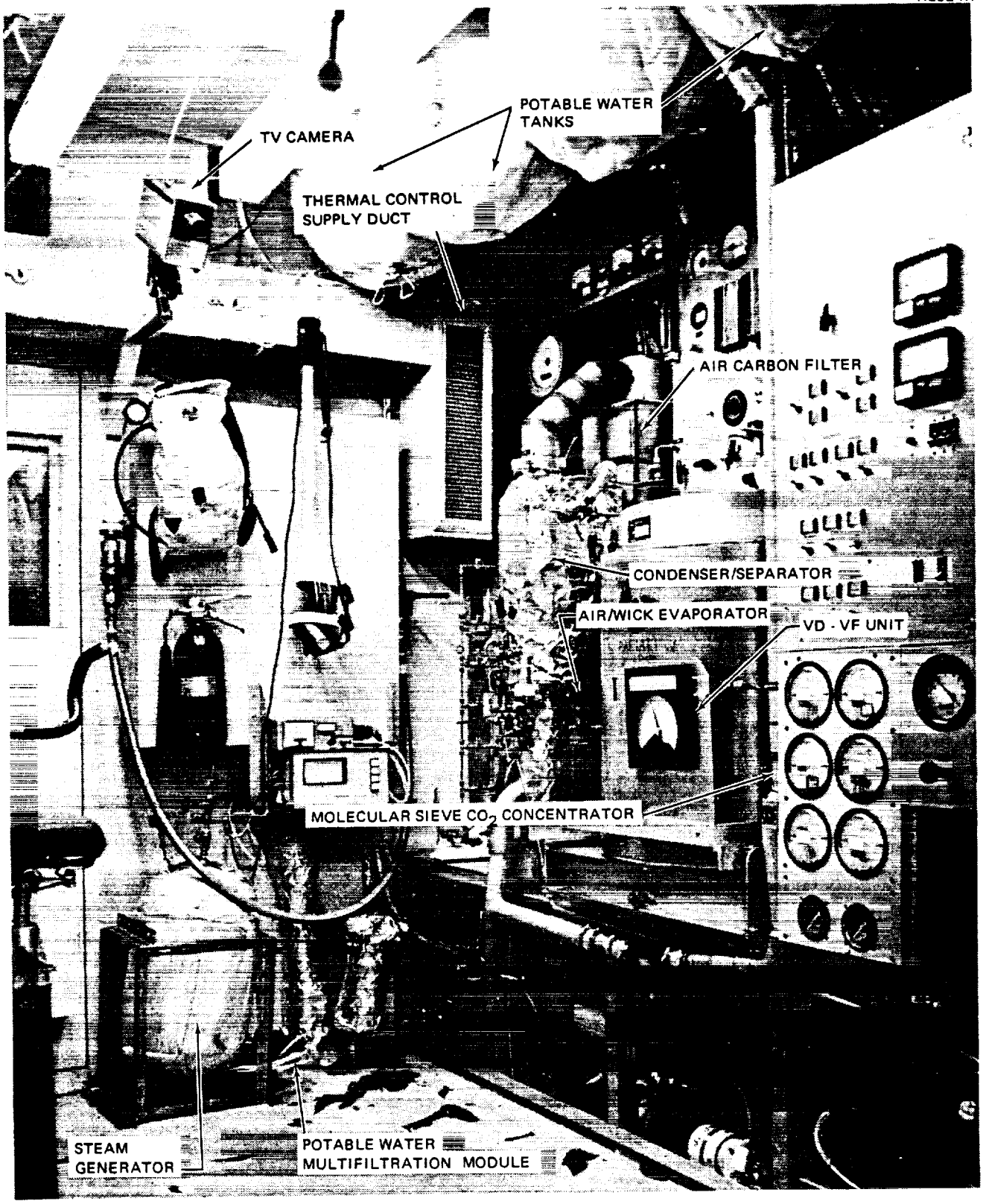


Figure 2-3. SSS Interior Equipment Area—Looking Aft

NOT REPRODUCIBLE

Table 2-1

SPACE STATION SIMULATOR
LIFE SUPPORT SYSTEM

Function	Advanced Subsystem Unit	Baseline Unit	Backup Unit
Potable water recovery	Vacuum Distillation-Vapor Filtration (AMRL)	Open-loop wick evaporator	
Carbon dioxide concentrator	Solid amine absorber	Molecular sieve	LiOH
Carbon dioxide reduction	---	Sabatier reactor	
Water electrolysis	Alkaline electrolyte (Allis-Chalmers)		*Electrolyzer
	*Circulating electrolyte (LRC-Lockheed)		
Atmosphere supply control	Flight-weight two-gas control (LRC-MDAC)	Mark II two-gas control	
Atmosphere composition sensor	Mass spectrometer sensor (LRC-Perkin Elmer)	Beckman polarographic (O_2) Statham strain gage (Total)	
Waste management	Slinger commode (AMRL-General Electric)		
Food preparation	Microwave oven (Litton)	Electric laboratory oven	

*Installed outside adjacent to SSS

Table 2-2

SSS ENVIRONMENTAL DESIGN REQUIREMENTS

Total Pressure	68.9 ± 2 kN/m^2 (517 ± 15 mm Hg)
Oxygen Partial Pressure (Nitrogen Diluent)	20.7 ± 0.67 kN/m^2 (155 ± 5 mm Hg)
Cabin Temperature	294 ± 2.8°K (70° ± 5°F)
Relative Humidity	40 to 70 percent
CO_2 Partial Pressure	0.507 kN/m^2 (3.8 mm Hg)

Table 2-3

WEIGHT AND VOLUME OF LIFE SUPPORT EQUIPMENT

Subsystem	Unit	Weight kg (lb)	Volume m^3 (cu ft)
Waste management	Commode	45.8 (101)	0.241 (8.5)
	Urine collector	29.5 (65)	0.113 (4.0)
Water management	VD-VF: Boiler	29.5 (65)	
	Radiation shield	68 (150)	
	Shield water	182 (400)	0.425 (15)
	Humidity control/wick evaporator	115 (253)	0.765 (27)
	Potable water tanks (6)	109 (240)	0.340 (12)
	Wash water recovery	22.7 (50)	0.057 (2)
	Wash water tanks (2)	36.3 (80)	0.113 (4)
Atmosphere purification	Solid amine	295 (650)	0.510 (18)
	Molecular sieve	235 (517)	0.566 (20)
	Thermal control	109 (240)	1.033 (36.5)
Atmosphere supply and control	Sabatier/toxin burner	77 (170)	0.283 (10)
	Allis Chalmers electrolysis	99.8 (220)	0.170 (6)
	Lockheed electrolysis	129 (285)	0.283 (10)
	Flight-weight two-gas control	3.6 (8)	0.028 (1)
	Baseline two-gas control	22.7 (50)	0.198 (7)
	Mass spectrometer	18.2 (40)	0.099 (3.5)
Food management	Microwave oven	52.3 (115)	0.110 (3.9)

In addition to the above, the data management system included an acoustical data link (time share computer link) for use by the SSS crew for the recording of mass balance, food management, and questionnaire data. Logs were also kept, both by inside crewmen and by operating staff, for manually recorded data.

The data management system is shown schematically in Figure 2-4. The monitoring and recording equipment in the operations control area can be seen in Figure 2-5.

The remainder of this section contains the 90-day test overall LSS performance summary and the detail results of the subsystem and unit performance.

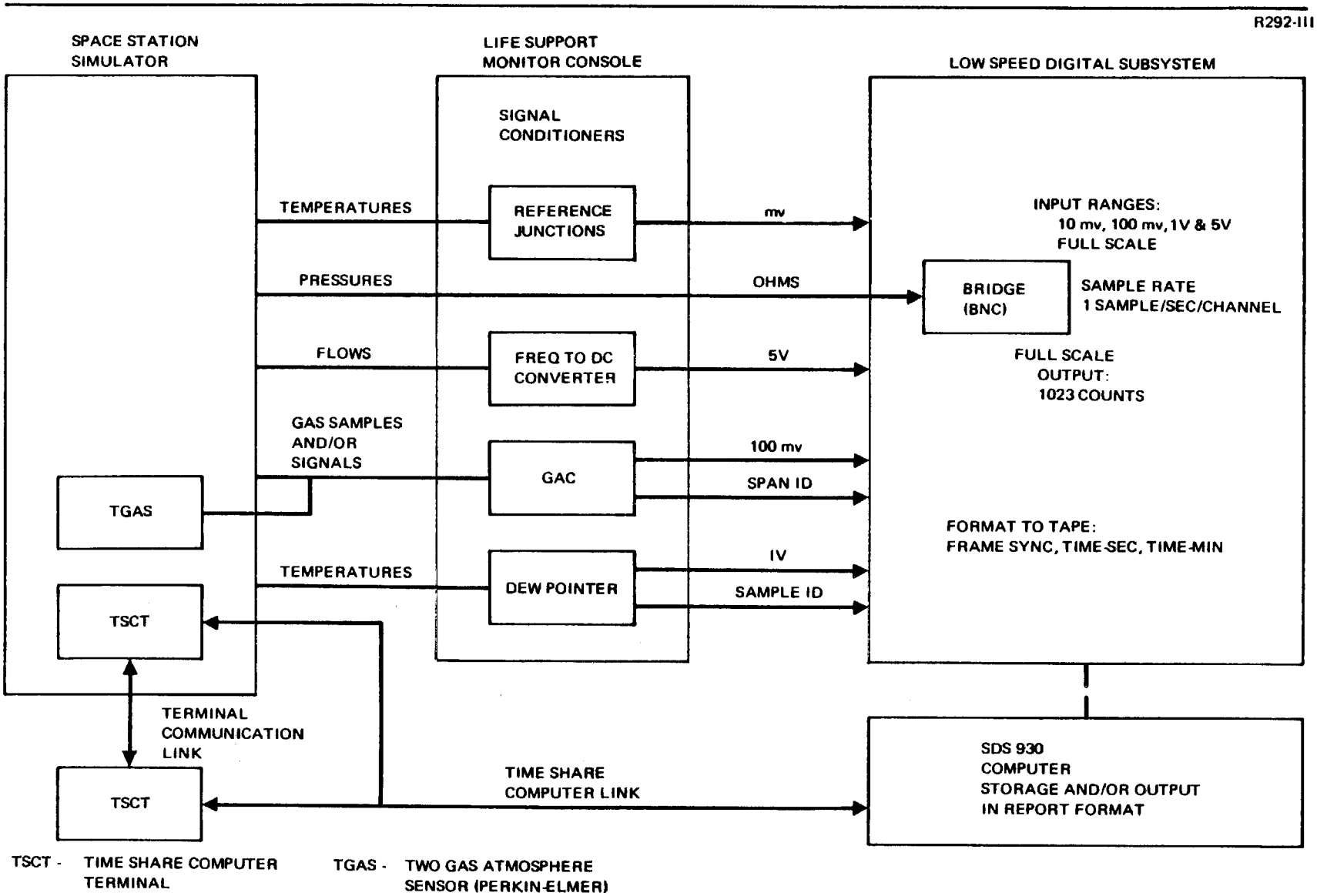


Figure 2-4. Life Support Instrumentation Data Management System

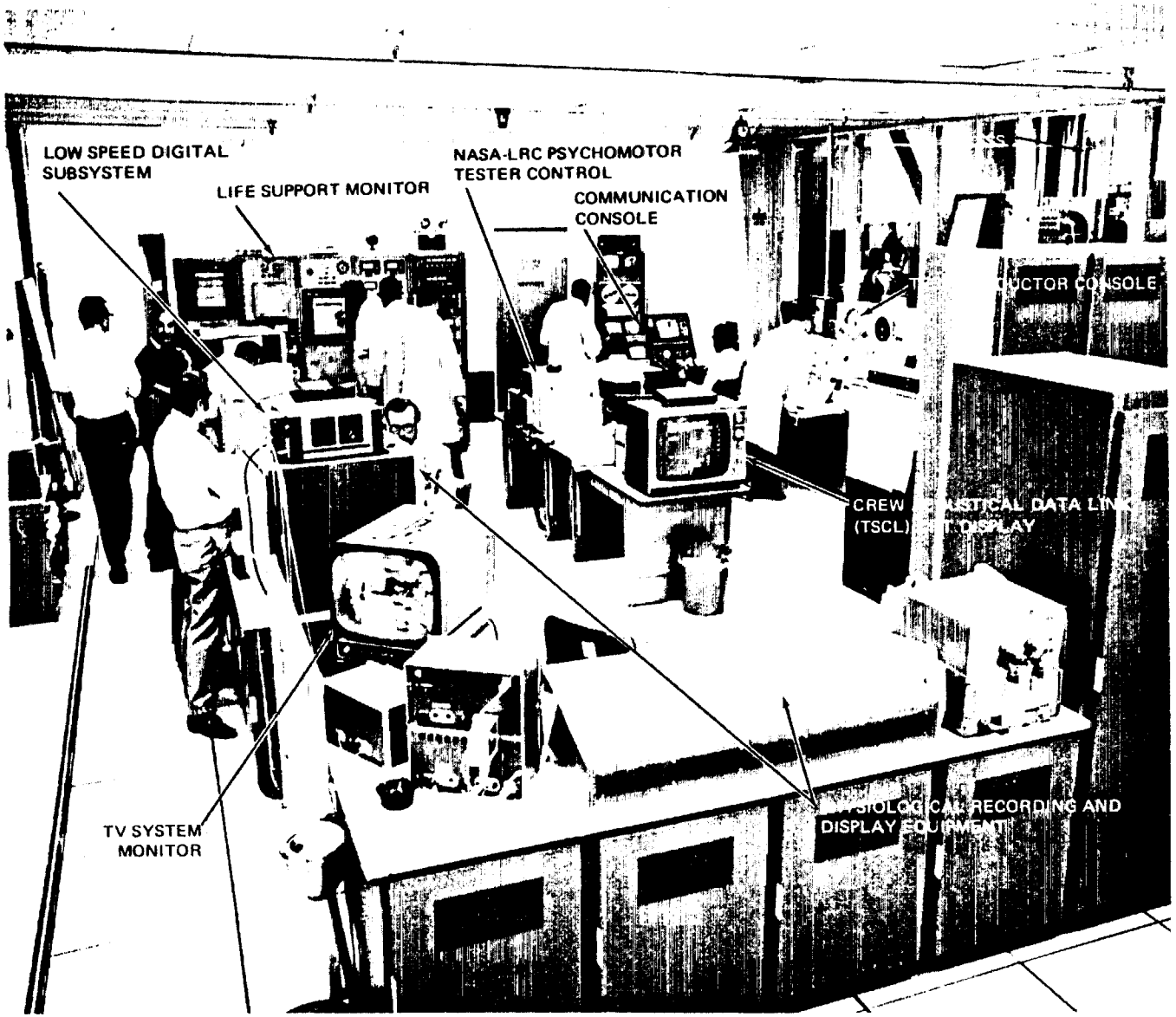


Figure 2-5. SSS Operations Control Area

2.1 OPERATIONAL SUMMARY

A chronological summary of the LSS operation during the 90-day test is shown in Figure 2-6. The nonoperational periods for the wick evaporator, molecular sieve concentrator, toxin control, mass spectrometer, and baseline O_2 control sensor do not signify malfunction but were usually periods when operation was not required and these units were in standby.

A summary of the LSS operating history (Table 2-4) includes a comparison of actual operating time, down time, standby time, and required operating time for each unit. The actual and required operating hours were determined by the following relationships:

Actual Hours = 2, 156.5 hours - (hours down time + hours standby)

Required Hours = Actual hours + hours down time

The 2, 156.5 hours is the actual 90-day test duration. The down time represents time that the unit was not available because of equipment malfunctions. Standby represents time that unit operation was not required due to the required operation of the primary (or advanced subsystem) unit, the intermittent operation mode of the unit, or malfunctions of other equipment which necessitated shutdown of the unit. Since the zero-g phase separator of the urine collector failed early in the test, the down time and standby hours were estimated based on the anticipated usage. The ratio of actual hours to required hours may be considered as a reliability factor with a higher number signifying higher reliability.

The failures which contributed to unit down time are discussed in greater detail below. Also included, are operational mass balance, thermal balance, electrical power usage, and trace contaminant data.

2.1.1 Maintenance and Repair Requirements

To ensure the successful completion of the 90-day test, extensive planning was required to determine the spares and maintenance actions necessary for continuous operation of the SSS equipment. The basis of this planning task was the failure mode, effects, and criticality analysis (FMECA). The results of the FMECA were used as inputs to a computer program which generated a spares inventory list which was then reviewed by the responsible subsystem engineers for commonality of spares and for practical levels of component replacement or repair. The maintenance procedures were then formulated and the tool requirements and storage volume delineated in accordance with the procedures in NASA CR-111882.

The test crew was required to monitor, maintain, and repair the life support equipment installed within the SSS. The only life support unit which was not installed within the SSS was an electrolysis unit which was developed for NASA by the Lockheed Missiles and Space Company (LMSC). This advanced subsystem was provided as a backup to the onboard Allis-Chalmers electrolysis unit and, due to space and time limitations, was installed outside the SSS. However, the LMSC unit was integrated in parallel with the onboard unit and utilized the same Sabatier-produced water to supply oxygen and hydrogen, thereby maintaining closed-chamber operations.

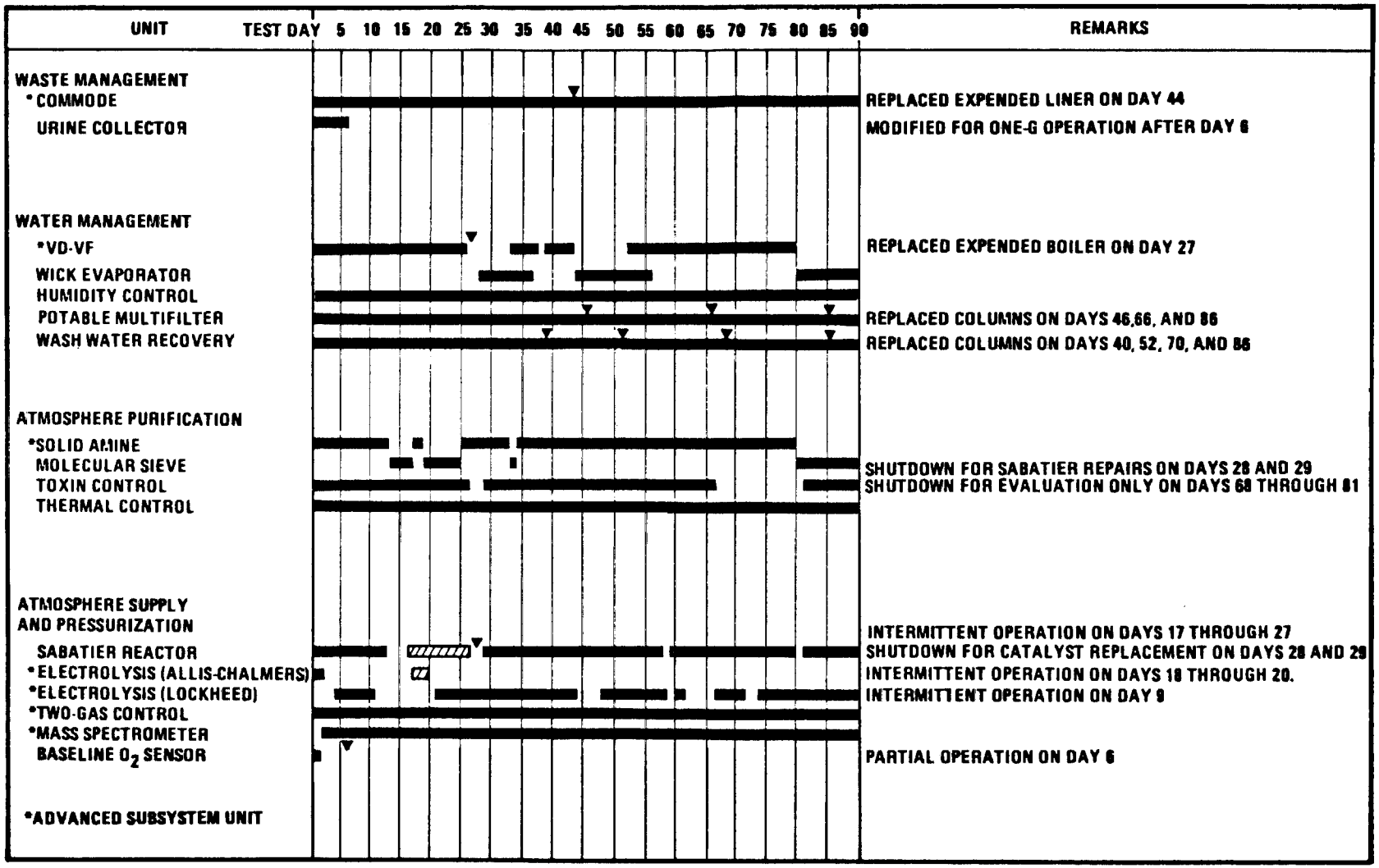


Figure 2-6. Life Support System Operation Summary

Table 2-4

SUMMARY OF LSS OPERATION

Life Support Unit	Actual Operating (hr)	Down Time (hr)	Standby (hr)	Required Operating (hr)	Actual hr/ Reqd hr
Waste management					
Commode*	23.3	0	2,133.2	23.3	1.000
Urine collector	2.5	34.9	2,119.1	37.4	0.067
Water management					
VD-VF*	1,529	597.5	30	2,126.5	0.720
Wick evaporator	744	0	1,412.5	744	1.000
Humidity control	2,156.5	0	0	2,156.5	1.000
Potable multifilter	2,026.8	0	129.7	2,026.8	1.000
Wash water recovery	2,156.5	0	0	2,156.5	1.000
Atmosphere purification					
Solid amine concentrator*	1,662	494.5	0	2,156.5	0.772
Molecular sieve concentrator	494.5	0	1,662	494.5	1.000
Toxin control	1,790.5	0	366	1,790.5	1.000
Thermal control	2,156.5	0	0	2,156.5	1.000
Atmosphere supply and pressurization					
Sabatier reactor	1,918.7	104	133.8	2,022.7	0.947
Electrolysis (Allis-Chalmers)*	96	2,036.5	24	2,132.5	0.045
Electrolysis (Lockheed)*	1,492.8	475.3	188.4	1,968.1	0.758
Two-gas control*	2,156.5	0	0	2,156.5	1.000
Mass spectrometer sensor*	2,118.8	0	37.7	2,118.8	1.000
Baseline two-gas control	0	0	2,156.5	0	1.000
Baseline two-gas sensors	37.7	0	2,118.8	37.7	1.000

*Advanced subsystem unit

The approach to life support equipment repair and maintenance simulated that aboard a space station. The test crew was trained to complete normal repairs, maintenance, and part replacement. Standby procedures and units were provided and used until repairs could be completed on the primary unit.

2.1.1.1 Maintenance and Repair Activity

All repairs and maintenance on inside equipment was accomplished by the test crew, utilizing the onboard spares. Verbal assistance, when required, was provided by the outside staff.

The reliability of the equipment was generally very good. The only major failures that could not be corrected during the test occurred with the onboard electrolysis unit and the zero-g urine phase separator. A detail discussion of the maintenance and repair activity for each unit is contained in subsequent sections of this report. The failures which caused unit down time are summarized as follows:

A. Urine Collector—On day 6, the phase separator failed because of addition of excessive urine pretreatment which severely damaged the separator impeller. The crew modified the unit for one-g operation.

B. VD-VF—Between days 27 and 33, a malfunctioning boiler liquid-level control was repaired and the catalyst, which had been flooded with urine, was washed. On day 39, the condensate tanks, which had been microbiologically contaminated by the flooding, were sterilized. Between days 45 and 52, the catalyst was again washed and the unit sterilized after a malfunction of the urine accumulator liquid-level control. On day 81, the unit was shut down when the second boiler was expended.

C. Solid Amine Concentrator—Between days 14 and 17, unsuccessful attempts were made to repair a faulty bed selector valve. The unit was returned to operation on the remaining two beds. Between days 20 and 25, the unit was shut down to evaluate lack of CO_2 removal efficiency. Data evaluation revealed that the temperature reference junction had drifted 8.44°K (15°F) and required recalibration. On day 34, the pneumatic compressor, which supplied control power, failed and was replaced by a nitrogen pressure line from the two-gas control supply cource. On day 81, the unit was shut down when acceptable CO_2 levels could not be maintained in the SSS.

D. Sabatier Reactor—Between days 14 and 16, the unit was in standby for evaluation of a suspected gas contamination problem. Nitrogen had been detected in the H_2 and Freon had been detected in the CO_2. Between days 17 and 27, the operation was intermittent with 25 shutdowns and restarts. On days 28 and 29, the catalyst was replaced. On day 51, the unit was in standby resulting from a lack of H_2 and available crew time for restart. On day 81, a failed zero-g condenser/separator was replaced.

E. Allis Chalmers Electrolysis—Between days 3 and 17, a failed module was replaced and all modules flushed. In addition, repairs were completed on the electronic control and an N_2 pressure regulator. Between days 18 and 20, the operation was intermittent and final failure occurred on day 20.

F. LMSC Electrolysis—Between days 1 and 3, the unit was in standby. On day 4, an H_2 leak in module 1 was repaired. On day 9, operation was intermittent because repeated shut downs of the 28-vdc power supply. Between days 12 and 17, the unit was shut down to replace defective N_2 purge solenoid valves and the 28-vdc power supply. Between days 18 and 21, the unit was in standby. Between days 45 and 48, the unit was shut down to repair a short in module 1, to repair leaks in modules 2 and 3, and to replace defective temperature switches. On day 60, a defective N_2 solenoid valve was repaired and the 28-vdc logic power supply was replaced. Between days 63 and 66, module 2 was rebuilt. Between days 73 and 74, modules 1, 3, and 4 were rebuilt.

The LSS repair operations requiring hardware disconnect, repair, and replacement during the 90-day test are outlined in Table 2-5. The crew was also required to perform maintenance on equipment and the maintenance items which directly affected the LSS are also noted in Table 2-5. The hours noted are the best information obtainable from the test logs maintained by outside staff and crewmen.

Since the LMSC electrolysis unit was located outside the SSS, all 16 repair operations on this unit were performed by outside personnel. In addition, certain failures, which occurred in external gas sample and vent lines, were repaired by outside personnel. These items were: the replacement of a flow transducer; the installation of an activated carbon filter and five carbon changes in the Sabatier CO_2 sample loop; the draining of water from the Sabatier methane vent pump; and the replacement of the O_2 purifier in the electrolysis sample loop. These outside activities covered 25 items in 90.2 hours. There were 212 onboard maintenance and repair items which required 151.8 hours of crew time.

In addition to repair and maintenance of the LSS, the crew performed additional tasks on onboard experiments and other support equipment. The significant items are outlined in Table 2-6. Not included in Table 2-6 is the scheduled maintenance which was required for items, such as the TV cameras, radiation monitor, and aerosol particle counters. This scheduled maintenance was estimated to be a total of approximately 23 hours. The total onboard crew time for all maintenance and repair activities was approximately 203 hours, or 2.3 hours/day.

Outside personnel were required to monitor and maintain the facility support equipment. Since this maintenance activity did not directly relate to the LSS operation and did not require onboard crew time, these activities are not noted in Table 2-5. The major facility repair items were: two replacements of the hot Coolanol pump seal; two replacements of the Stuart Electrolyzer (backup electrolysis unit) oxygen pump valves and diaphragms; and one replacement of the Electrolyzer rectifier control cooling blower motor.

Table 2-5

LSS MAINTENANCE AND REPAIR SUMMARY

Life Support Unit	Repair		Maintenance		Unit Totals	
	Items	hr	Items	hr	Items	hr
Waste management						
Commode*	2	0.7	2	5.5	4	6.2
Urine collector	8	14.3	0	0	8	14.3
Water management						
VD-VF*	20	19.9	1	4.0	21	23.9
Wick evaporator	0	0	4	0.3	4	0.3
Humidity control	3	1.2	30	15.0	33	16.2
Potable multifilter	3	5.3	1	0.3	4	5.6
Wash water recovery	18	4.1	1	0.7	19	4.8
Atmosphere purification						
Solid amine concentrator*	33	30.1	14	3.3	47	33.4
Molecular sieve concentrator	7	3.7	1	0.7	8	4.4
Toxin control	0	0	0	0	0	0
Thermal control	0	0	0	0	0	0
Atmosphere Supply and pressurization						
Sabatier reactor	20	18.6	0	0	20	18.6
Electrolysis (Allis-Chalmers)*	47	26.5	0	0	47	26.5
Electrolysis (Lockheed)*	16	83.2	0	0	16	83.2
Two-gas control*	0	0	0	0	0	0
Mass spectrometer*	0	0	5	4.1	5	4.1
Baseline two-gas control	0	0	0	0	0	0
Baseline two-gas sensors	0	0	1	0.5	1	0.5
Life support system totals	177	207.6	60	34.4	237	242

*Advanced subsystem unit

Table 2-6

MISCELLANEOUS MAINTENANCE AND REPAIR SUMMARY

Activity	Repair		Maintenance	
	Items	hr	Items	hr
Defrost refrigerator	0	0	9	4.5
Cleaned cabin floor	0	0	9	9.0
Cleaned dew pointer mirrors	0	0	4	1.5
Corrected leak in trash container	2	0.3	0	0
Repaired psychomotor pedal	1	1.0	0	0
Deactivated smoke alarm sensor	2	0.7	0	0
Repaired radiation monitor	1	0.3	0	0
Repaired particle counter	1	0.5	0	0
Replaced videcon tube	1	0.5	0	0
Repaired TV coaxial cable	5	2.5	0	0
Installed intercom call light	1	1.0	0	0
Attempted repair of visual sensitivity tester	4	6.7	0	0
Totals	18	13.5	22	15.0

The performance of the equipment was excellent considering the system complexity and the extensive use of nonflight-qualified prototype equipment. The performance of the crew was outstanding in completing the many repair and maintenance tasks.

2.1.1.2 Spares Usage

As previously noted, all spares for the LSS and critical support equipment were stored onboard the SSS. The location and quantity were documented in the spares inventory list. There were 365 major items included in the spares inventory, not including items such as fluid fittings, wire, tubing, tape, and sealant. The usage of these major spare parts is noted in Table 2-7 and amounted to 14.3 percent of the available spares.

The stocked spares were sufficient to support the 90-day test, except for those required for the urine phase separator and the Allis-Chalmers electrolysis unit. The use of the zero-g features of the urine collector were lost when the phase separator impeller was severely damaged on day 6. Unfortunately, this type of failure had not been anticipated by the FMECA and

Table 2-7

MAJOR ONBOARD SPARES USAGE

Equipment Affected	Spare Part Used	Number
Waste management		
Commode	Liner assembly	1
Urine collector	Relay	1
	Timer	1
Water management		
VD-VF	Float switch	1
	Relay	1
	Boiler assembly	1
	Pump assembly	1
Humidity control	Sump screen	2
	Pump*	1
Potable multifilter	Carbon column	2
	Resin column	1
	Filter	1
Wash water recovery	Carbon column	4
	Resin column	2
	Filter	5
Atmosphere purification		
Solid amine concentrator	Filter	11
	Compressor*	1
	Blower*	1
	Water pump*	1
	Solenoid valve	1
Molecular sieve concentrator	Check valve	1
Atmosphere supply and pressurization		
Sabatier reactor	Catalyst refill	1
	Condenser	1
Electrolysis (Allis-Chalmers)	Electrolysis module	2
	Zener diode	2
	Pressure regulator	2
Baseline two-gas sensors	Polarographic sensor	1
Miscellaneous		
Communications	Videcon tube	1
Radiation Monitor	Photomultiplier tube	1
*Installed spares	Total Spares	52

adequate spares were not available. Although two spare modules were provided for the Allis-Chalmers electrolysis unit, both spares were expended before day 20 and subsequent failures terminated the operation of this unit.

The lack of adequate spares for these two units emphasizes the importance of adequate reliability data. Analysis such as the FMECA is only as good as the available data. On new prototype equipment, this can only be obtained by extensive bench testing and long-duration tests, such as the 90-day test. It is important to note that the flight-type two-gas control and mass spectrometer sensor, which exhibited a high degree of reliability during the test, were advanced subsystem units being tested for the first time in a manned test. However, both unit designs were evolved from prototype equipment with a long history of bench and manned testing. Some of the new prototype life support units which had been evaluated by bench test only exhibited low reliability. In many instances where units operate satisfactorily in laboratory bench tests, operation as an integrated system, with all the attendant interface matching problems and realistic input/output conditions, emphasizes weaknesses which appear as lower performance or outright failure.

2.1.2 Mass Balance

Mass balance data for the 90-day test is presented primarily to show the performance of the various units and subsystems and their interactions, providing data on operation of an integrated system which will be useful to spacecraft LSS designers in the evaluation of advanced subsystems.

The mass balance data were derived from a number of sources. Flow meters and flow totalizers were installed in most of the water and gas transfer lines between units. Manually obtained and recorded measurements of water transfers were used to augment recorded data.

The data which are presented in the following sections consider the water and atmospheric gas mass balances derived from a system standpoint. In addition to overall data for the 90-day test, information is presented for shorter segments of time when various units were not operating and effects of changing loads imposed on other units can be determined. Finally, information is presented on the input and output of the four crewmen. This is derived from the water and gas mass balance data, as well as recorded data on food intake, fecal production, and blood samples.

2.1.2.1 Water Management Mass Balance

The overall water mass balance for the 90-day test is shown in Figure 2-7. To show variations in water circulation during various operating modes, some segment of the total period were examined in more detail as shown in Figures 2-8, 2-9, and 2-10. Figure 2-11 provides details on the wash water recovery portion of the water management subsystem.

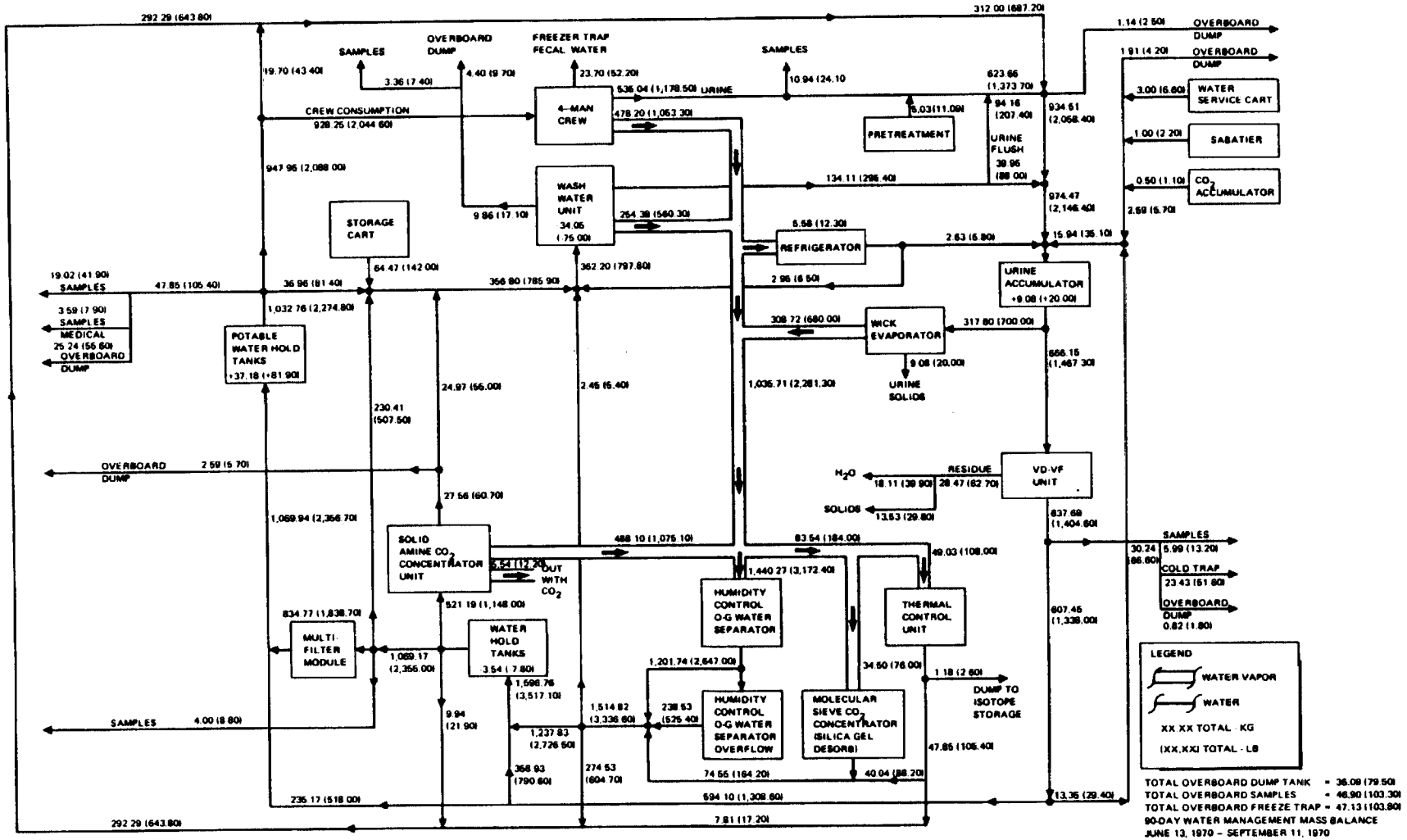


Figure 2-7. Overall Water Mass Balance

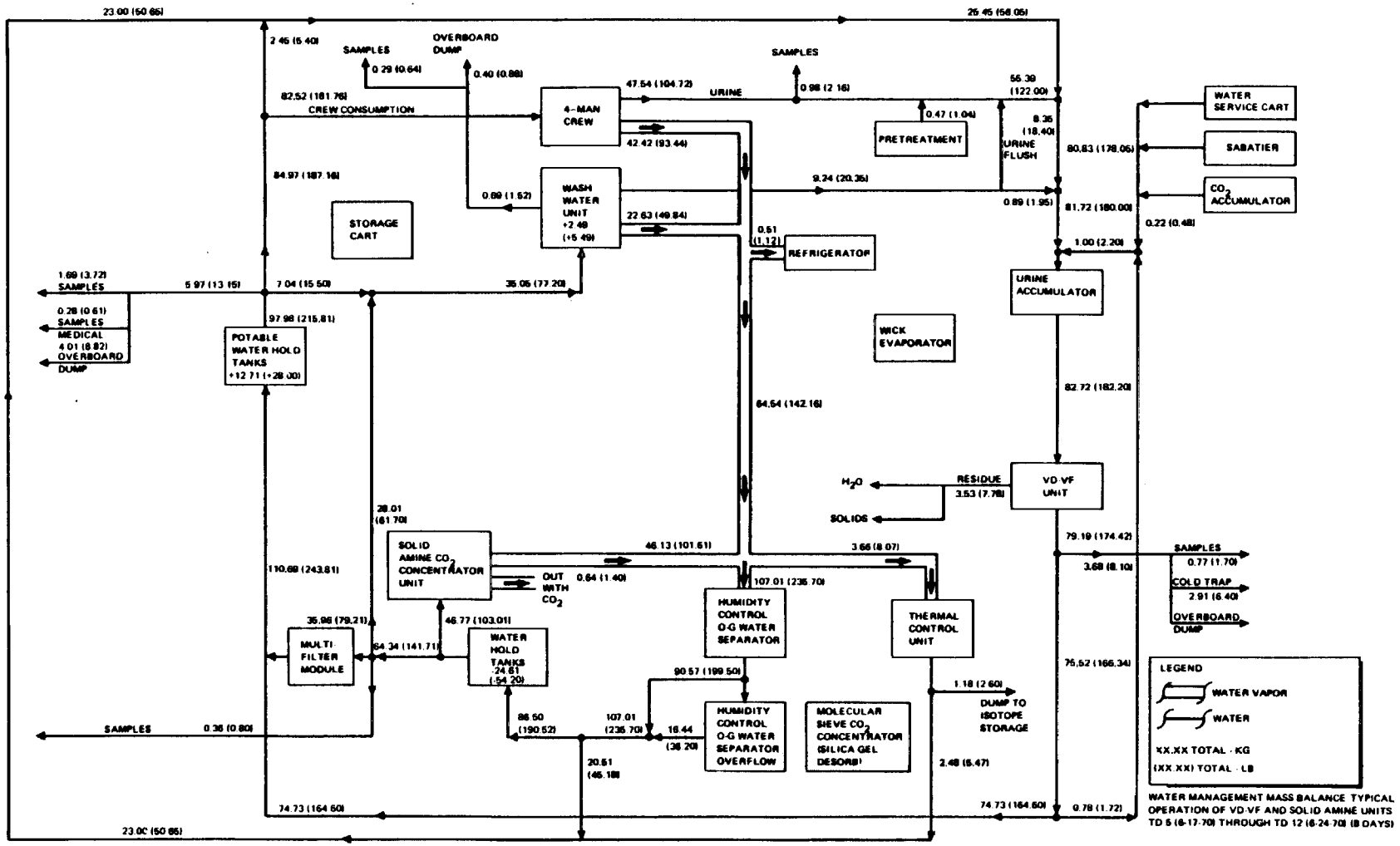
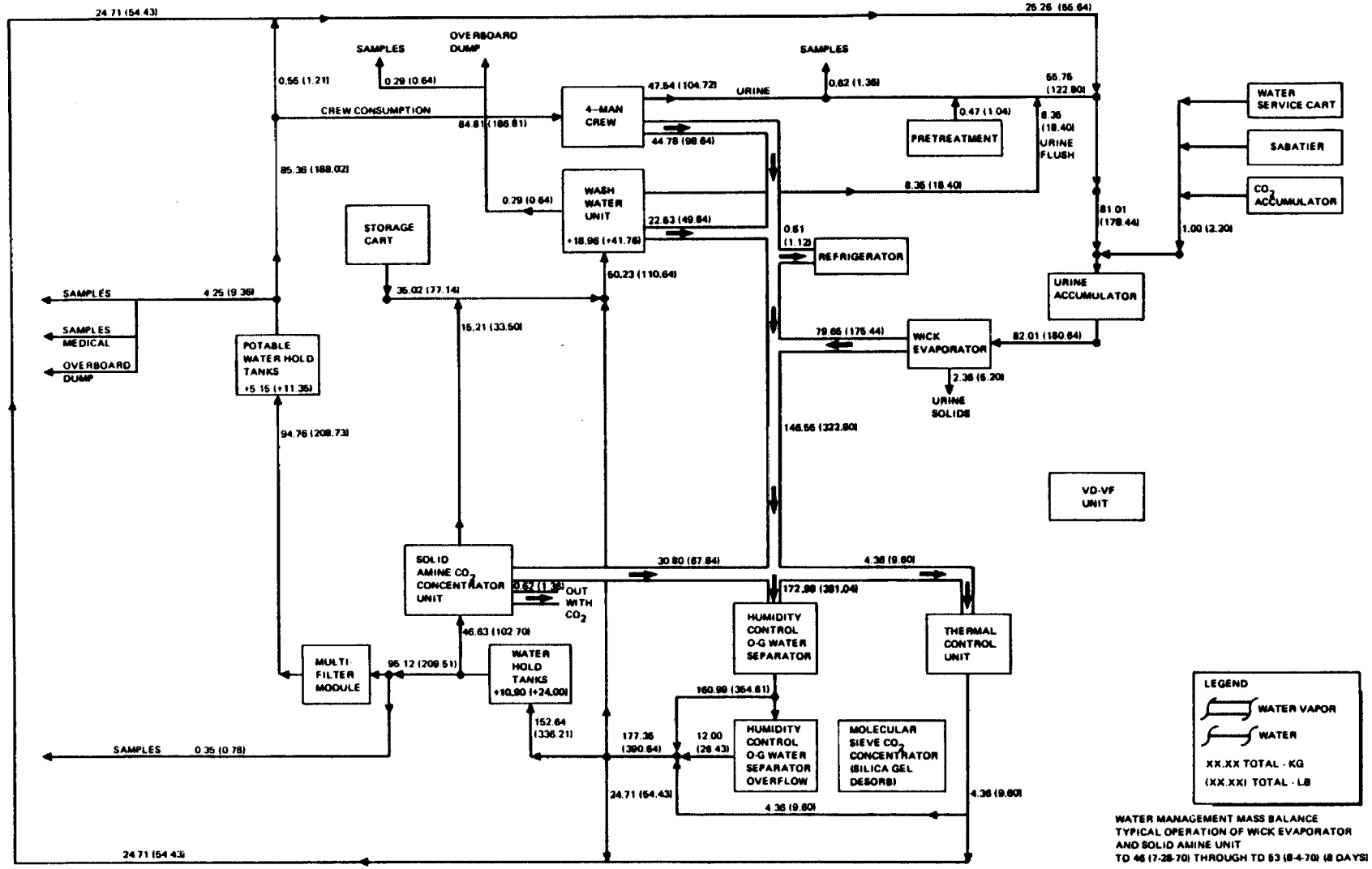


Figure 2-8. Potable Water Mass Balance—Days 5 Through 12



WATER MANAGEMENT MASS BALANCE
TYPICAL OPERATION OF WICK EVAPORATOR AND SOLID AMINE UNIT
TD 46 (7-28-70) THROUGH TD 53 (8-4-70) (8 DAYS)

Figure 2-9. Potable Water Mass Balance—Days 46 Through 53

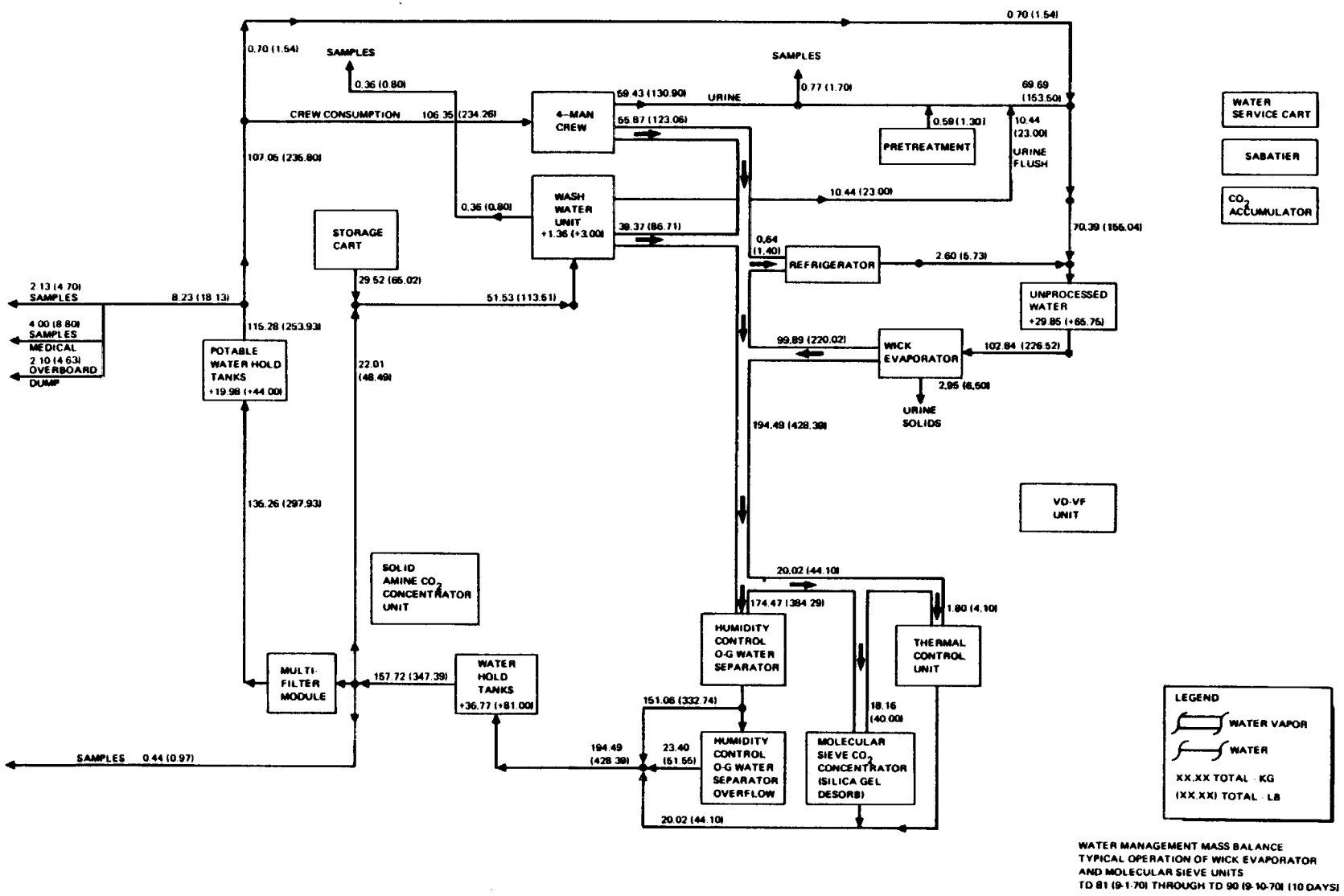


Figure 2-10. Potable Water Mass Balance—Days 81 Through 90

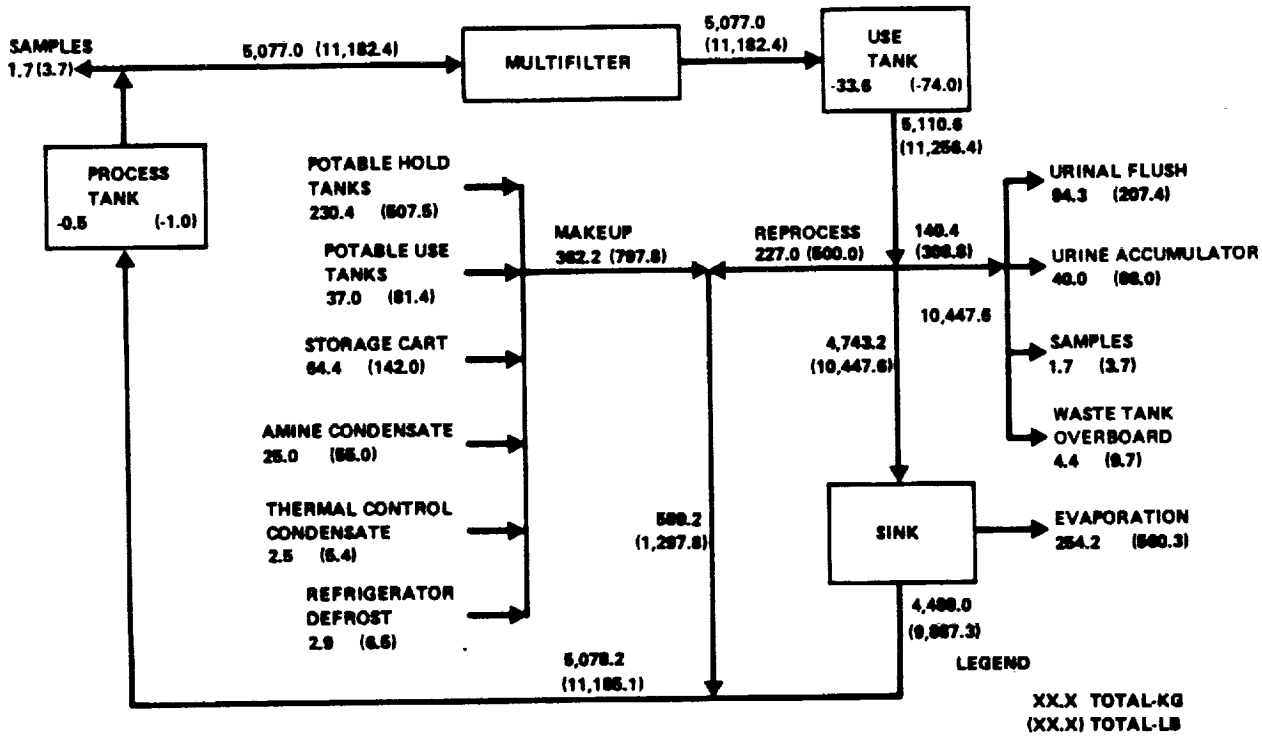


Figure 2-11. Wash Water Mass Balance

Overall Potable Water Mass Balance

Listed below is a summary of the results given in detail in Figure 2-7 which provides the complete water mass balance for the 90-day test:

Item	Value	Remarks
Urine production	535.0 kg (1,178.5 lb)	
Respiration/perspiration	478.2 kg (1,053.3 lb)	Represents a total of 1,220.7 kg (2,688.7 lb) or 13.55 kg/day (29.87 lb/day) of humidity condensate removed from the cabin.
Wash water evaporation	254.4 kg (560.3 lb)	
Solid amine unit exhaust	488.1 kg (1,075.1 lb)	
Potable water certified for crew consumption	1,069.9 kg (2,356.7 lb)	594.1 kg (1,306.6 lb) produced by the VD-VF unit, 475.8 kg (1,048.1 lb) produced by the air/wick evaporator unit
Potable water consumed by the crew	928.5 kg (2,044.6 lb)	
Humidity condensate supplied to the solid amine unit	521.2 kg (1,148.0 lb)	Supplied as makeup water

Humidity condensate supplied to the wash water unit	232.9 kg (512.9 lb)	Supplied as makeup water
Wash water unit production	4,743.2 kg (10,447.6 lb)	

Typical Operation: Solid Amine/VD-VF Units

Figure 2-8 presents one of the operating modes for days 5 through 12. During this period, the solid amine and VD-VF units were operating and no wick evaporator operation occurred. In deriving this chart, 90-day average values were used for urine production, crew latent loss, wash water evaporation, urinal flush water, VD-VF vent losses, and boiler residuals. Other values represent recorded data during this period. It will be noted that VD-VF production averaged 9.34 kg/day (20.58 lb/day), and none of this product was multifiltered during this period. The total humidity condensate averaged 13.83 kg/day (30.47 lb/day), of which 5.72 kg/day (12.70 lb/day) resulted from the solid amine unit. Diluent water to the VD-VF feed was 26.55 kg (58.48 lb) or 3.32 kg/day (7.31 lb/day) most of which was provided from the humidity condensate.

Typical Operation: Solid Amine/Wick Evaporator Units

Figure 2-9 shows the 8-day period from test day 46 through 53, when the wick evaporator and solid amine units were operating and no VD-VF operation occurred. Again, 90-day average values were used for urine production, wash water evaporation, urinal flush water, and wick evaporation residual solids. Actual data were used for crew consumption, 10.60 kg/day (23.35 lb/day), and average metabolic water production was used to determine crew latent loss of 5.60 kg/day (12.33 lb/day). All other data represent measured values. During this period, the solid amine unit contribution to cabin humidity was 3.85 kg/day (8.48 lb/day). The wick evaporator was processing urine which was previously diluted for VD-VF feed, averaging 9.96 kg/day (21.93 lb/day). The total humidity condensation rate was 22.17 kg/day (48.84 lb/day), which was one of the peak periods during the test. An average of 11.85 kg/day (26.09 lb/day) was certified for crew consumption.

Typical Operation: Molecular Sieve/Wick Evaporator Units

Figure 2-10 shows data for the final 10 days of the test. On day 81, the VD-VF and the solid amine units were shut down for the balance of the test. This period represents operation on the molecular sieve CO_2 concentrator and the wick evaporator. At the beginning of this period approximately 29.85 kg (65.75 lb) of diluted urine was available which was processed in the wick evaporator as well as the urine produced. No further dilution of the urine occurred from humidity condensate. Also, the crew was actively preparing for the end of the test, and a number of extra cycles of the washer/dryer were performed, increasing the wash water evaporation loss to 3.94 kg/day (8.67 lb/day). Even so, the total humidity condensate was down to 9.46 kg/day (20.84 lb/day) because of the shutdown of the solid amine unit. The evaporation rate of the wick evaporator was 9.99 kg/day (22.0 lb/day), producing a total condensation of 19.45 kg/day (42.84 lb/day). Of this, the net inventory in the two potable holding tanks was increased by 36.8 kg (81.0 lb) and the potable use tanks by 20.0 kg (44.0 lb), averaging an increase of 5.7 kg/day (12.5 lb/day).

Wash Water Mass Balance

Figure 2-11 provides the details on the wash water recovery mass balance during the 90-day period. A total of 4, 743.2 kg (10, 447.6 lb) or 52.78 kg/day (116.08 lb/day) was dispensed by the unit. Of this 254.4 kg (560.3 lb) (about 5 percent) was lost by evaporation. Much of this was probably from the clothes dryer and sponge bathing. Makeup water included 362.2 kg (797.8 lb) from various sources to compensate for evaporation losses as well as 94.3 kg (207.4 lb) used for urinal flush water and 47.7 kg (105.1 lb) of other losses. The net change in inventory in the holding and use tanks was a loss of 34.1 kg (75.0 lb). About 227.0 kg (500.0 lb) of wash water was reprocessed, after changes in multifiltration columns, to remove accumulated contaminants.

2.1.2.2 Gaseous Mass Balance

Figure 2-12 shows the complete gaseous mass balance for the 90-day test. The following is provided to summarize the analysis of Figure 2-12.

Oxygen for crew consumption and hydrogen for the Sabatier reactor were normally generated by water electrolysis. It was intended that this be done by a flight-type unit built by Allis-Chalmers and installed inside the SSS. However, as explained in Section 2.4.2, this unit soon had operational problems and was responsible for generation of only 10.2 kg (22.4 lb) of oxygen and 1.3 kg (2.8 lb) of hydrogen. Most of the balance of the test depended upon the Lockheed unit which was installed outside the SSS and generated 257 kg (566.0 lb) of oxygen and 32.1 kg (70.8 lb) of hydrogen. These units were supplied with water produced by the Sabatier reactor, 150.7 kg (332.0 lb), or from a storage reservoir inside the chamber, 149.8 kg (330.0 lb). The hydrogen generated was normally used by the Sabatier reactor, although it was was shut down for periods of time during which it was necessary to vent 7.1 kg (15.6 lb).

When neither flight-type water electrolysis unit was able to meet cabin requirements, supplementary oxygen and hydrogen were produced by the commercial Stuart electrolysis unit. This amounted to 117.3 kg (258.3 lb) of oxygen and 10.4 kg (23.0 lb) of hydrogen. Since the Stuart unit was manually controlled at a fixed electrolysis rate, the excess gas generated was vented, and measurements were not made of the amount of water supplied to the unit.

In addition to the 384.4 kg (846.7 lb) of oxygen generated by electrolysis, 7.0 kg (15.3 lb) were supplied from the high-pressure storage unit. This was done once on day 6 when the oxygen setpoint of the two-gas control was increased by 1.3 kN/m^2 (10 mm Hg) and approximately 1.8 kg (4.0 lb) of oxygen were added manually to compensate. Other usages of bottled gaseous oxygen occurred during several short periods when none of the electrolysis units was functioning.

Nitrogen was supplied from high-pressure gaseous storage and controlled by the two-gas control. Total nitrogen use was determined from the pulse counter totalizer on this unit. This amounted to 126.6 kg (278.9 lb) or 1.41 kg/day (3.10 lb/day). Of this input, 1.0 kg (2.3 lb) of N_2 and 0.5 kg (1.1 lb) of O_2 were removed from the SSS for atmospheric analysis. The balance of the nitrogen is indicative of losses and leakage. Average analysis of the CO_2 output of the molecular sieve and solid amine units indicates a

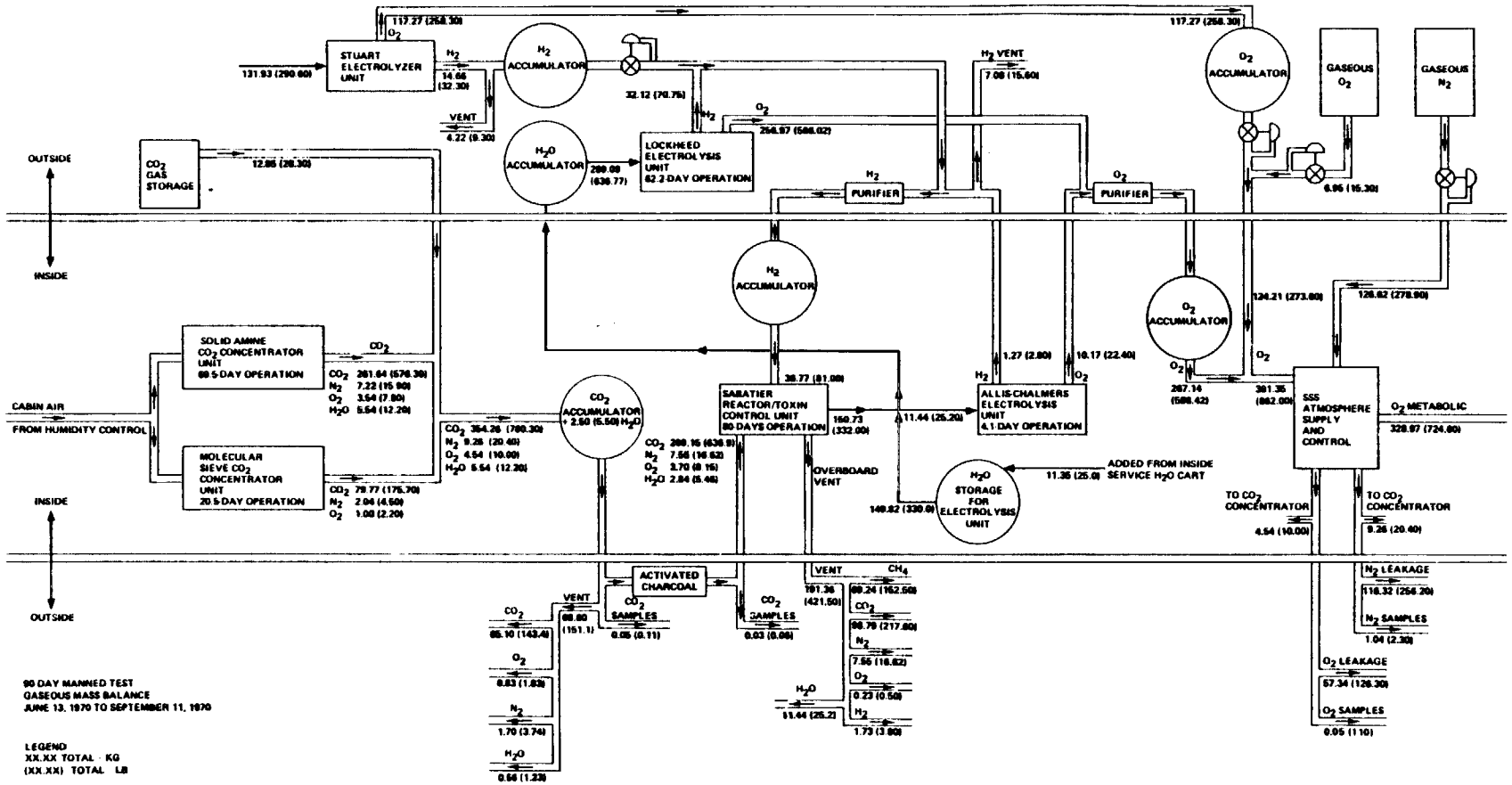


Figure 2-12. Gaseous Mass Balance

total of 9.3 kg (20.4 lb) of N_2 and 4.5 kg (10.0 lb) of O_2 were removed with this gas. Other losses may have occurred by undetected leaks in the VD-VF vent, the commode sealing valve, the commode fecal sampler, the dry waste can vent to annulus, and other sources. Data are not available to define these values. Previous experience with the SSS indicates that basic chamber leakage is normally very low. In any event the total of unaccounted losses and leakage is 116.3 kg (256.2 lb) or 1.29 kg/day (2.85 lb/day) of nitrogen and 57.3 kg (126.3 lb) or 0.65 kg/day (1.40 lb/day) of oxygen. The remaining 328.9 kg (724.5 lb) of the oxygen or 3.66 kg/day (8.05 lb/day) is accounted for by crew metabolic consumption.

CO_2 was removed from the cabin either by the solid amine or the molecular sieve unit. Purity of the removed CO_2 was determined by periodic analysis of samples taken outside the chamber. Average values of these analyses were used to determine the nitrogen and oxygen removed with the CO_2. Also the effluent CO_2 from the solid amine unit contained excess water. After the test 2.5 kg (5.5 lb) of water were removed from the CO_2 accumulator. Additional water vapor was present in the CO_2 to establish an average dewpoint of the CO_2 of about 297°K (75°F). This resulted in removal of about 5.5 kg (12.2 lb) of water from the SSS during the 69.5 days of operation. The molecular sieve unit provided CO_2 with a dewpoint of about 228°K (-50°F) and therefore removed very little water from the cabin although there may have been some water entrapped in the beds.

The Sabatier reactor was normally operated with all the produced CO_2 being processed through it. However, low CO_2 feed rates were used during a period of intermittent operation before the catalyst change, and venting of CO_2 occurred during periods when it was not operating. During one period when catalyst poisoning was suspected, 12.9 kg (28.3 lb) of bottled CO_2 was furnished to the reactor in an attempt to regain catalyst activity, and CO_2 removed from the cabin was vented.

The CO_2 feed to the Sabatier reactor necessarily included O_2, N_2, and H_2O as impurities. Analysis indicated that the hydrogen feed was essentially pure. The exhaust gas was passed through a water bath, in which the increase in water content was noted to determine the loss of water in the exhaust vent, and measured by wet test meter. Average of periodic analyses determined the vent gas composition, which confirmed the presence of nitrogen and CO_2. Normally the oxygen content was very low, indicating that it had reacted with hydrogen in the reactor to produce product water. Unreacted hydrogen was vented, including some during short periods of reactor operation with excess hydrogen to produce catalyst reduction. The Sabatier reactor operated for a total of 80 days, producing 150.7 kg (332.0 lb) of water for an average rate of 1.86 kg/day (4.10 lb/day). Peak rates were somewhat higher.

2.1.2.3 Crew Input/Output Data

The input/output of the four crewmen for the 90-day test is shown on Figure 2-13. As indicated, the input included averages of 3.66 kg/day (8.05 lb/day) of oxygen, 10.31 kg/day (22.70 lb/day) of water, and 2.45 kg/day (5.40 lb/day) of food. Most of this food (approximately 90 percent) was freeze dehydrated. The crewmen showed a net weight increase of 1.02 kg (2.25 lb).

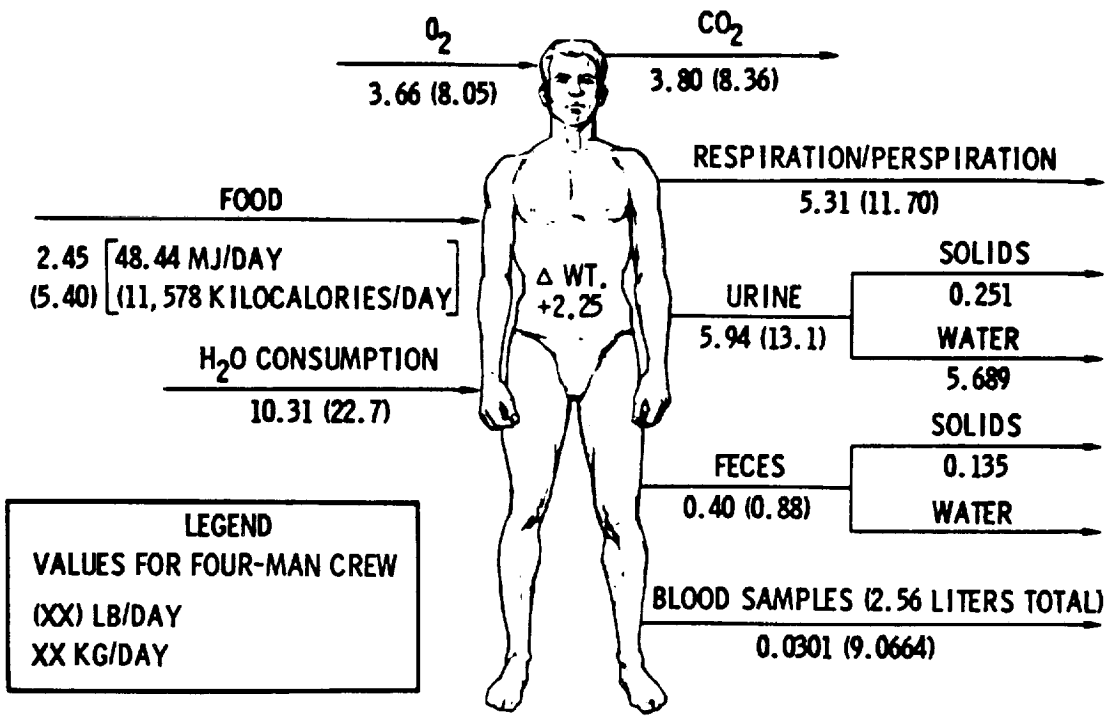


Figure 2-13. Average Crew Input/Output Data

Output of the crewmen included 3.80 kg/day (8.36 lb/day) of CO_2. The derived respiratory quotient (RQ) was therefore 0.75 (The RQ is the volumetric ratio of the rate of CO_2 production to the rate of O_2 input). Crew respiration and perspiration averaged 5.31 kg/day (11.70 lb/day). The urine output of 535.0 kg (1,178.5 lb) was found to include 22.6 kg (49.8 lb) of solids and 512.0 kg (1,128.7 lb) of reclaimable water. The average reclaimable water was 5.69 kg/day (12.54 lb/day). The reclaimable water in urine, respiration, and perspiration was therefore 11.01 kg/day (24.24 lb/day); 0.70 kg/day (1.54 lb/day) or 62.92 kg (138.6 lb) more than the potable water consumption. Water was collected in the commode freeze traps, 23.7 kg (52.2 lb), and 12.1 kg (26.6 lb) of dried fecal solids in the commode. Total fecal production was therefore 35.8 kg (78.8 lb) or 0.40 kg/day (0.88 lb/day).

2.1.3 Thermal Balance

Equipment which must be considered in the thermal balance is listed in Table 2-8. This shows the major heat producing and removal equipment. Although some condensation did occur in the thermal conditioning unit, this amounted to less than 3 percent of the maximum total latent load. Condensation also occurred in the solid amine unit, although this was rarely enough to remove all the water vapor introduced in the steam desorption of the bed when this unit was operating. Condensation in the silica gel bed desorbing air stream of the molecular sieve assisted in reducing the cabin humidity during operation of this unit. Condensation that occurred in the Sabatier reactor exhaust and VD-VF vent gas did not influence the cabin latent load because these exhaust products were vented to overboard vacuum.

Table 2-8

LIFE SUPPORT EQUIPMENT INVOLVED IN THERMAL BALANCE

Equipment	Heat Producing			Heat Removal	
	Electrical	Latent	Sensible	Latent	Sensible
CO_2 removal					
Solid amine unit	X	X	X	**	
Molecular sieve unit	X		X	X	
Sabatier/toxin	X	*	X	*	
Potable water recovery					
VD-VF	X	*	X	*	
Air evaporator/humidity control	X			X	X
Lighting and recreation	X				
Crewmen		X	X		
Miscellaneous, including	X				
Wash and potable water storage	X				
Refrigerator and freezer	X		X	X	
Hot process fluid line loss			X		
Experiments	X				
Miscellaneous units	X				
Thermal conditioning unit	X				X

*Latent heat production to be removed by condensers within units.
**Latent heat to be partially removed by condenser within unit.

Process heating fluid, which is also Coolanol 35, is furnished to the chamber from an external, electrically heated reservoir. This fluid was used either by the solid amine or the molecular sieve CO_2 concentrator. Original plans for the SSS also included a Coolanol-heated oven, but this unit was eliminated before the test because of possible material incompatibility. As the molecular sieve and solid amine systems were not required to operate simultaneously, the proper circuit temperature was achieved by setting the heater thermostat at the reservoir. This was approximately 388°K (240°F) for the solid amine unit and 433°K (320°F) for the molecular sieve unit.

In thermal conditioning of the SSS during the 90-day test, coolant was provided from external dual redundant refrigeration units that simulate a space radiator. The coolant, which is Coolanol 35, is supplied at 273°K (32°F) to 277.4°K (40°F) at about 0.86 liter/sec (14 gpm). Coolant is supplied to a

number of the life support units within the chamber to remove the heat generated and is also used for atmospheric cooling in the thermal conditioning unit to pick up all heat rejected to the atmosphere. The SSS is insulated to reduce heat transfer, and is operated at a temperature very close to the outside environment. It is estimated that heat transfer between the SSS and outside was less than 293.3 J/sec (1,000 Btu/hr) under any operating mode.

The thermal balance was subject to considerable changes from day to day as the operating modes of the various life support units were changed. Chief among these variations were the following·

A. When the wick evaporator was processing urine, an electrical air preheater was used, adding about 300 watts (1,020 Btu/hr) to the heat input to the unit.

B. When the VD-VF unit was not operating, heat generation by the Pu-238 radioisotope capsules was removed in a storage chamber cooled by the coolant fluid loop.

C. Large changes in thermal inputs occurred, depending on use of the solid amine or molecular sieve units for CO_2 removal.

D. Changes in latent load from the washer and dryer resulted from variations in the laundry operations.

In order to describe system operations with these variations included, data are presented in Figure 2-14 through 2-17 representing unit operating modes for four typical days of the mission. These are as follows:

A. Figure 2-14, Day 23: Molecular sieve and VD-VF operating, solid amine not operating, wick evaporator preheater not operating.

B. Figure 2-15, Day 50: Solid amine unit and wick evaporator preheater operating; molecular sieve and VD-VF not operating.

C. Figure 2-16, Day 58: Solid amine unit and VD-VF operating.

D. Figure 2-17, Day 83: Molecular sieve unit and wick evaporator operating.

Although these represent typical days, data presented for each unit generally represent averages over much longer periods of time. The crew sensible and latent loads are averages for the entire mission, and were derived from caloric values of food intake, net weight change, and respiration/perspiration values from the water recovery mass balance data. Values for the molecular sieve and solid amine units represent averages over significant periods of apparently normal operations.

2.1.4 Electrical Power Usage

The power distribution system for the SSS was designed to meet all industrial code requirements. As a result, a large number of circuits were provided and many of these were very lightly loaded. Further requirements were established during the safety reviews which included insurance that each

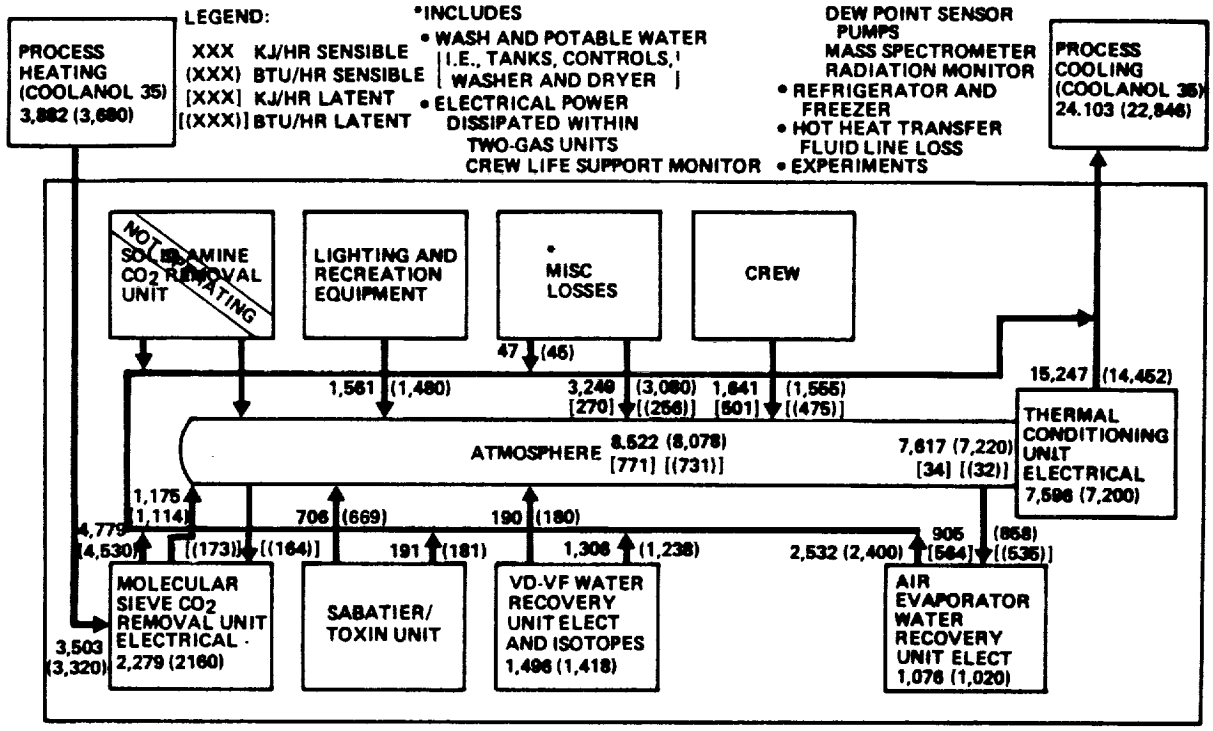


Figure 2-14. Overall Thermal Balance—Typical for Day 23

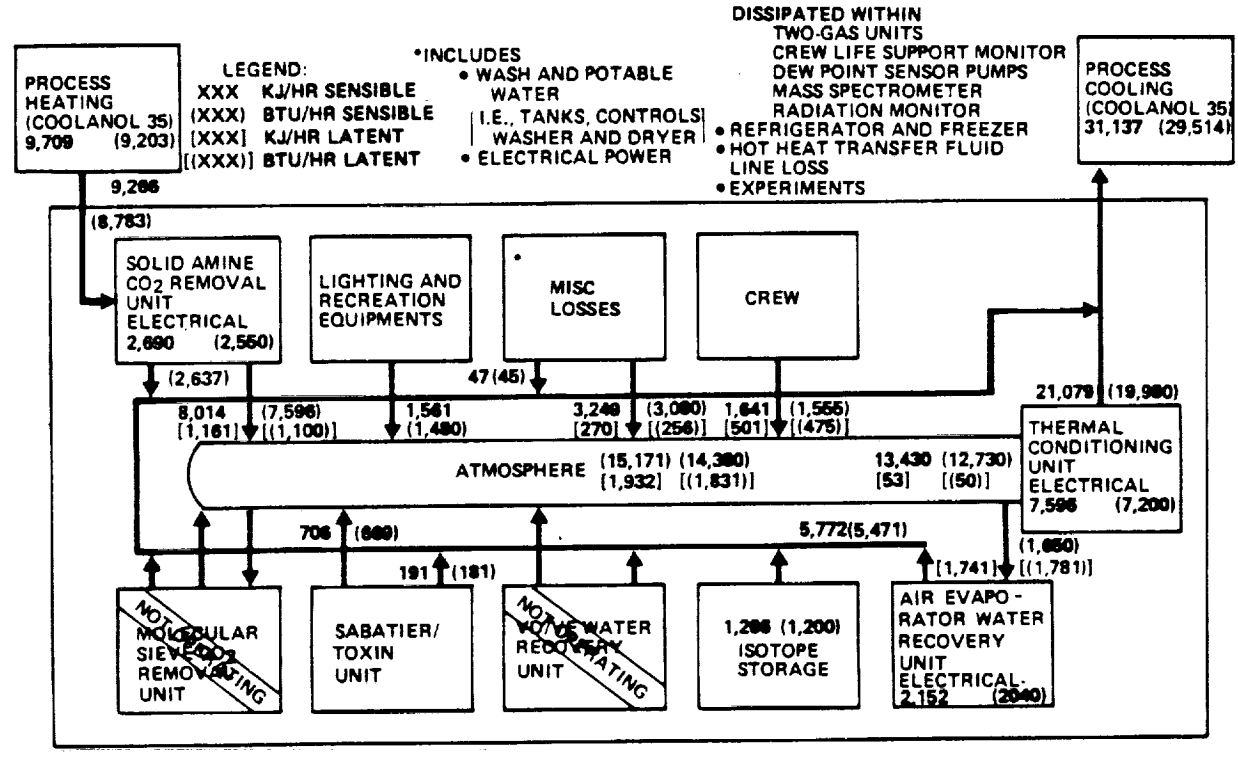


Figure 2-15. Overall Thermal Balance—Typical for Day 50

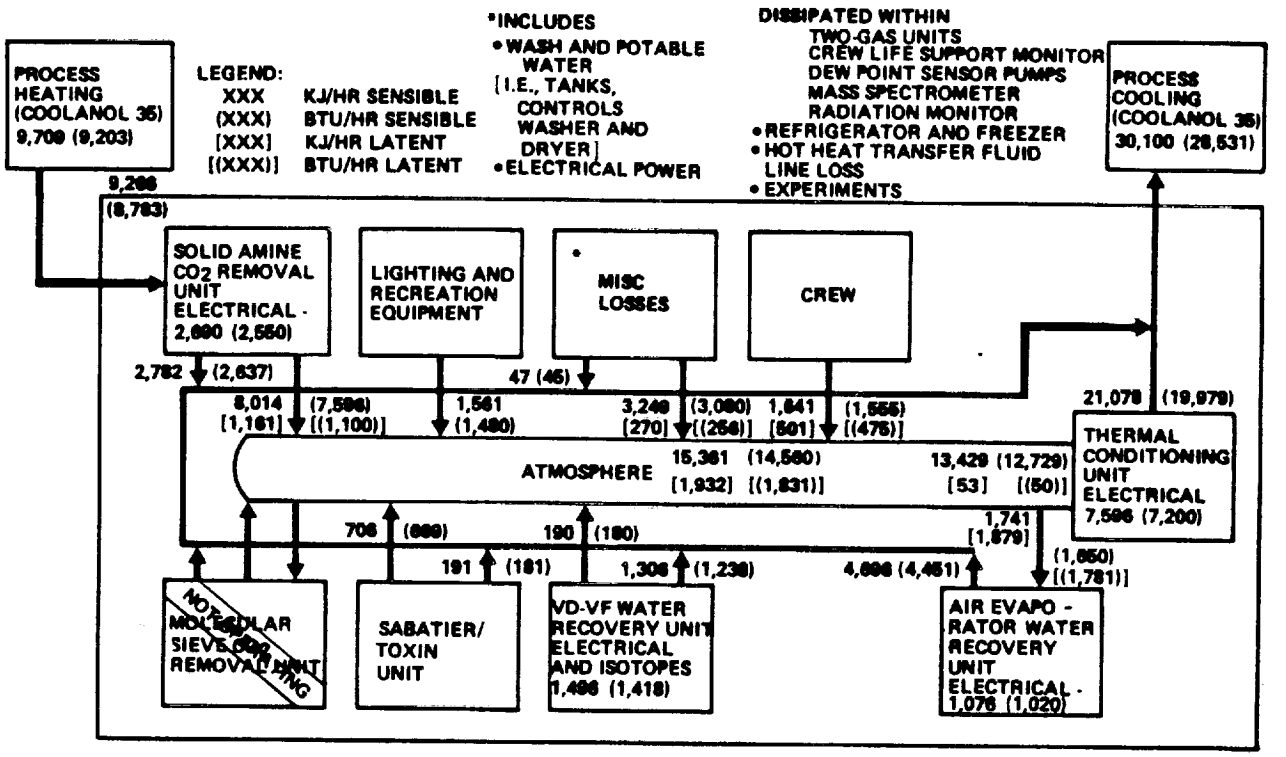


Figure 2-16. Overall Thermal Balance—Typical for Day 58

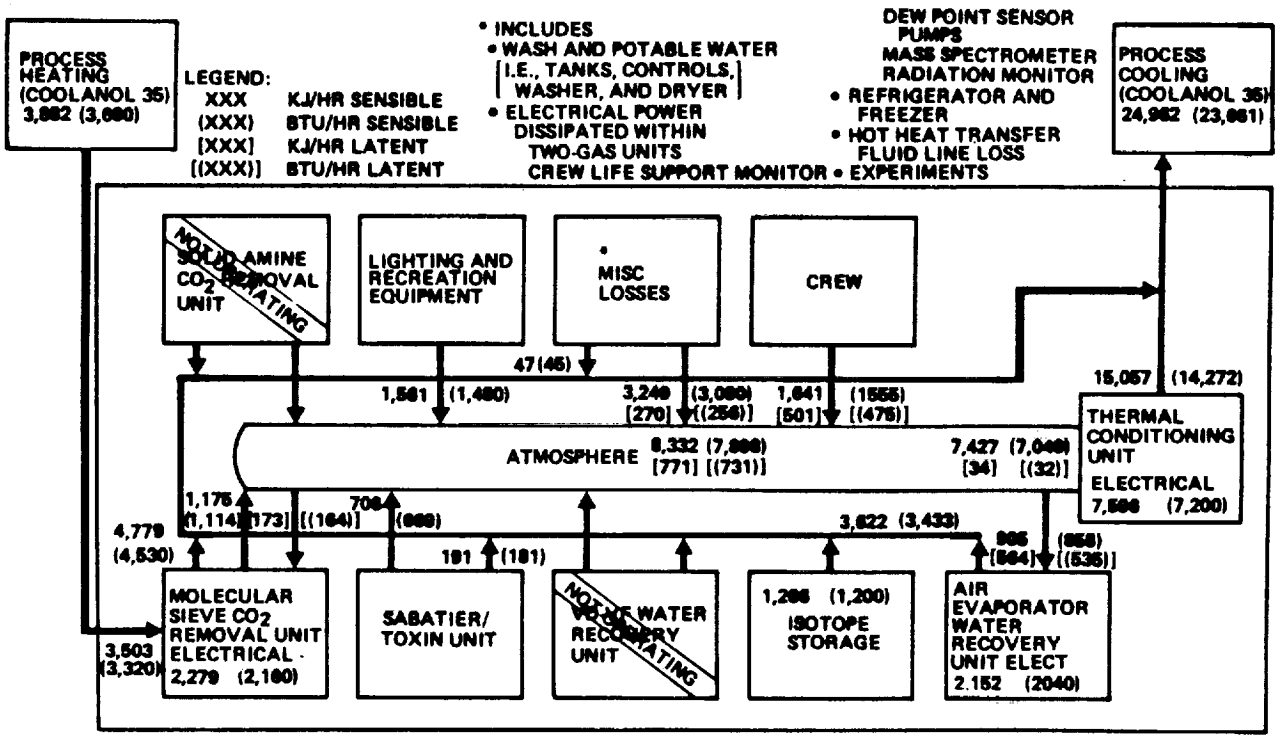


Figure 2-17. Overall Thermal Balance—Typical for Day 83

circuit wire gage was adequate for the circuit breaker protection provided and that each using element was fused to prevent destructive currents.

The electrical hardware incorporated into the SSS was designed to use one or more of the following power forms, 115 vac, 60 Hz, single phase; 120/208 vac, 400 Hz, three phase; and 28 vdc.

Twenty 115-vac, 60-Hz circuits were utilized with 20-amp circuit protection in each circuit. One 120/208-vac, 400-Hz circuit was employed with a maximum circuit capacity of 50 amps with individual breakers on each unit. Two 28-vdc circuits of 60 amps each were utilized to supply 28-vdc power to the SSS/LSS. An additional onboard 28-vdc power distribution panel was incorporated for more efficient distribution of the 28-vdc power. A third 28-vdc power circuit provided power for the test control area.

Backup power supplies were connected in parallel with the primary 28-vdc and the 400-Hz motor generator to allow fast manual switchover if necessitated by loss of the primary supply or need for preventive maintenance.

An emergency backup 28-vdc supply was incorporated into the overall electrical power system to automatically activate should the facility 115-vac, 60-Hz power fail. The emergency power supply consisted of a battery pack which, when activated, provided power to the emergency power bus for emergency onboard lighting and all safety-oriented chamber control functions. The emergency battery pack was maintained at full voltage with a trickle charger when not on line.

The power system block diagram for the 90-day SSS/LSS is shown in Figure 2-18.

The SSS power subsystem experienced two major facility 115 vac, 60 Hz power failures, the longest lasting approximately 20 sec. The power failure produced no problems with the onboard or facility support equipment, but required restarting the affected systems. The emergency backup 28-vdc activated properly and provided the required SSS lighting and chamber control power. The backup 400-Hz motor generator was used on days 66 and 67 to facilitate preventive maintenance on the primary motor generator drive belt. Table 2-9 lists the major power events for the 90-day test.

Power consumption for the run was derived from the commercial watt-hour meters identified by a WHR prefix in Figure 2-18. Additional power instrumentation was incorporated into the SSS power lines to allow real-time recording of instantaneous power on most lines entering the chamber. The real-time power instrumentation is identified by a WIR prefix in Figure 2-18.

The average power consumed during the 90-day run is diagrammed in Figure 2-19. The detailed subsystem power consumption and total power for the 90-day run are itemized in Tables 2-10 and 2-11.

Three power profiles were made during the run on days 38, 67, and 79 to document a 24-hour period for representation of power consumption for the 90-day test. Samples were taken and recorded on the LSDS every 4 minutes for each of the three 24-hour periods. Figures 2-20 through 2-25 show the resulting power profile for the ac power circuits on day 67 and represent power consumption for a typical day in the 90-day test.

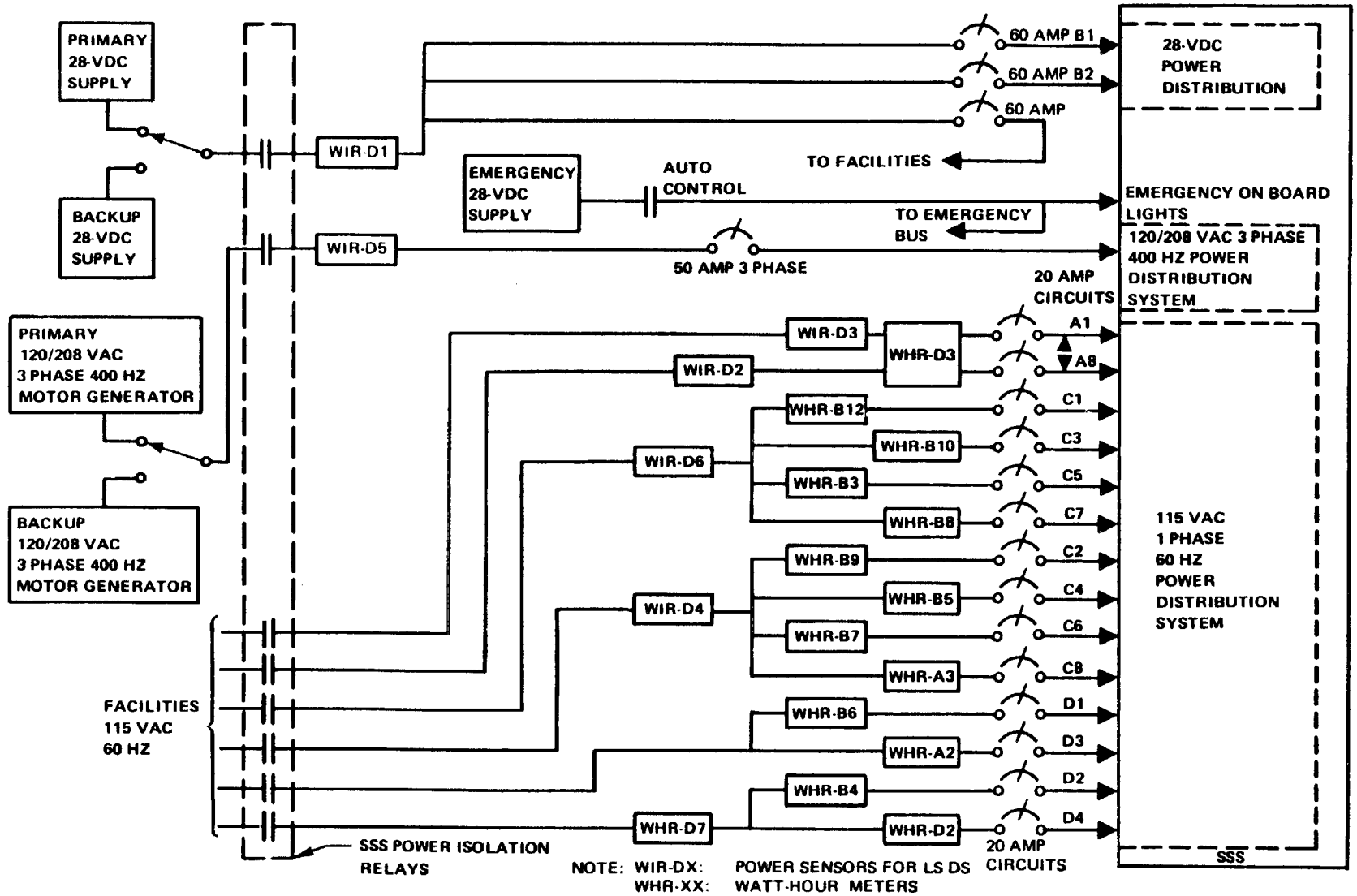


Figure 2-18. Power System Block Diagram

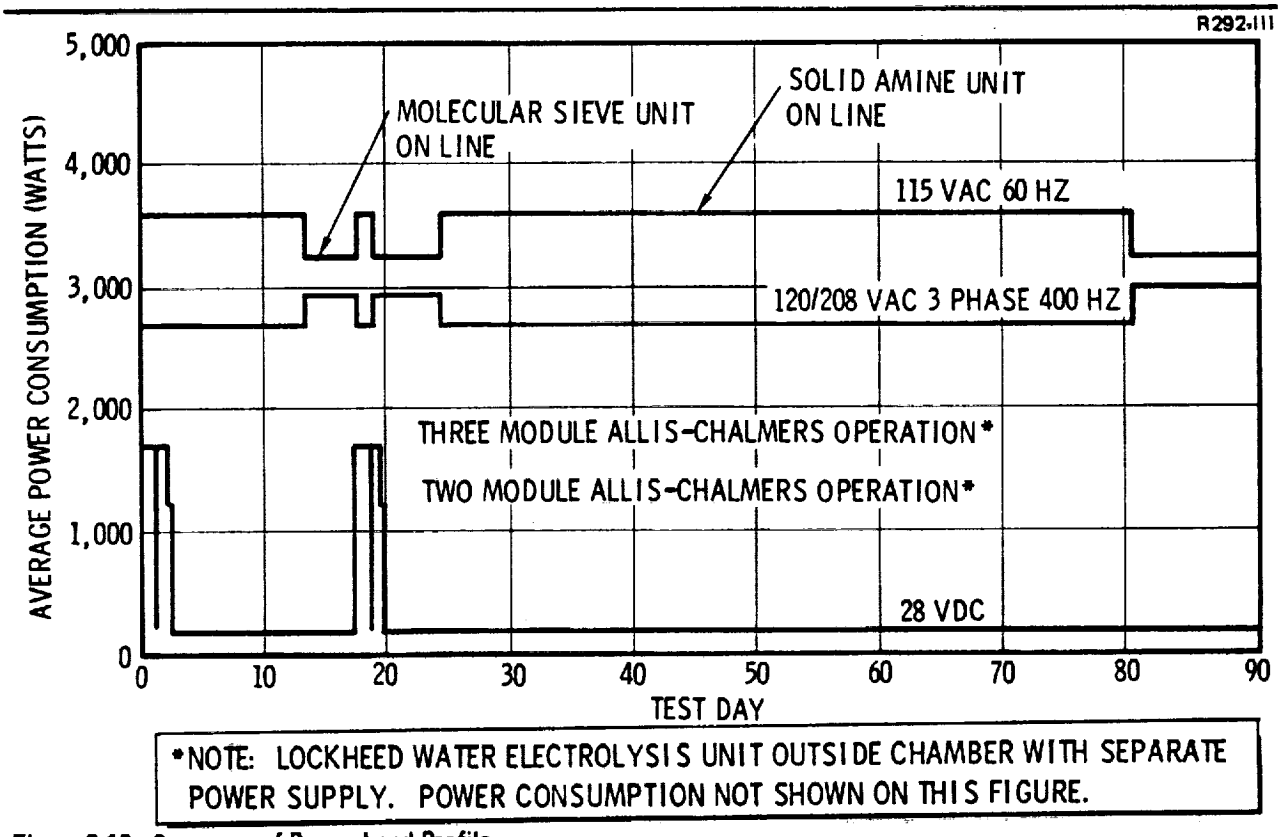


Figure 2-19. Summary of Power Load Profile

Power provided to the Lockheed electrolysis unit which was located outside the SSS was not included in the SSS power instrumentation system. During the run, the following power was provided the Lockheed electrolysis unit while it was on line and supplying gas to the SSS:

300 ma	120/208 vac, 3 phase, 400 Hz (3 sec on, 15 min off)
2.5 amp	115 vac, 1 phase, 60 Hz for controls and the oxygen compressor
1,300 watts	DC on high mode operation, 1,349.1 hr
445 watts	DC on low mode operation, 140.1 hr

In summarizing these data for the 90-day test, the electrical energy usage was 7,869.4 kwh on the 60-Hz circuits, 5,885 kwh on the 400-Hz circuits, and 2,311.3 kwh on the dc circuits. The total energy was 16,065.7 kwh, for an average power consumption of 7,471 watts.

2.1.5 Trace Contaminants

Analysis of atmospheric samples for the presence of trace contaminants was conducted by MDAC to ensure the continued health and safety of the test crew. Additional analysis performed by others and the results of the aerosol analysis experiment is reported in Reference 2-1. Analysis was done by gas

Table 2-9

SIGNIFICANT POWER SYSTEM EVENTS

Test Day	Time	Event
10	12:06	DC power surge on all consoles, problem traced to a momentary short created by onboard crewman working on Allis-Chalmers electrolysis unit. Onboard DC breaker for unit tripped, reset breaker with no problem.
28	09:50	SSS 115 vac, 60 Hz circuit A5 (20 amp) circuit breaker tripped due to short in VD-VF control wiring. Corrected short and reset breaker and performed a restart on mass spectrometer (on same circuit).
40	02:00	Facility 115 vac, 60 Hz power momentarily failed, lost Coolanol system, solid amine, and 400-Hz motor generator, performed restart on affected systems.
45	08:30	SSS 115 vac, 60 Hz circuit A5 (20 amp) circuit breaker tripped due to short in VD-VF liquid level switch, corrected malfunction, reset breaker and performed a restart on mass spectrometer (on same circuit).
57	06:30	Facility 115 vac, 60 Hz power failure occurred for approximately 20 sec, all onboard and SSS support systems went off, emergency SSS 28-vdc battery power automatically came on to provide SSS lighting, maintained communication system via communication backup battery supply. Performed normal restart on all affected systems with no problem.
66	08:50	Switched to backup 400-Hz motor generator to perform preventive maintenance on drive belt of primary motor generator.
68	08:00	Switched back to primary 400-Hz motor generator.

Table 2-10

POWER USAGE FOR SPACE STATION SIMULATOR
(60 Hz, 115 vac, single phase)

Subsystem/Unit	Components	Energy Input (kwh)	Average Power (watts*)
Wash Water	2 Tank Heaters 2 Pumps	519.6	240.9
Potable Water	6 Tank Heaters Wick Evaporator Preheater 2 Pumps	1,565	725.2
Thermal Control	Circulating Pump Controls	2,158	1,000.7
Molecular Sieve (20 days)	Vacuum Pump Controls	180	394.7
Solid Amine (70 days)	---	1,296	762.1
Water Electrolysis (62 days)	Lockheed, O_2 Compressor**	428.1	287.5
Sabatier/Toxin Housekeeping	---	22	10.2
	Washer (4 hours)	3.5	
	Dryer (44 hours)	82.3	
	SSS Lights	862.0	
	Auxiliary Lights	14.24	
	Microwave Oven	47.0	
	Biomed	13.0	756.3
	Refrigerator and Freezer	32.34	
	Radiation Monitor	32.34	
	Crew Life Support Monitor	32.34	
	Dew Point Pumps	258.72	
	Miscellaneous	253.385	
Two-Gas Control		70.7	32.8
		7,869.4	

*All subsystems include small intermittent dc loads for controls.
**Lockheed water electrolysis unit installed outside SSS. Power data include estimated component efficiency for compressor.

Table 2-11

POWER USAGE FOR SPACE STATION SIMULATOR
(400 Hz and 28 vdc)

Power Source	Subsystem/Unit	Components	Energy Input (kwh)	Average Power (watts*)
120/208 vac 400 Hz, 3 phase	Wick Evaporator	Blower (Humidity Control)	660.585	306.3
	Thermal Control	Blowers (2)	5,170.35	2,368.3
	Molecular Sieve (20 days)	Blower	116.28	255.0
	Commode	---	**	
	Total 400 Hz		5,885.00	
28 vdc	Water Electrolysis	Allis Chalmers (4 days)	139.6	1,454.2
		Lockheed+ (62 days)	1,816.1	1,219.5
	Toxin Burner (75 days)		123.48	67
	Other uses inside chamber*		232.12	98
	Total 28 vdc		2,311.3	
115 vac 60 Hz, 1 phase	Total from other table		7,869.4	
Totals			16,065.7	7,471.6

*All subsystems include small intermittent dc loads for controls
**Commode operation includes intermittent 400-Hz power
+Lockheed water electrolysis unit installed outside chamber. Unit required small intermittent 400-Hz power for water pump power. Data includes allowance for estimated efficiency of dc-dc converter.

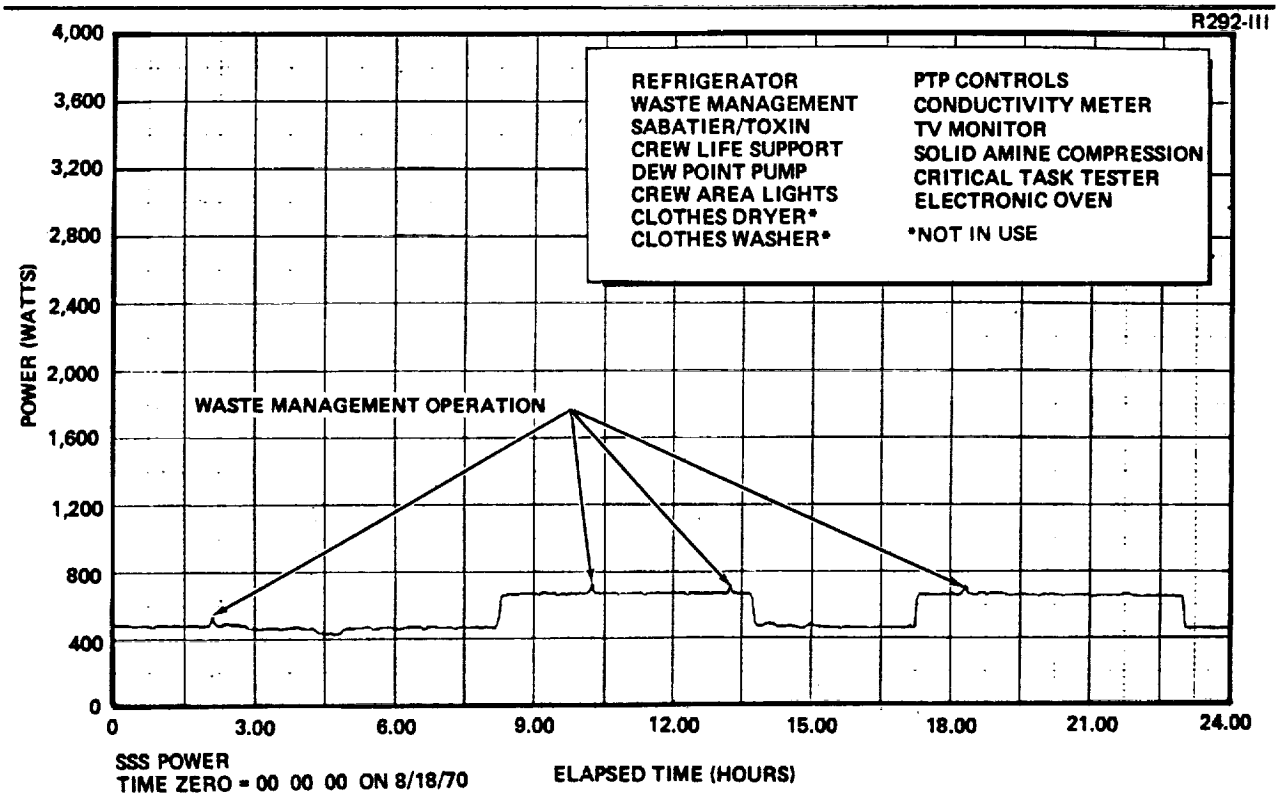


Figure 2-20. Power Load Profile for Day 67, Circuit WIR-D2

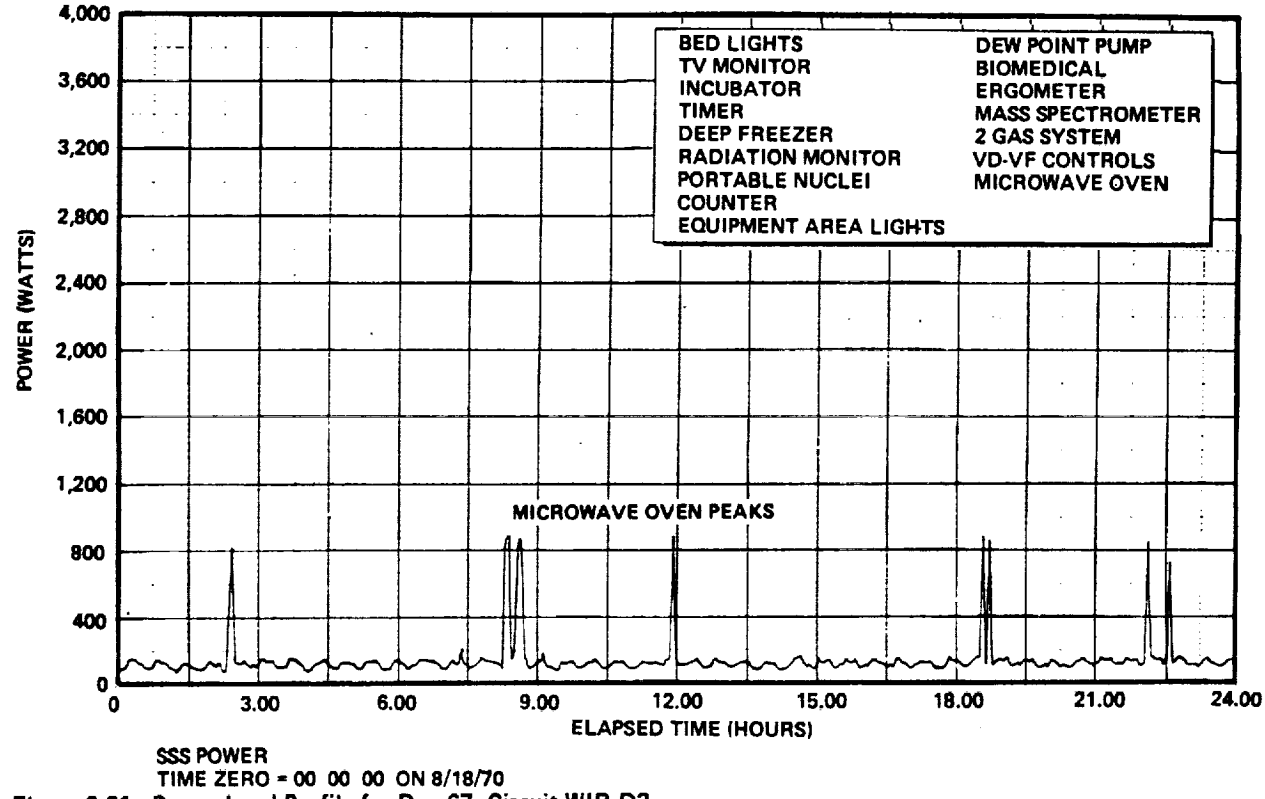


Figure 2-21. Power Load Profile for Day 67, Circuit WIR-D3

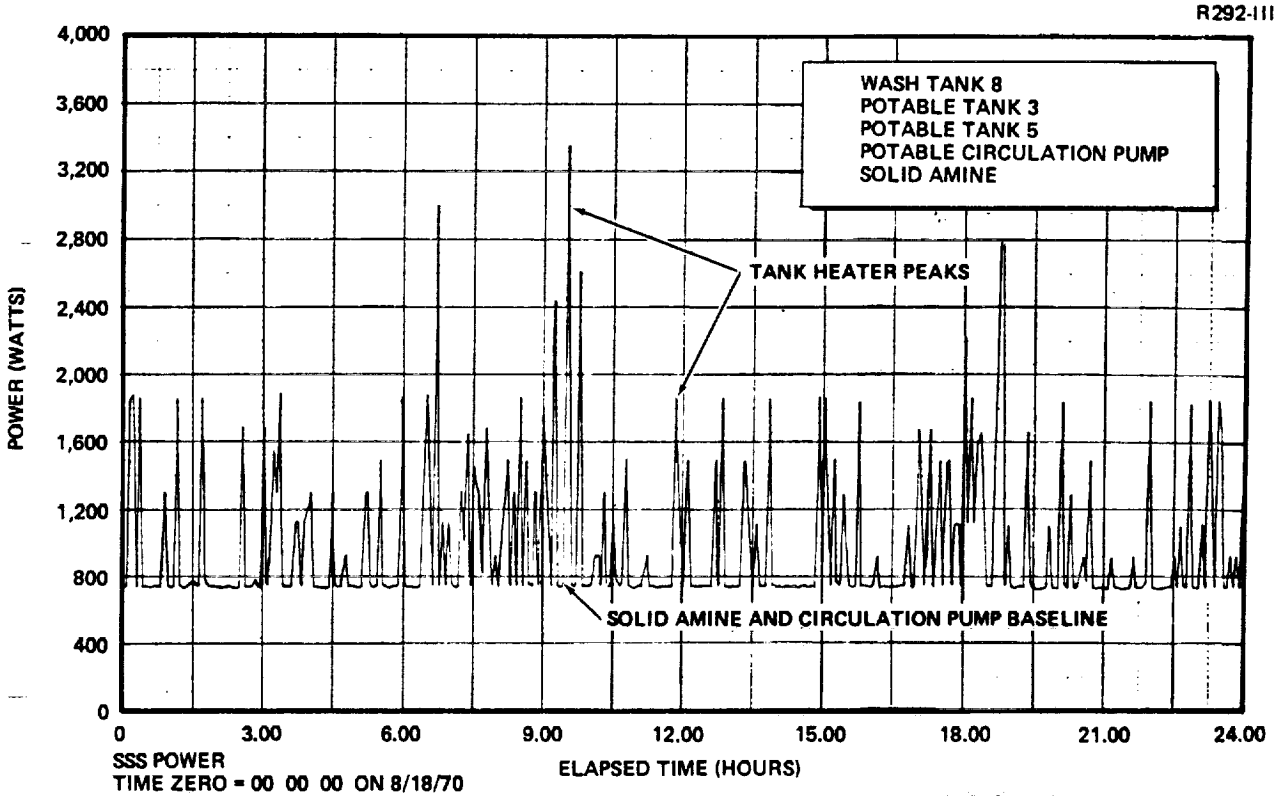


Figure 2-22. Power Load Profile for Day 67, Circuit WIR-D4

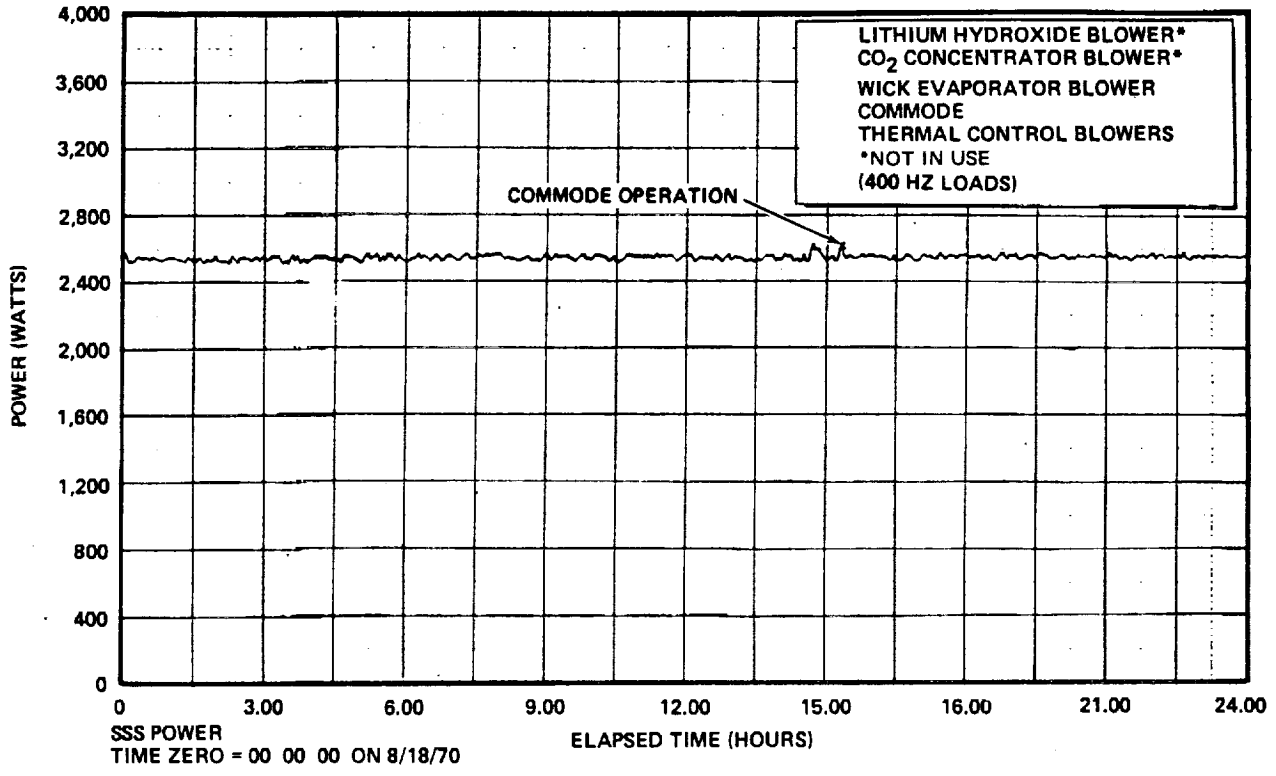


Figure 2-23. Power Load Profile for Day 67, Circuit WIR-D5

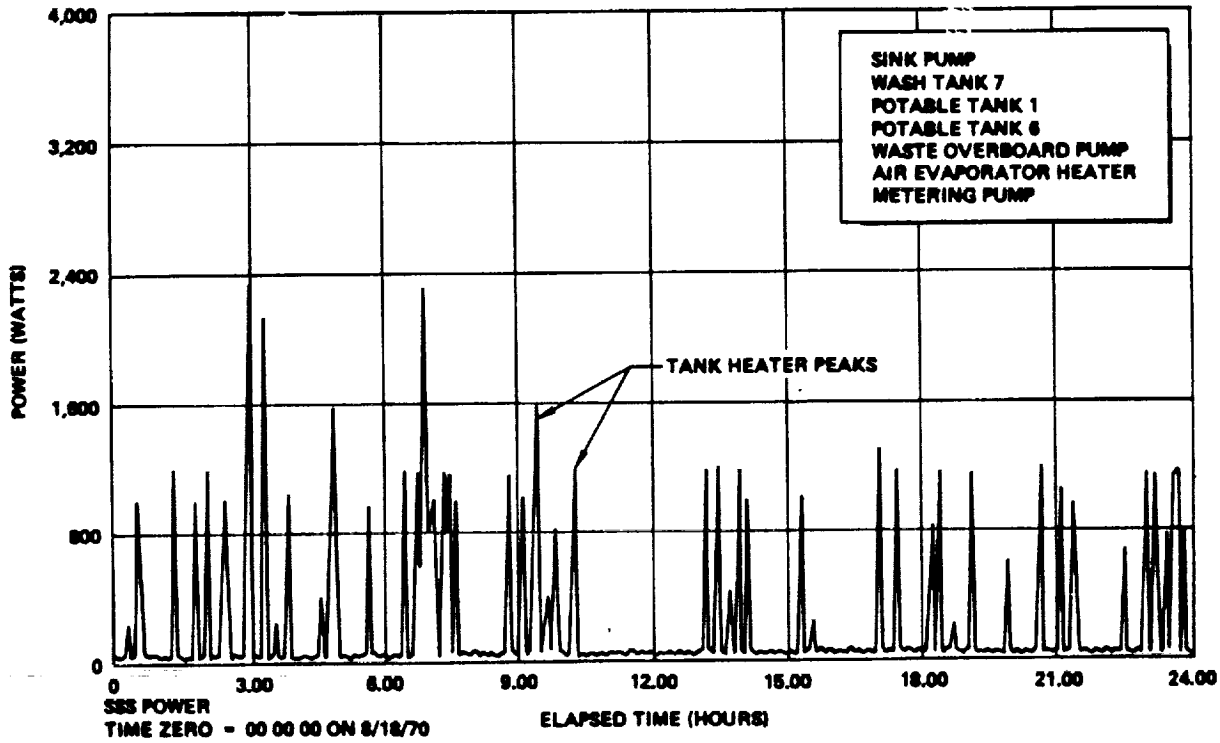


Figure 2-24. Power Load Profile for Day 67, Circuit WIR-D6

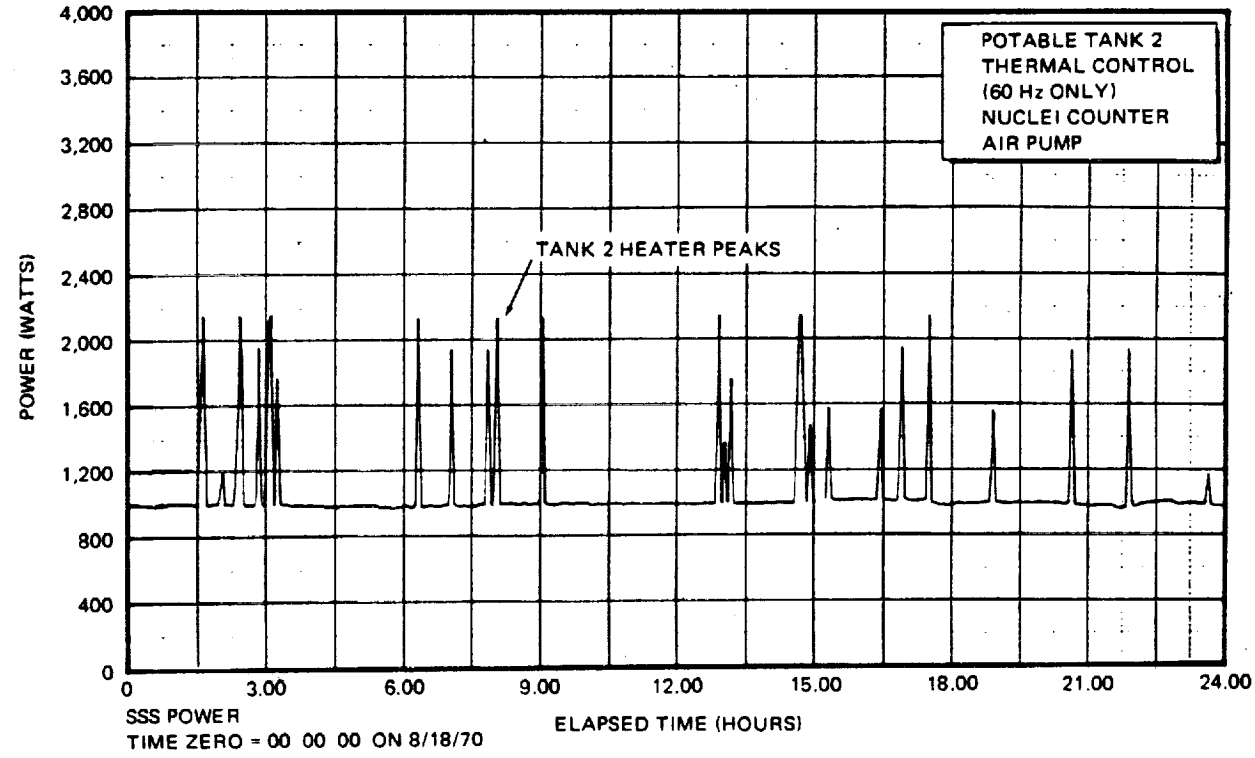


Figure 2-25. Power Load Profile for Day 67, Circuit WIR-D7

chromatography on direct samples, and on concentrated samples obtained by freeze-out techniques to determine the presence of organic compounds. The direct samples indicated the presence of as many as nine organic contaminants although none were present at levels approaching critical values. The concentrated samples, taken weekly, indicated as many as 23 compounds, most of which occurred at very low levels. Major trace contaminants included methane, as high as 290 ppm near the end of the run; carbon monoxide, which varied from 10 to 27 ppm; and Freon 113, which reached peak values as high as 11.6 ppm. Methane and carbon monoxide are most probably the metabolic products of the crewmen. The Freon 113 is a cleaning solvent which was used before the test, apparently leaving residuals that maintained the cabin concentration throughout the test.

Inorganic compounds were measured by wet chemical analysis on samples taken daily. Compounds detected included total aldehydes, which maintained a fairly stable concentration of about 0.35 ppm during the test, and ammonia during some periods, reaching levels of 2 to 3 ppm. During toxin burner operation, the presence of ammonia was frequently accompanied by trace amounts of oxides of nitrogen (about 0.1 ppm). Sulfur dioxide, hydrocyanic acid, hydrogen sulfide, chlorine, hydrochloric acid, and phosgene were tested for and not found at any time during the test.

Tests run on CO_2 removed from the cabin by the molecular sieve and solid amine units indicated increased concentration of Freon 113 over the cabin levels. As a result of these findings, an activated carbon filter was located in the CO_2 line, as described in Section 2.4.1.2., on approximately day 29 to remove this contaminant for the remainder of the test.

Qualitative tests on catalyst from the Sabatier reactor and a white powder found at the outlet of the toxin burner indicated heavy concentrations of halogens. This apparently resulted from catalytic decomposition of the Freon 113 in these heated catalyst beds and may have caused a significant loss in catalyst effectiveness in both units.

During the 90-day operation of the SSS and the short-duration manned and unmanned test runs which preceded it, analytical support was provided by determining the composition and daily fluctuations of trace contaminants. A daily search was instituted in which representative air samples were withdrawn from the SSS and analyzed. Both sampling and analytical procedures depended on whether the tests pertained to organic or inorganic compounds.

In the analysis of trace contaminants, particular attention was directed to the specific compounds listed in Table 2-12 which have been reviewed and to which pretest planning had assigned contingency and abort levels. Many of these levels were established upon the recommendation of the Panel on Air Standards for Manned Space Flights of the National Academy of Science.

Detailed below are the types and quantities of inorganic and organic compounds found in the SSS and the analyses of Sabatier CO_2 supply, toxin burner catalyst, and Sabatier catalyst.

Table 2-12

MAJOR ATMOSPHERIC CONTAMINANT GUIDELINES IN SSS

Contaminant	Accuracy	Normal Operations	Lower End of Contingency Operations	Abort Level	Allowable Level Specified By NAS/NRC Committee
CO (ppm)	±2.0	12.0	100	200	X
CO_2 (mm Hg)	±0.4	4.0	8	*	
Hydrocarbons (ppm)	±2.0	4.0	60	300	
NH_3 (ppm)	±1.0	4.0	75	150	
Aldehydes (ppm)	±0.005	1.0	15	25	
SO_2 (ppm)	±0.25	0.5	7	12	
H_2S (ppm)	±1.0	1.0	15	30	
$(NO)_x$ (ppm NO_2)	±0.1	0.5	1.5	15	
O_3 (ppm)	±0.001	0.03	0.15	1.5	
Chlorine (ppm)	±0.04	0.1	0.7	1.5	
Cyanides (ppm)	±1.0	1.0	3.0	15	
Phosgene (ppm)	±0.2	0.07	0.15	1.5	
Ethanol (ppm)	±0.2	2.5	300	1,500	
Toluene (ppm)	±0.2	0.5	30	300	
2-Ethyl butanol (ppm)	±0.2	1.0	20	60	
N-Butanol	±0.2	1.0	15	150	X
2-Butanone	±0.2	2.0	30	300	X
Chloroform	±0.2	0.5	7	70	X
Dichloromethane	±0.2	2.5	40	700	X
Dioxane	±0.2	1.0	15	150	X
Ethylacetate	±0.2	4.0	60	600	X
2-Methylbutanone	±0.2	2.0	30	300	X
Trichloroethylene	±0.2	1.0	15	150	X
1,1,2-Trichloro; 1,2,2-Trifluoroethane and related congeners	±0.2	20	150	1,500	X
Formaldehyde	---	0.05	0.15	3.0	X
Dichlorolacetylene	---	0	Detected	0.1	X
Vinylidene Chloride	---	2.0	10	25	X

*>60 (3 min), 60 to 40 (10 min), 40 to 30 (30 min), 30 to 20 (60 min), 20 to 15 (48 hours)

2.1.5.1 Inorganic Contaminants

Conventional wet chemical analyses of the cabin air were performed daily for ammonia, sulfur dioxide, oxides of nitrogen, and aldehydes. Twice a week tests were run for hydrocyanic acid, hydrogen sulfide, chlorine, hydrochloric acid, and phosgene. These test data, as well as those obtained during the 4-day unmanned and the 5-day manned tests that preceded the 90-day test, are tabulated in Tables 2-13 and 3-14.

During the 90-day manned operation of the SSS, the VD-VF unit and the wick evaporator unit were alternately used for water recovery. It was desired to obtain data on the effect of the open-loop wick evaporator on the normal contaminant level measured in the cabin air, and whether a correlation existed between the observed contaminants such as ammonia and oxides of nitrogen. Additionally, information was desired on the effects of the toxin control unit on formation and buildup of contaminants in the SSS.

During the unmanned and manned test periods preceding the 90-day test, the space cabin air was almost free of contaminants. Analyses conducted after the start of the 90-day test also showed the absence of all inorganic compounds, as seen in Table 2-14, with the only exception being the aldehydes which started with a low value of 0.04 ppm, and soon increased to 0.2 to 0.4 ppm. They remained at this level throughout the entire test. Initially, neither ammonia nor oxides of nitrogen were detected in the cabin air, regardless whether the VD-VF or wick evaporator unit was in operation. This lasted until test day 52, when the presence of ammonia was detected at about 0.5 ppm. Simultaneously with the appearance of ammonia, traces of oxides of nitrogen (less than 0.1 ppm) were found. This reinforces a previous indication that the catalytic burner may cause oxidation of ammonia to oxides of nitrogen.

On test day 57, after the wick evaporator had been in operation for 12 days, the further feeding of the wick was stopped, and the VD-VF unit was placed in operation. In spite of this, the ammonia concentration in the chamber increased during the following few days, reaching a peak at about 2.8 ppm. This may be due to the fact that after starting to dry the wick, more ammonia was formed from the wick deposits and released into the cabin air. After several days without the wick operation, the ammonia concentration in the atmosphere returned to zero.

The effects of the toxin control unit with regard to the ammonia conversion can be seen from the data of test days 68 through 82. During this time, the unit was inoperative. In this entire period, no oxides of nitrogen were found in the SSS although the amount of ammonia that was present in the cabin atmosphere was similar to the previous period. Soon after the toxin burner was activated, the oxides of nitrogen again appeared, reaching a maximum of about 0.15 ppm.

2.1.5.2 Organic Contaminants

Daily gas samples were withdrawn from the cabin air by the syringe and needle technique. Analyses were carried out from the two gas chromatographs calibrated for 80 organic compounds at two temperatures and with two column packing materials (didecyl phthalate and carboway 1450). Ten

Table 2-13

ATMOSPHERIC CONTAMINANTS

Date	NH_3	NO_2	SO_2	Aldehydes	HCN	H_2S	Cl_2	HCl	Phosgene
				(All values in parts per million)					
				Unmanned 4-Day Test					
4/25/70	0*	0	0	--**					
4/26	0	0	0	--					
4/27	0	0	0	0.24					
4/28	0	0	0	0.067					
				Manned 5-Day Test					
4/29	0	0	0	0.12					
4/30	0	0	0	0.18	0	0	0	0	0
5/1	0	0	0	0.11					
5/2	0	0	0	0.25					
5/3	0	0	0	--					
5/4	0	0	0	0.06	0	0	0	0	0

*0 Not detected

**-- Not tested. (Blank) Test not scheduled

Table 2-14 (page 1 of 4)

ATMOSPHERIC TRACE CONTAMINANTS DURING 90-DAY TEST

(All values in parts per million)

Date	Test Day	NH_3	SO_2	NO_2	Aldehydes	HCN	H_2S	Cl_2	HCl	Phosgene
6/13/70	1	0*	0	0	0.04	0	0			
6/14	2	0	0	0	0.35	0	0			
6/15	3	0	0	-**	0.32	0	0	0	0	0
6/16	4	0	0	0	0.27					
6/17	5	0	0	0	0.25					
6/18	6	0	0	0	0.27	0	0	0	0	0
6/19	7	0	0	0	0.33					
6/20	8	0	0	0	0.27					
6/21	9	0	0	0	0.27					
6/22	10	0	0	0	0.28	0	0	0	0	0
6/23	11	0	0	0	0.25					
6/24	12	0	0	0	0.31					
6/25	13	0	0	0	0.29	0	0	0	0	0

*0 Not detected. **- Not tested. (Blank) Test not scheduled.

Table 2-14 (page 2 of 4)

ATMOSPHERIC TRACE CONTAMINANTS DURING 90-DAY TEST
(All values in parts per million)

Date	Test Day	NH_3	SO_2	NO_2	Aldehydes	HCN	H_2S	Cl_2	HCl	Phosgene
6/26	14	0	0	0	0.35					
6/27	15	0	0	0	0.27					
6/28	16	0	0	0	0.30					
6/29	17	0	0	0	0.27	0	0	0	0	0
6/30	18	0	0	0	0.26					
7/1	19	0	0	0	0.27					
7/2	20	0	0	0	0.47	0	0	0	0	0
7/3	21	0	0	0	0.33					
7/4	22	0	0	0	0.38					
7/5	23	0	0	0	0.24					
7/6	24	0	0	0	0.38	0	0	0	0	0
7/7	25	0	0	0	0.31					
7/8	26	0	0	0	0.33					
7/9	27	0	0	0	0.34	0	0	0	0	0
7/10	28	0	0	0	0.32					
7/11	29	0	0	0	0.34					
7/12	30	0	0	0	0.32					
7/13	31	0	0	0	0.33	0	0	0	0	0
7/14	32	0	0	0	0.33					
7/15	33	0	0	0	0.34					
7/16	34	0	0	0	0.33	0	0	0	0	0
7/17	35	0	0	0	0.34					
7/18	36	0	0	0	0.34					
7/19	37	0	0	0	0.31					
7/20	38	0	0	0	0.35	0	0	0	0	0
7/21	39	0	0	0	0.31					
7/22	40	0	0	0	0.28					
7/23	41	0	0	0	0.29	0	0	0	0	0
7/24	42	0	0	0	0.34					
7/25	43	0	0	0	0.23					
7/26	44	0	0	0	0.23					

Table 2-14 (page 3 of 4)

ATMOSPHERIC TRACE CONTAMINANTS DURING 90-DAY TEST
(All values in parts per million)

Date	Test Day	NH_3	SO_2	NO_2	Aldehydes	HCN	H_2S	Cl_2	HCl	Phosgene
7/27	45	0	0	0	0.27	0	0	0	0	0
7/28	46	0	0	0	0.31					
7/29	47	0	0	0	0.30					
7/30	48	0	0	0	0.28	0	0	0	0	0
7/31	49	0	0	0	0.32					
8/1	50	0	0	0	0.25					
8/2	51	0	0	0	0.29					
8/3	52	0.5	0	tr	0.31	0	0	0	0	0
8/4	53	0.5	0	tr	0.34					
8/5	54	0.5	0	tr	0.34					
8/6	55	0.5	0	tr	0.34	0	0	0	0	0
8/7	56	0.5	0	tr	0.35					
8/8	57	0.5	0	tr	0.33					
8/9	58	2.8	0	tr	0.33					
8/10	59	1.9	0	0.1	0.32	0	0	0	0	0
8/11	60	2.8	0	0.1	0.30					
8/12	61	0.5	0	tr	0.33					
8/13	62	0	0	0	0.32					
8/14	63	0	0	0	0.33					
8/15	64	0	0	0	0.25					
8/16	65	0	0	0	0.26					
8/17	66	tr	0	0	0.30	0	0	0	0	0
8/18	67	1.4	0	0	0.31					
8/19	68	1.9	0	0	0.25					

Remarks:

8/8—Stopped feeding wick

8/9—After starting to dry wick, more NH_3 formed from wick deposits and was released into cabin air

8/11—Correlation between NH_3 and $(NO)_X$

8/19—Toxin burner turned off

8/19—Wick evaporator preheater, left on since previous use of wick evaporator, was turned off last night

Table 2-14 (page 4 of 4)

ATMOSPHERIC TRACE CONTAMINANTS DURING 90-DAY TEST
(All values in parts per million)

Date	Test Day	NH_3	SO_2	NO_2	Aldehydes	HCN	H_2S	Cl_2	HCl	Phosgene
8/20	69	2.4	0	0	0.33	0	0	0	0	0
8/21	70	1.4	0	0	0.31					
8/22	71	1.3	0	0	0.33					
8/23	72	tr	0	0	0.34					
8/24	73	tr	0	0	0.35	0	0	0	0	0
8/25	74	0	0	0	0.37					
8/26	75	tr	-	-	0.38					
8/27	76	1.3	0	0	0.39	0	0	0	0	0
8/28	77	1.6	0	0	0.39					
8/29	78	1.8	0	0	0.30					
8/30	79	1.3	0	0	0.27					
8/31	80	1.6	0	0	0.23	0	0	0	0	0
9/1	81	1.8	0	0	0.32					
9/2	82	1.8	0	0	0.31					
9/3	83	1.8	0	0	0.38	0	0	0	0	0
9/4	84	1.1	0	0	0.39					
9/5	85	1.8	0	0	0.39					
9/6	86	1.8	0	0	0.39					
9/7	87	3.5	0	0.15	0.42					
9/8	88	4.0	0	0.12	0.41	0	0	0	0	0
9/9	89	1.8	0	tr	0.43					
9/10	90	0.5	0	tr	-	0	0			

Remarks:

8/21—Floor was washed with CO_2 condensate water from solid amine

9/1—Solid amine unit discontinued

9/1—Molecular sieve started

9/1—Wick evaporator started

9/1—VD-VF discontinued

9/2—Toxin burner burned on

9/7—Hole in Sabatier exhaust line discovered

organic compounds including carbon monoxide (which was measured with a LIRA Infrared Analyzer) were identified and quantitatively determined. Figures 2-26 through 2-30 show the identification and concentrations of these compounds for each test day. The concentration ranges were: Freon 113, 1.6 to 11.6 ppm; acetone, 0.06 to 2.39 ppm; toluene, 0.05 to 0.15 ppm; ethyl alcohol, 0.35 to 1.4 ppm; dichloroethane, 0.08 to 0.25 ppm; methylethylketone, 0.05 to 0.27 ppm; 2-ethyl butanol, 0.14 to 0.43 ppm; 2-ethyl hexanol, 0.1 to 0.68 ppm; methane, 110 to 290 ppm; and carbon monoxide, 7 to 27 ppm.

The horizontal bar between test days 68 and 82 on Figure 2-30 represents the time interval during which the toxin burner was not operating. After test day 68, the carbon monoxide level (Figure 2-30) increased from about 16 to 26 ppm. When the toxin burner was reactivated, the level was gradually reduced to 17 ppm at the end of the test.

With regard to methane (Figure 2-30), it was noted that the concentration of this hydrocarbon increased from approximately 160 to 245 ppm when the toxin burner was inoperative. However, no decrease in the methane level was observed when the toxin burner was placed in operation again. A further increase resulted between samples taken on days 87 and 88. This was caused by a leak in the exhaust line of the Sabatier reactor which vented exhaust gases into the cabin, thereby adding to the methane level in the cabin air, since the methane concentration in the exhaust was approximately 50 percent. Replacement of the faulty tube stopped this venting and the corresponding rise in methane level.

R292-III

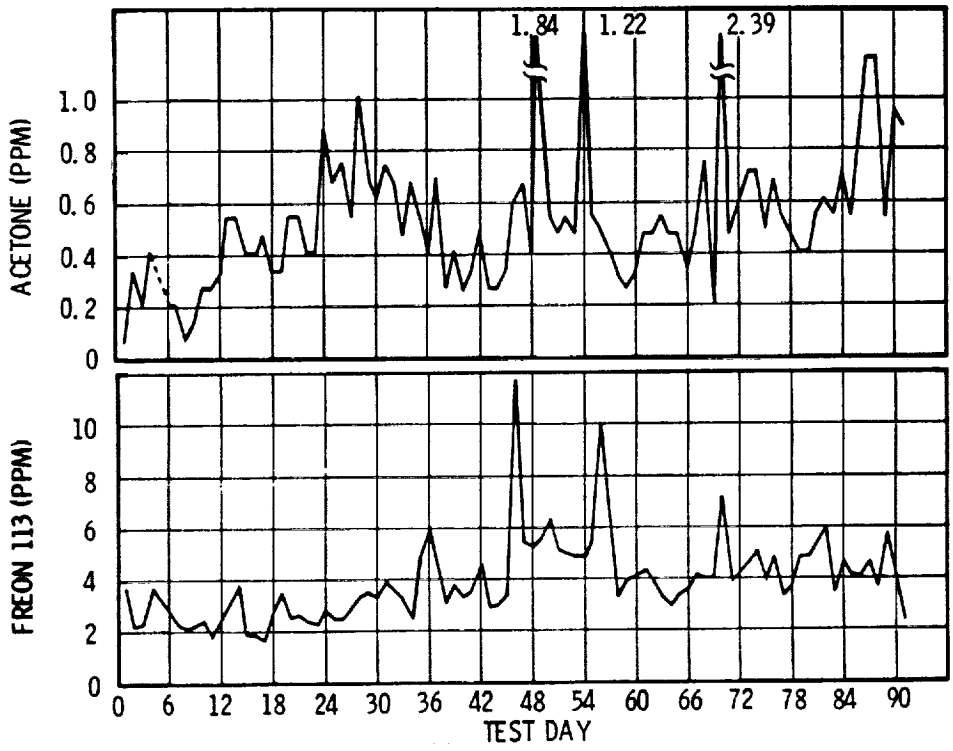


Figure 2-26. Freon 113 and Acetone Concentration

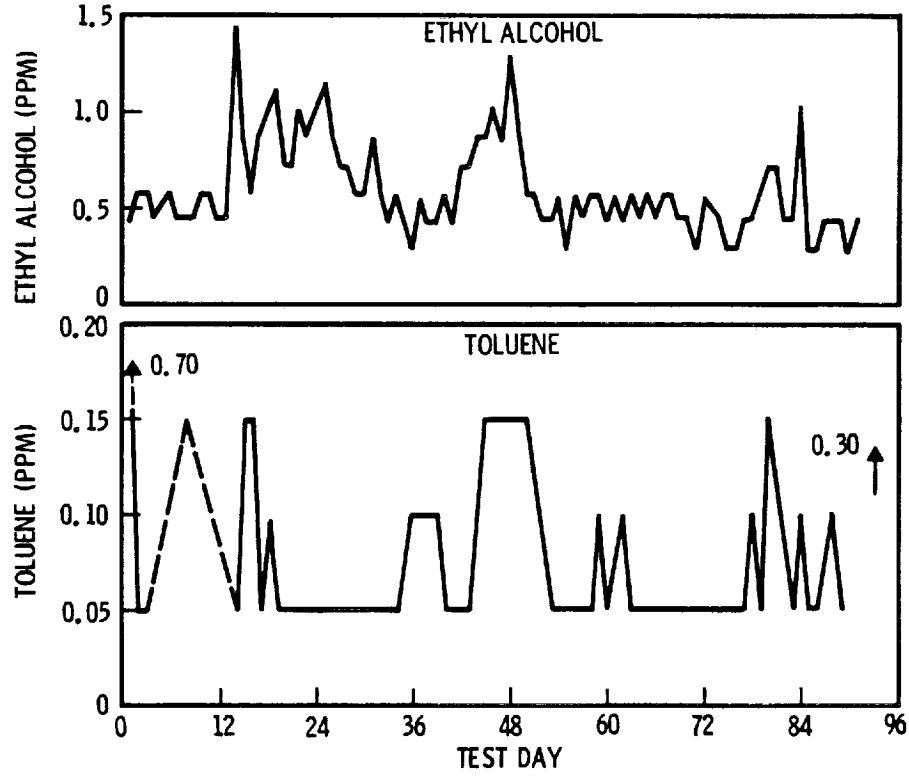


Figure 2-27. Toluene and Ethyl Alcohol Concentration

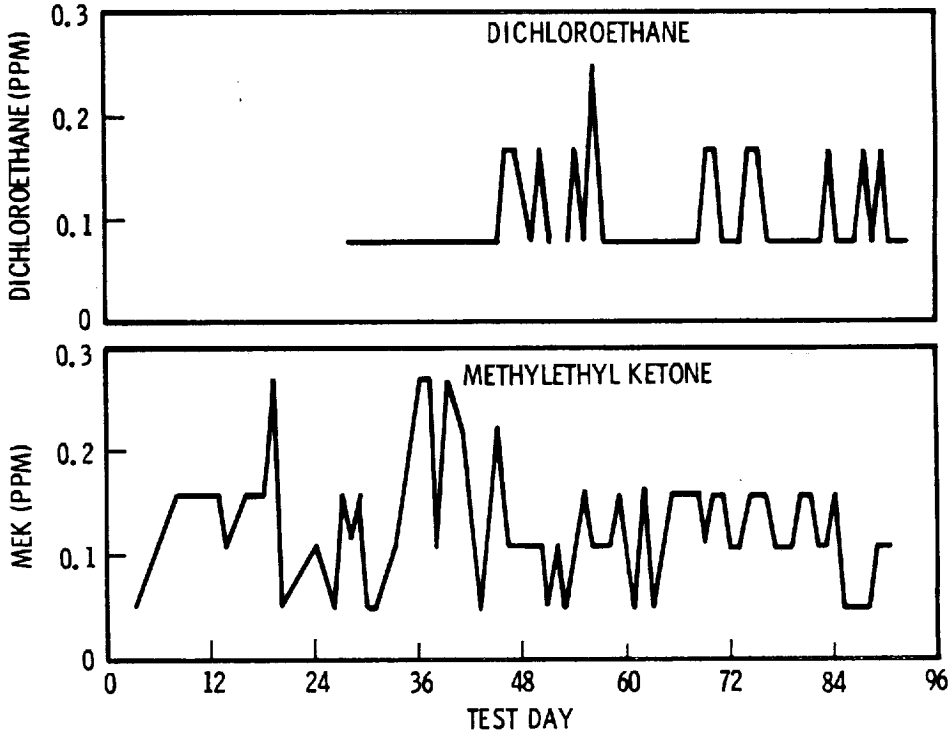


Figure 2-28. Dichloroethane and MEK Concentration

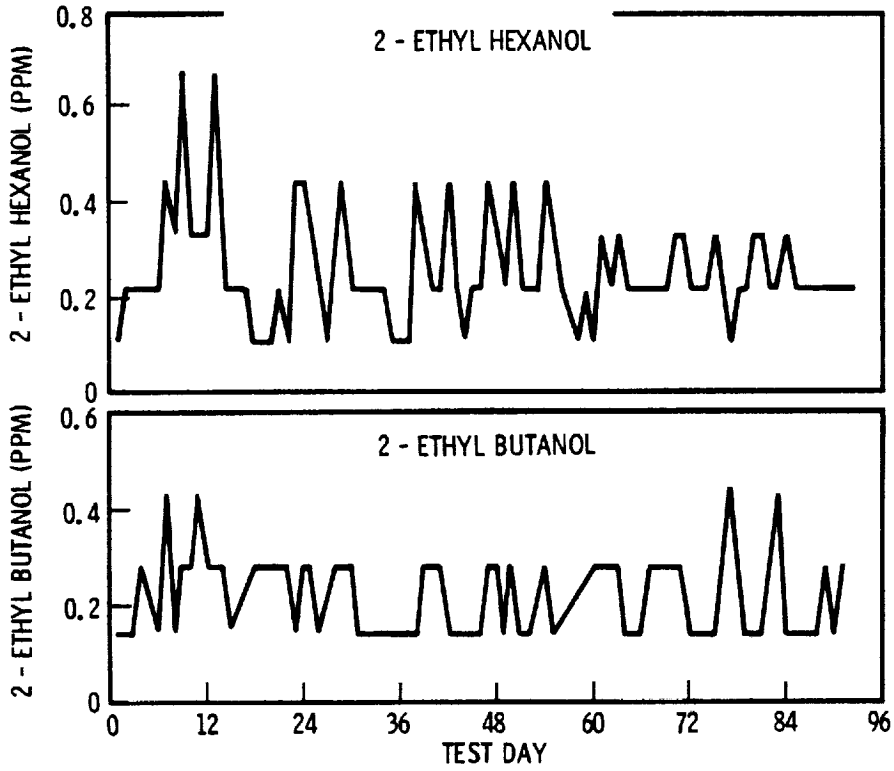


Figure 2-29. 2-Ethyl Hexanol and 2-Ethyl Butanol Concentration

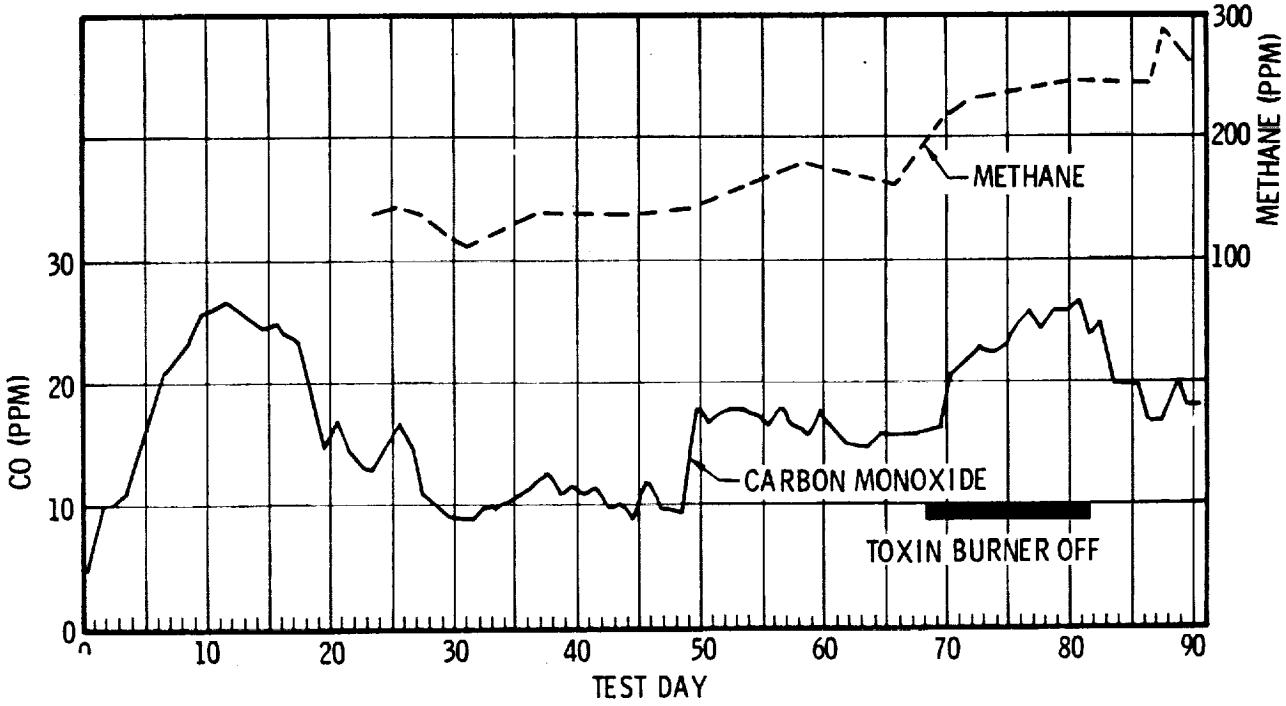


Figure 2-30 Methane and Carbon Monoxide Concentration

With regard to the other organic compounds plotted in Figures 2-26 through 2-29, no specific trends were noticeable. Measured concentrations were relatively low in all cases.

Freeze-out samples were collected on a weekly basis by passing 0.06 m^3 of cabin air into a stainless steel trap which was immersed in liquid nitrogen. The noncondensable gases were returned to the cabin, while the remainder was condensed in the trap and was analyzed by gas chromatography. A total of 23 organic compounds could be identified by the use of the concentrated samples, as compared to 10 compounds when noncondensed samples were used.

Most of the chromatographic peaks exhibited by the large-volume samples could be identified. Those from the pretest checkout runs are shown on Table 2-15 and from the 90-day test on Tables 2-16 and 2-17. A few unassigned minor peaks remained to be identified. Efforts in this direction are being undertaken.

It may be of interest that three compounds (methyl isobutyl ketone, N-amyl achohol, and N-valeraldehyde) were present only during the unmanned 5-day run. These compounds were not found during any of the manned runs.

2.1.5.3 Analysis of Carbon Dioxide

The carbon dioxide desorbed from molecular sieve or solid amine sorbent after removal from the SSS atmosphere was then processed in the Sabatier reactor. Since the CO_2 originated in the cabin air, the possibility existed that other contaminants may be presented in the CO_2 stream leaving the concentrator. It was important to know the composition of the gas stream reaching the Sabatier unit because the catalyst, upon which the Sabatier reaction is based, may be gradually deactivated or completely destroyed by the presence of undesirable contaminants.

Analysis of the CO_2 showed the presence of Freon 113 at a concentration of 5.0 to 39.0 ppm. The average detected concentration of Freon 113 varied from 9.0 ppm, when the solid amine unit was operating, to 33.8 ppm, when the molecular sieve unit was operating. Acetone and ethyl alcohol were also detected at low concentrations. Carbon dioxide, oxygen, and nitrogen comprised 98 to 100 percent of the total gas flow.

2.1.5.4 Analysis of Sabatier and Toxin Burner Catalysts

An analysis of the Sabatier catalyst, which consists mainly of metallic nickel deposited on Kieselguhr as carrier, was performed. This sample was removed from the reactor by the crew on day 29 and passed out of the chamber, during a scheduled pass-out operation, after a long period of intermittent operation had led to the conclusion that catalytic activity had been lost. It was found to contain large amounts of chlorides and fluorides. Although there were no samples of unused catalyst available, it is probable that the identified halogens came from the Freon 113 in the CO_2 initially supplied to the reactor. The efficiency of the catalyst may have been impaired or completely destroyed by continuous contact with halogens from the Freon 113.

Table 2-15

CONSTITUENTS OF FREEZE-OUT SAMPLES

	Freon 113	Toluene	Acetone	Ethyl Alcohol	2-Ethyl Butanol	2-Ethyl Hexanol	Cyclo-hexane	Ethylene Dichloride	MEK	Chloroform	M-Xylene
Unmanned 5 day 4-28-70	●	●	●	—	●	●	—	—	●	—	—
Second day of 5 day manned 5-1-70	●	—	●	●	●	—	—	—	—	—	—
Fifth day of 5 day manned 5-4-70	●	●	●	●	●	●	—	—	●	—	—

	2, 2, Dimethyl Butane	Butyl Alcohol	Methyl Alcohol	Dichloro-methane	Heptane	Isopropyl Alcohol	P-Xylene	O-Xylene	Methyl Isobutyl Ketone	N-Amyl Alcohol	N-Valeraldehyde	Isoamyl Alcohol
Unmanned 5 day 4-28-70	●	●	●	—	—	●	●	●	●	●	●	—
Second day of 5 day manned 5-1-70	●	—	●	●	●	●	—	—	—	—	—	—
Fifth day of 5 day manned 5-4-70	●	—	—	—	—	●	●	—	—	—	—	●

Note: ● Present — Not Found Sample Volume: 60 Liters

Table 2-16

CONSTITUENTS OF WEEKLY FREEZE-OUT SAMPLES

Date	Test Day	Freon 113	Toluene	Acetone	Ethyl Alcohol	2-Ethyl Butanol	2-Ethyl Hexanol	Cyclo-hexane	Ethylene Dichloride	MEK	Chloroform	M-Xylene
6-15-70	3	●	●	●	●	●	●	–	●	–	–	–
6-23	11	●	●	●	●	●	●	●	●	●	–	–
6-30	18	●	●	●	●	●	–	–	●	●	–	–
7-7	25	●	●	●	●	●	–	–	●	●	–	●
7-14	32	●	●	●	●	●	●	●	●	●	●	●
7-21	39	●	●	●	●	●	●	●	●	●	●	●
7-28	46	●	●	●	●	●	●	–	●	●	●	●
8-5	54	●	●	●	●	●	●	–	●	●	●	–
8-11	60	●	●	●	–	●	●	●	●	●	●	–
8-18	67	●	●	●	–	●	●	–	●	●	●	●
8-25	74	●	●	●	●	●	●	●	●	●	●	●
9-1	81	●	●	●	●	●	●	–	●	–	●	●
9-8	88	●	●	●	●	●	●	●	●	●	–	–

Note: ● Present – Not Found Sample Volume: 60 Liters

Table 2-17

CONSTITUENTS OF WEEKLY FREEZE-OUT SAMPLES

Date	Test Day	2, 2 Dimethyl Butane	Butyl Alcohol	Methyl Alcohol	Dichloro-methane	Heptane	Isopropyl Alcohol	P-Xylene	O-Xylene	Methyl Isobutyl Ketone	N-Amyl Alcohol	N-Valeraldehyde	Isoamyl Alcohol
6-15-70	3	●	-	-	●	-	-	-	-	-	-	-	-
6-23	11	●	-	-	●	-	●	-	-	-	-	-	-
6-30	18	●	-	-	-	-	●	-	-	-	-	-	-
7-7	25	●	●	-	●	●	●	●	-	-	-	-	-
7-14	32	●	-	●	●	●	●	●	-	-	-	-	-
7-21	39	●	●	-	●	●	●	●	-	-	-	-	-
7-28	46	●	●	-	●	-	●	●	-	-	-	-	-
8-5	54	●	-	●	-	●	-	-	-	-	-	-	-
8-11	60	●	●	-	-	●	-	-	-	-	-	-	-
8-18	67	●	●	●	●	●	-	●	-	-	-	-	-
8-25	74	●	●	-	●	-	●	●	-	-	-	-	-
9-1	81	●	●	-	●	●	●	●	-	-	-	-	-
9-8	88	●	●	●	●	-	●	-	-	-	-	-	-

Note: ● Present - Not Found Sample Volume: 60 Liters

A metal analysis of the catalyst by atomic adsorption showed nickel and silicon as major components. Present in trace amounts were boron, phosphorus, manganese, iron, magnesium, and lead. These elements may be assumed to be normally present in the catalyst.

After the test crew replaced the spent nickel catalyst with new material from onboard stores on test day 29, an activated carbon filter was placed in the CO_2 line. Analyses of samples taken downstream of the carbon filter showed that Freon 113 as well as the two organic compounds mentioned above had been completely removed. This point was subsequently monitored periodically for the balance of the test and the carbon filter replaced to prevent further contamination of the catalyst by Freon.

A white powder at the outlet of the toxin burner was collected at the end of the test. Analysis of this powder showed an extremely high concentration of chlorides. The presence of fluoride was not specifically identified because it was obscured by the high chloride content. Analysis of the powder by atomic adsorption spectroscopy showed the following major constituents; iron, aluminum, nickel, and copper, besides several minor trace constituents. These major metallic constituents may have originated in the Hopcalite catalyst or from attack of the tubing or heat exchanger downstream of the catalyst bed.

2.2 WATER MANAGEMENT

The water management subsystem was composed of: (1) the isotope-heated Vacuum Distillation-Vapor Filtration (VD-VF) unit, (2) wick evaporator and humidity control unit, (3) detoxification-multifiltration unit, (4) potable water storage and distribution unit, (5) backup potable water supply, and (6) wash water recovery unit.

2.2.1 Subsystem Description

The water management subsystem is shown in Figures 2-31 through 2-33 and Figure 2-3. Figure 2-31 is a schematic which shows the interfacing between units of the potable water recovery subsystem. Figure 2-32 is a schematic of the potable water distribution unit, including the backup water supply. Figure 2-33 is a schematic of the wash water recovery unit. Figure 2-32 shows the potable water recovery installation in the SSS.

2.2.1.1 VD-VF Unit

The basic components of this unit were the urine accumulator, VD-VF boiler (supplied by AMRL), condenser, two condensate tanks, condensate pump, cold trap vacuum system, five radioisotope heat source capsules (plutonium -238 dioxide), radiation shield water jacket, and a cooled-water filled isotope tank. Figures 2-34 and 2-35 show the movable radiation shield water jacket and VD-VF installation, and Figure 2-36 shows the cooled water isotope storage tanks as installed in the SSS.

The VD-VF unit recovered potable water from pretreated urine and humidity condensate through the use of the radioisotope heat sources. Four of the five heat sources, each producing 73.5 watts, were normally used in the boiler section to vaporize the urine mixture at about 318°K (113°F) and

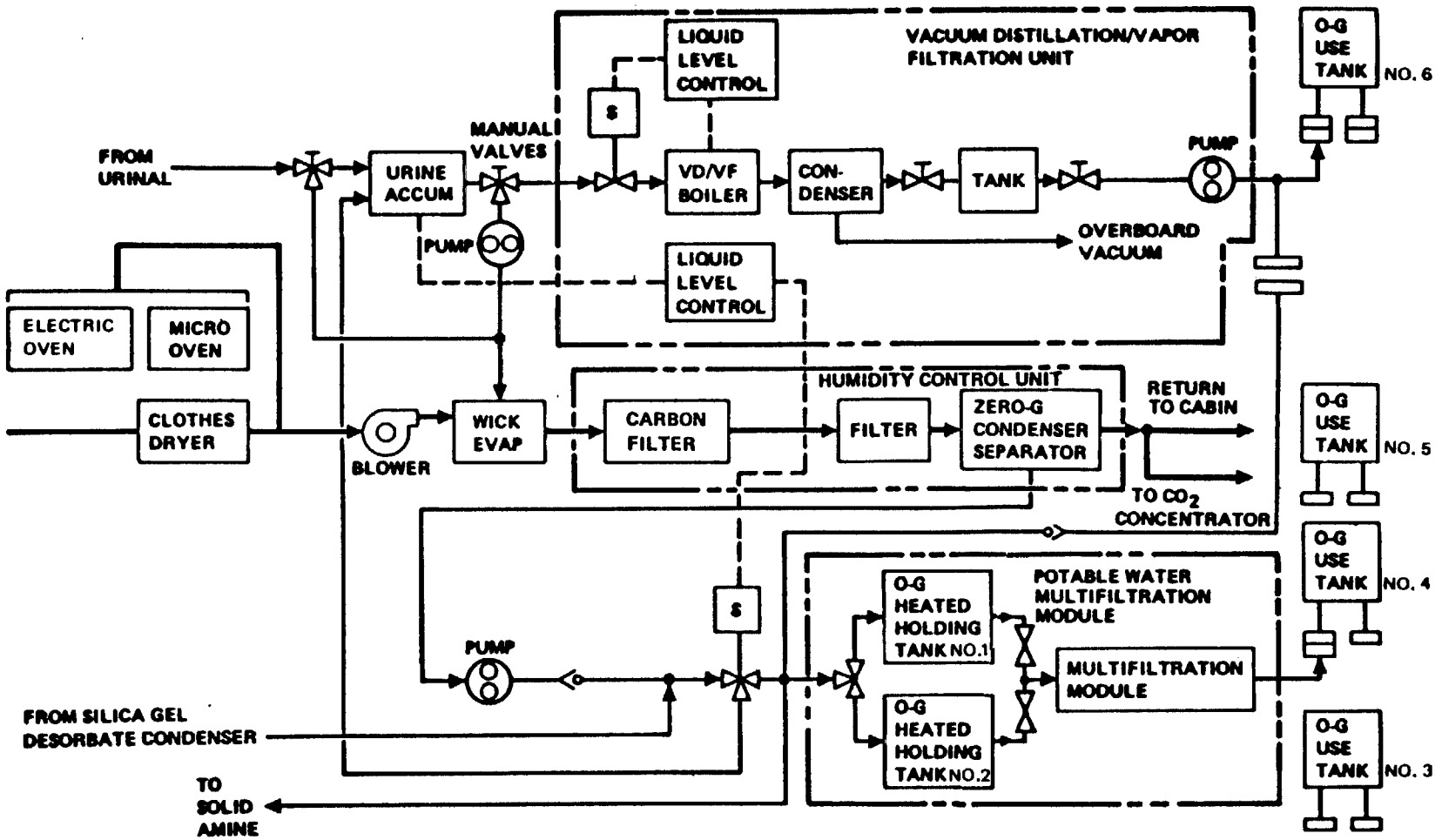


Figure 2-31. Integrated Potable H_2O and Humidity Control Subsystem Schematic

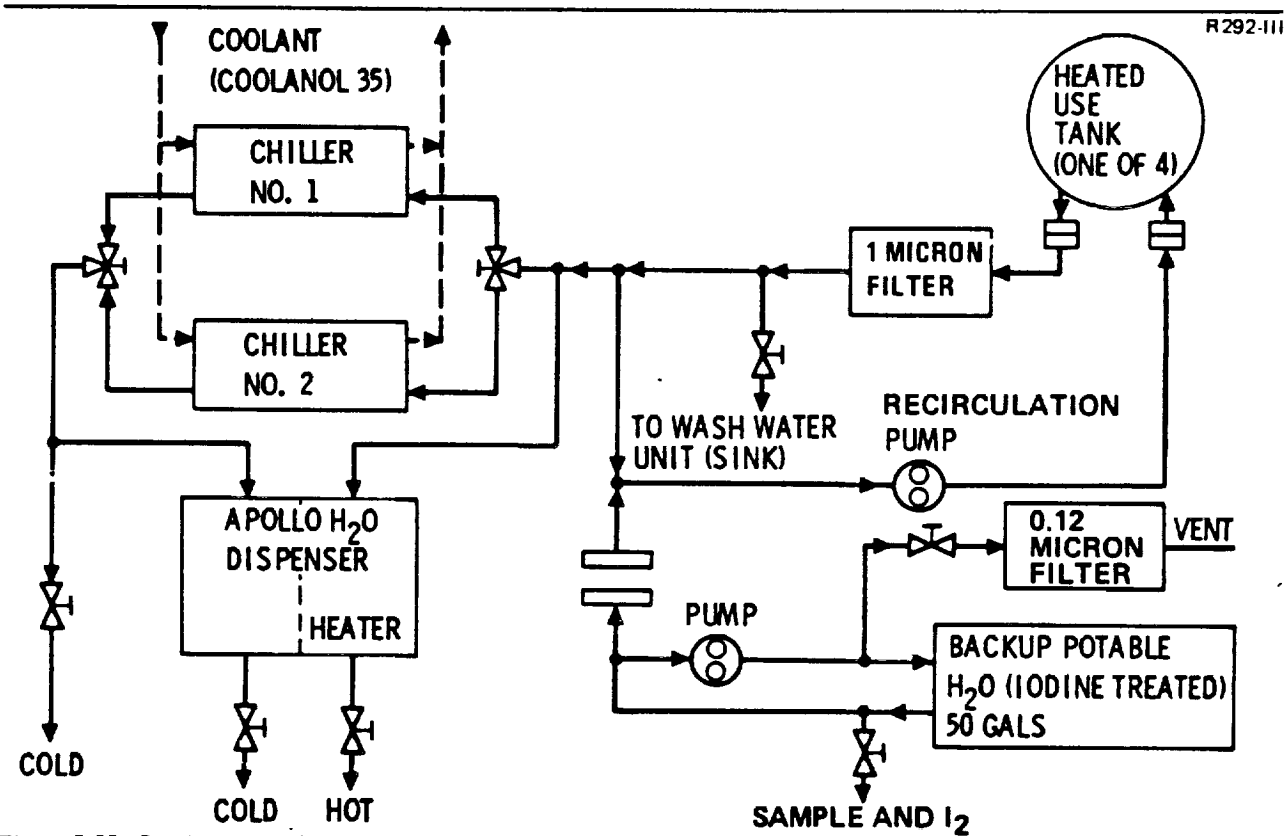


Figure 2-32. Potable Water Distribution Unit Schematic

6.4 mN/m^2 (0.93 psia). The resulting vapor, together with a small amount of cabin air bleed, passed through a porous matrix filter of Teflon and stainless steel wire mesh and then through a catalyst bed (Ardox) where it was superheated to 394°K (250°F) by the fifth isotope heater producing 48 watts. The water was condensed and stored at system vacuum pressure, in the first of two condensate tanks, while the noncondensible gases were vented overboard to a vacuum cold trap. The stored water was transferred each day from the first condensate tank to the second, which was at ambient pressure. When the condensed water was chemically and microbiologically acceptable, it was pumped directly to one of four heated zero-g storage tanks. During periods of unacceptability because of taste, odor, or microbiological contamination, it was pumped to the multifiltration unit for further processing. The urine was pretreated with 4 ml/l of the following solution: 39.8 percent H_2SO_4, 47.3 percent H_2O, 9.8 percent CrO_3 and 3.1 percent $CuSO_4$ with a density of 1.42 g/ml. A small amount of Dow Antifoam C was also added periodically to the urine accumulator to reduce foaming in the boiler. An adequate liquid supply to the boiler was maintained in the accumulator, through the use of a liquid level control switch that supplied makeup humidity condensate to the urine supply. The excess humidity condensate was directed to the detoxification-multifiltration unit when the urine accumulator level was adequate. The liquid level in the VD-VF boiler was maintained by a similar level control switch.

The five isotopes were stored in the cooled water storage tank whenever the VD-VF unit was inoperative.

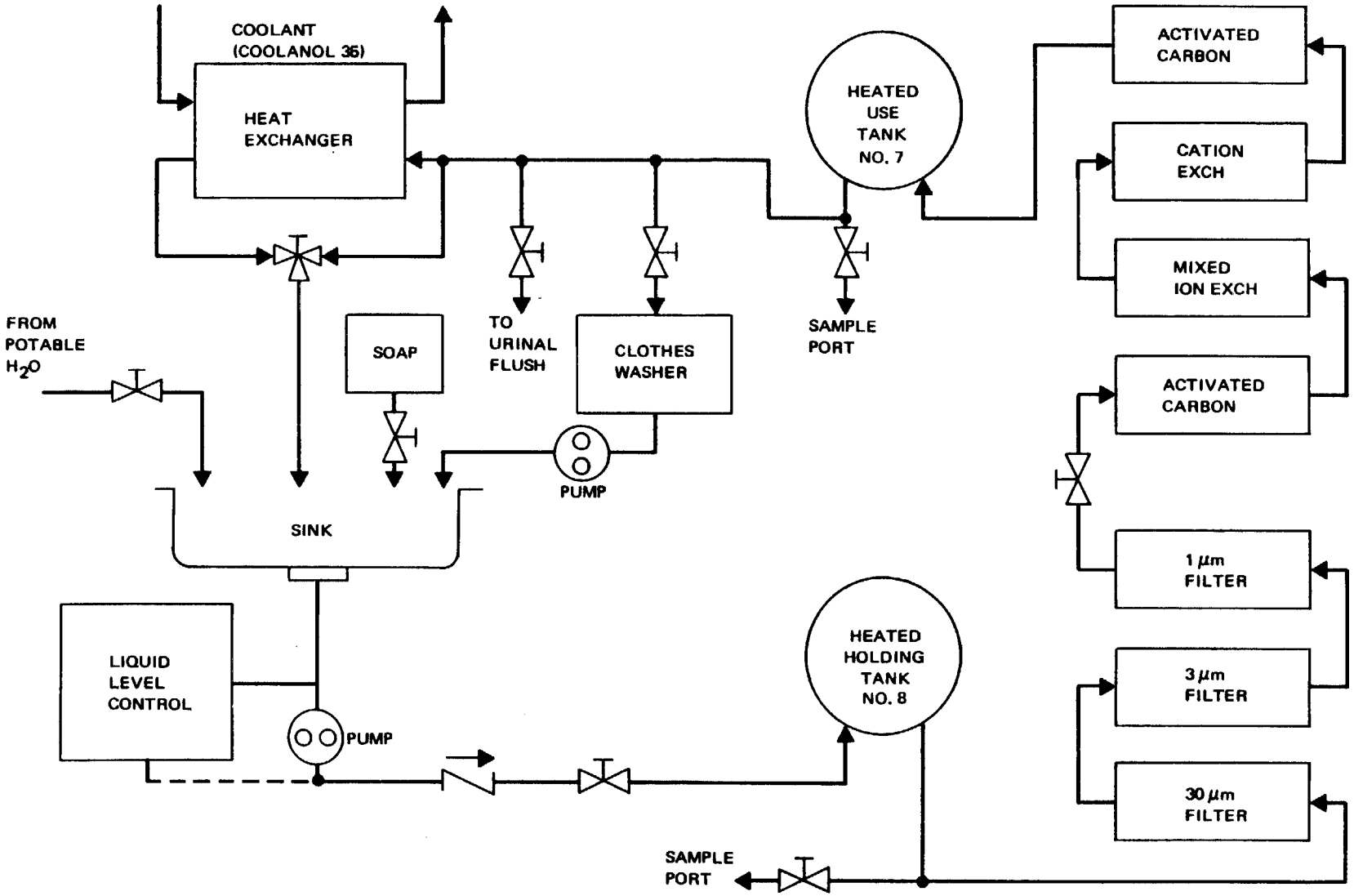


Figure 2-33. Wash Water Recovery Unit Schematic

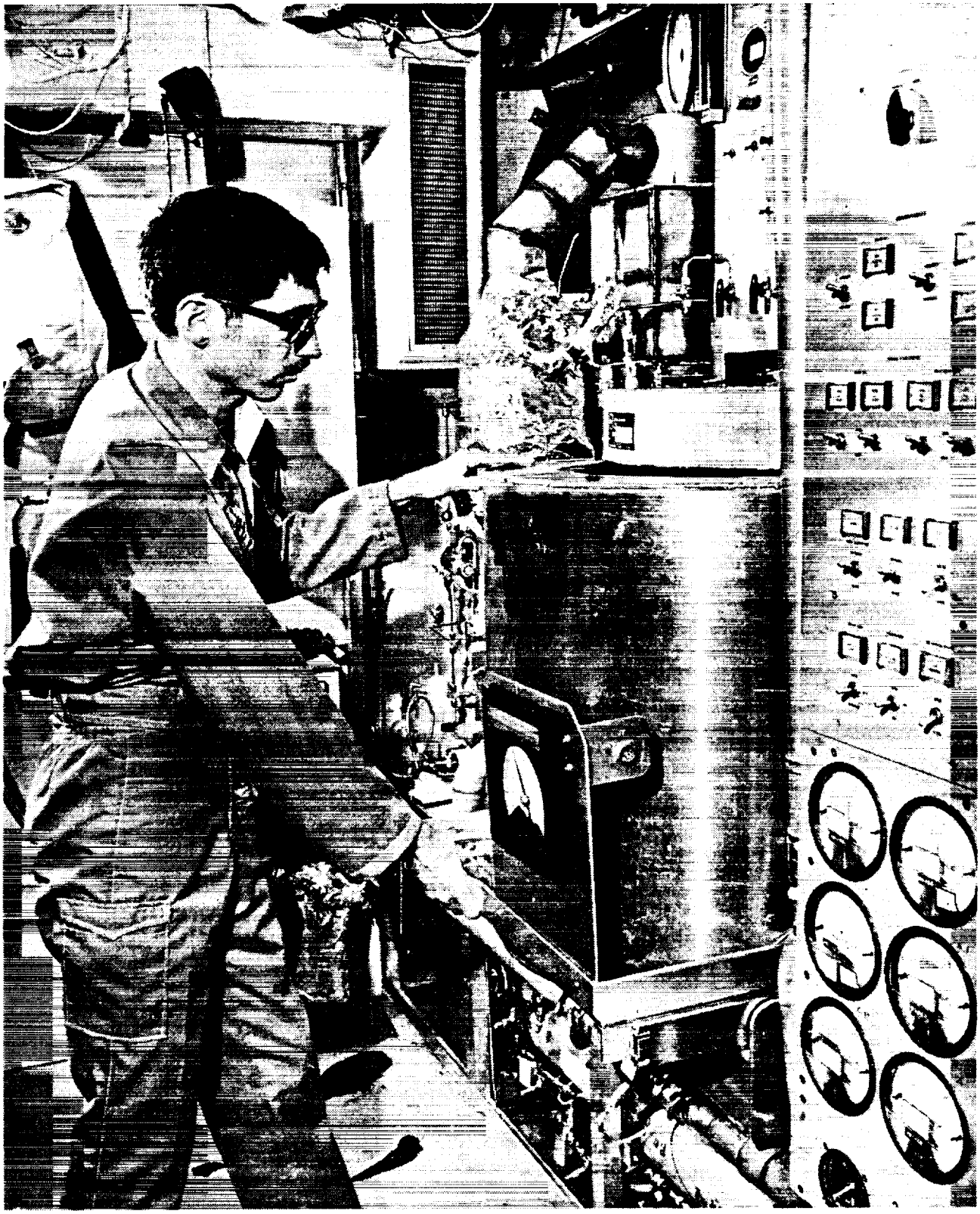


Figure 2-34. VD-VF Movable Radiation Shield

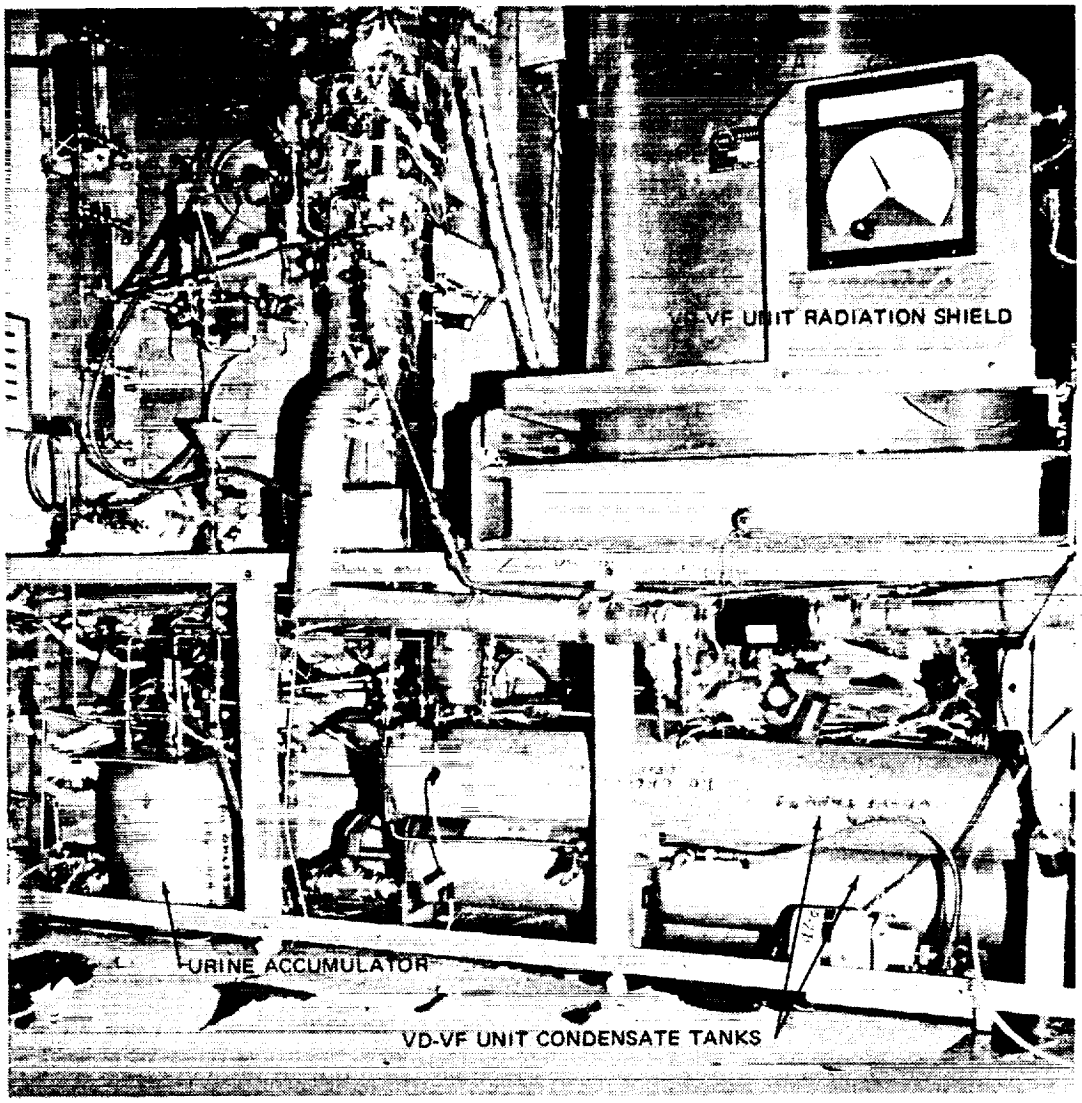


Figure 2-35. VD-VF Water Recovery Unit Installation - Urine Accumulator and Condensate Tanks



Figure 2-36. Cooled Water Isotope Storage Installation

2.2.1.2 Wick Evaporator and Humidity Control unit

The basic components of this unit are six wick packages, blower, an activated carbon air filter, particulate filter, and zero-g condenser/separator. Figure 2-37 shows the wick evaporator module before installation and Figure 2-38 shows the complete unit as installed in the SSS.

This unit was used as a backup for the VD-VF unit for recovering potable water from urine and for humidity control. When used to recover potable water from urine, the pretreated urine was pumped to one of the wick packages where heated cabin air from the blower evaporated the water, leaving the urine solids in the wick. The water vapor then passed through the activated carbon and particulate filters, and through the condenser/separator where the water was removed. The air was then returned to the cabin. Part of the dehumidified air was supplied to the CO_2 concentrator units.

When the unit was used for humidity control only, the air flow was bypassed around the wicks, providing an unrestricted flow to the condenser/separator. The separator in this unit, built by Lockheed Missile and Space Company (LMSC), operates on a hydrophobic-hydrophilic principle, with a fine mesh Teflon-coated stainless steel screen at the hydrophobic element in the air stream, and an uncoated stainless steel screen as the hydrophilic element for removing the separated water.

The separated water could be removed in either of two ways (1) normally a negative spring-loaded cylinder, having a spring force equal to the hydrophilic screen differential pressure rating, was filled from the separator and then pumped to one of the two holding tanks; or (2) the cylinder could be filled by utilizing the differential pressure sensing and pumping system, supplied as part of the condenser/separator unit. The supplied system consisted of a differential pressure switch, which sensed the hydrophilic screen differential pressure, and a small gear pump, which removed the available water when activated by the pressure switch. The cylinder and second pump were also required in this mode of operation, due to insufficient head pressure from the gear pump.

2.2.1.3 Detoxification-Multifiltration Unit

This unit was composed of two heated zero-g holding tanks and a detoxification-multifiltration module containing a 1-μm stainless steel filter, and activated carbon and ion exchange resin columns. A schematic of this unit is shown in Figure 2-39.

Water processed in this unit came from humidity condensate, wick evaporator condensate, and VD-VF product water that required further processing. The two tanks, each holding about 45 kg (100 lb) of water, were filled and processed on an alternate schedule. Each tank was held for a minimum of 6 hours at 344°K (160°F) after filling and then filtered through the module at approximately 2.5 ml/sec to one of the storage tanks. The materials used in the module columns were Barnebey-Cheney activated carbon type PC, Dow mixed ion exchange resin type ARM-381, and Dow cation exchange resin type ARC-351. Each column contained about 0.1 kg (0.2 lb) of material.



Figure 2-37. Wick Evaporator Module

NOT REPRODUCIBLE

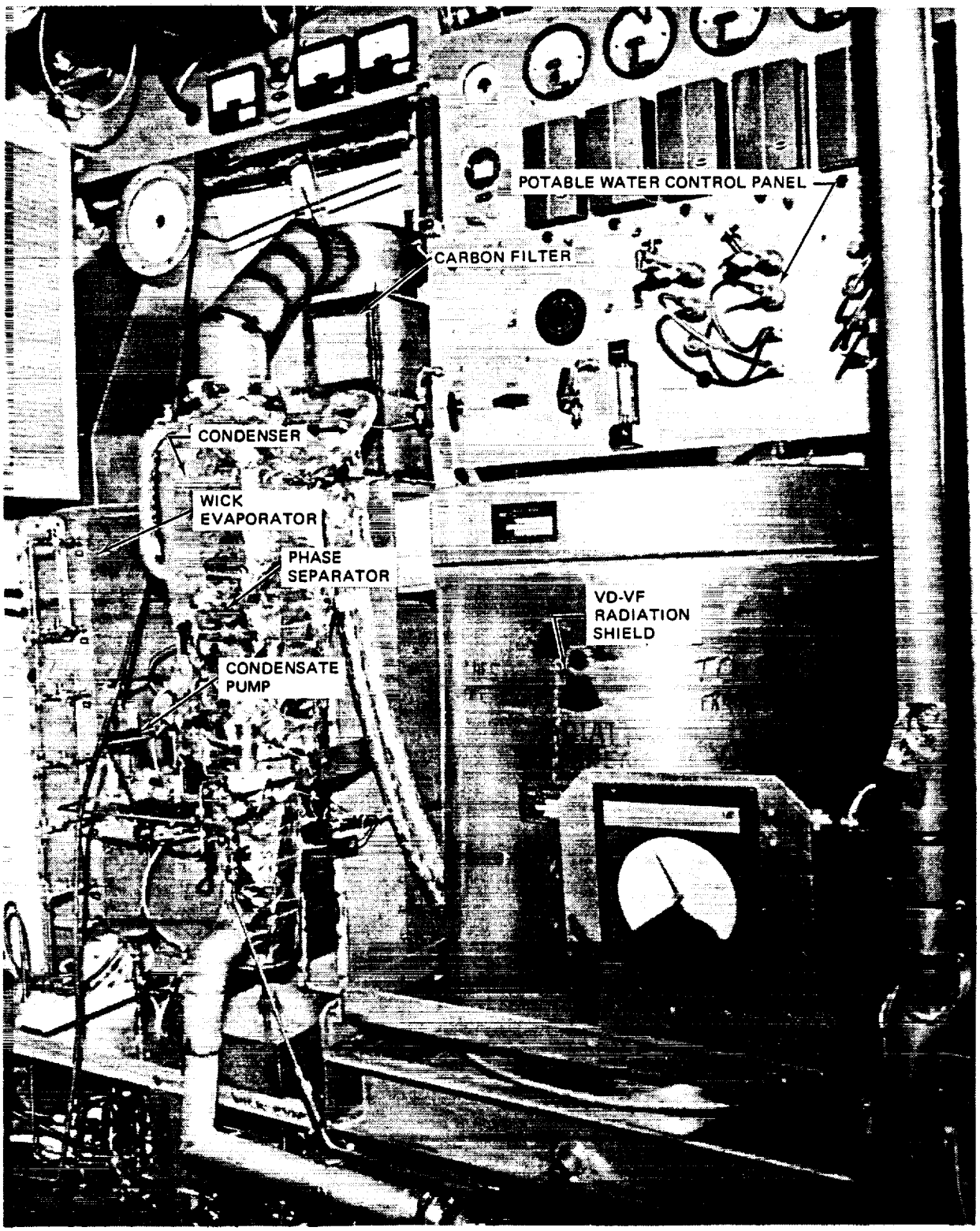


Figure 2-38. Potable Water Recovery and Humidity Control Unit—Air Evaporation Unit, VD-VF Unit, Water Control Panel

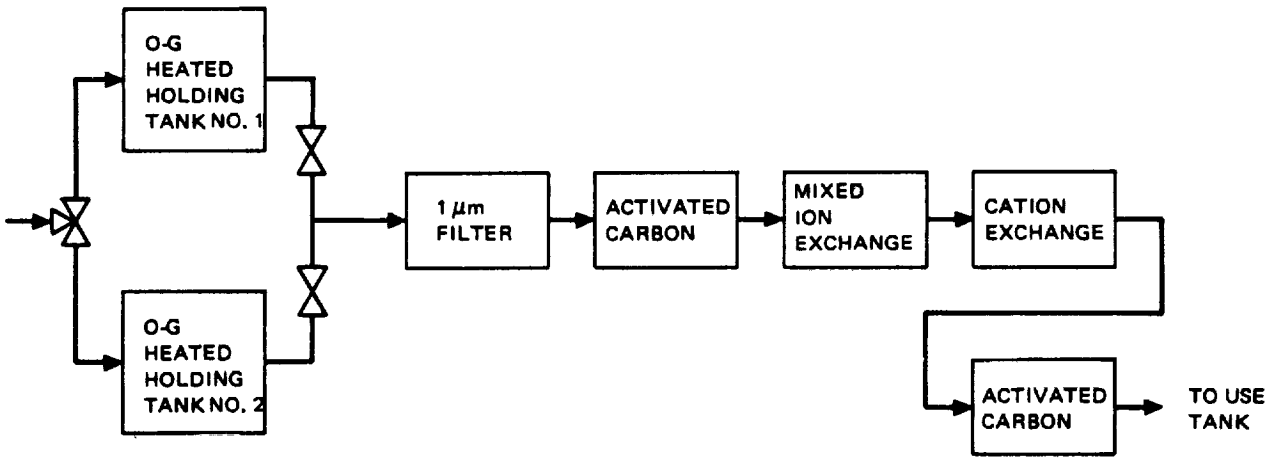


Figure 2-39. Detoxification-Multifiltration Unit Schematic

2.2.1.4 Potable Water Storage and Distribution Unit

This unit consisted of four heated zero-g storage tanks, a distribution panel, circulation pump, 1-μm stainless steel filter, two chillers, MDAC cold water dispenser, and Apollo hot and cold dispenser (see Figure 2-32). Figures 2-2 and 2-3 show the storage tanks hung overhead. Figure 2-40 shows the water dispenser, and the distribution panel can be seen in the upper right corner of Figure 2-38.

The four storage tanks, each holding approximately 45 kg (100 lb) of water, were used on a 48-hour rotational sequence according to a plan in which the status at any time was: one tank being filled, one tank being chemically and microbiologically checked, one tank certified potable awaiting use, and one tank being used. The distribution panel contained valving and flexible piping with quick-disconnect fittings, which allowed the placement of each of the storage tanks in its proper status. The panel also contained the tank heater temperature controllers, wick evaporator and VD-VF instrumentation, and provided a convenient location to draw water samples for analysis.

The dispensing unit provided for drawing measured amounts of hot and cold water from the Apollo dispenser or a continuous flow of cold water from the MDAC dispenser. The redundant chillers were cooled from the main Coolanol-35 system.

The circulation pump provided a continuous flow of hot water from the use tank to the use point and return to prevent bacterial growth during nonusage, in an otherwise stagnant line.

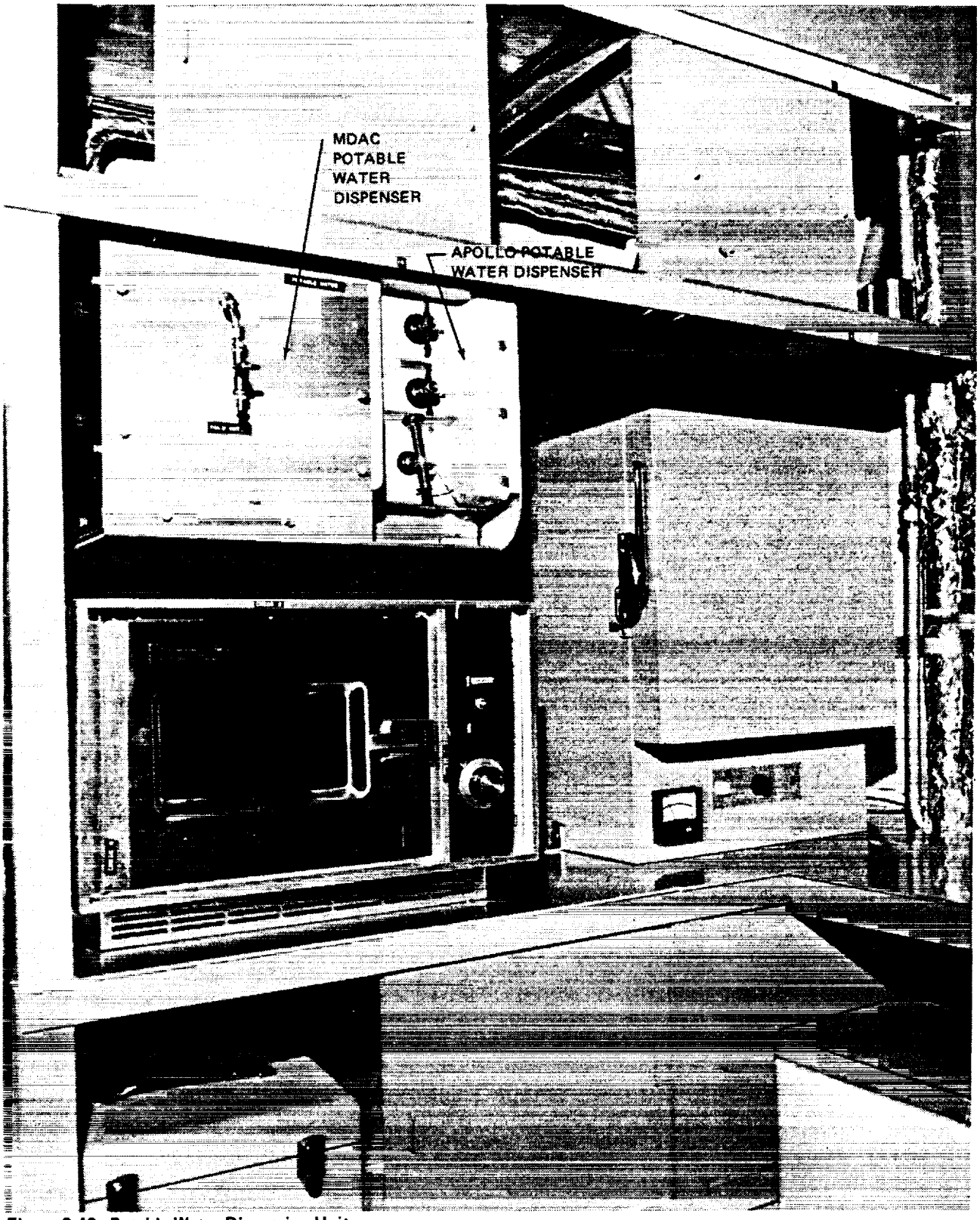


Figure 2-40. Potable Water Dispensing Unit

2.2.1.5 Backup Potable Water Supply

The backup potable water supply consisted of a stainless steel tank containing 182 kg (400 lb) of iodine-treated distilled water. This water was to be used if both the VD-VF unit and wick evaporator unit failed to produce potable water. The system also contained a circulation pump and syringe disconnect fitting to provide for additions of iodine, if required.

2.2.1.6 Wash Water Recovery Unit

This unit contained two heated zero-g water tanks; a heat exchanger; a sink with a mixing supply valve; a multifiltration module composed of a 30-, 3-, and 1-μm filter series followed by an activated carbon column, a mixed-bed ion exchange resin column, a cation exchange resin column, and a final carbon column; a pump; and a commercial clothes washer and dryer (see Figure 2-33). Figure 2-41 shows the installation in the SSS.

The unit was used to recover water for personal hygiene, laundry, and miscellaneous housecleaning chores. The cleansing agen used in the unit was Basic H, a nondetergent, biodegradable concentrated cleansing agent.

In operation, the used water was pumped from the sink to the heated holding tank and then processed automatically through the multifiltration module to the heated use tank. The manually operated mixing supply valve proportioned the water through the heat exchanger to provide the desired temperature.

The materials used in the module columns were identical to those used in the potable multifiltration unit (Section 2.2.1.3). However, larger columns were used in the wash water recovery unit and each column contained about 1.8 kg (4 lb) of material.

The water from the wash water use tank was also used as a urinal flush. Makeup water, when required, was supplied from the potable water supply.

2.2.2 Qualification and Certification Procedures

Prior to the start of the 90-day test, the water management subsystem was operated with urine feed for 3 weeks to obtain mechanical, chemical, and microbiological certification. The chemical results are shown in Table 2-18 and the microbiological results are shown in Table 2-19. During the check-out procedure, high levels of cadmium were initially found in water from tanks 4 and 5. A thorough inspection disclosed that a cadmium-plated brass fitting had inadvertently been installed in the discharge port of tank 4. It was also discovered that cadmium was leaching from a similar fitting in one of the VD-VF boilers. After both fittings were replaced, no further high cadmium levels were detected. A small amount of microbial contamination was found in two of the storage tanks (see Table 2-19), but in a later repeated tests no contamination was found. A silver-ion generator, which had been installed in the system for microbiological control, did not pass qualification tests because of insufficient ion concentration and high microbial levels down-stream of the generator (for details see Reference 2-2).

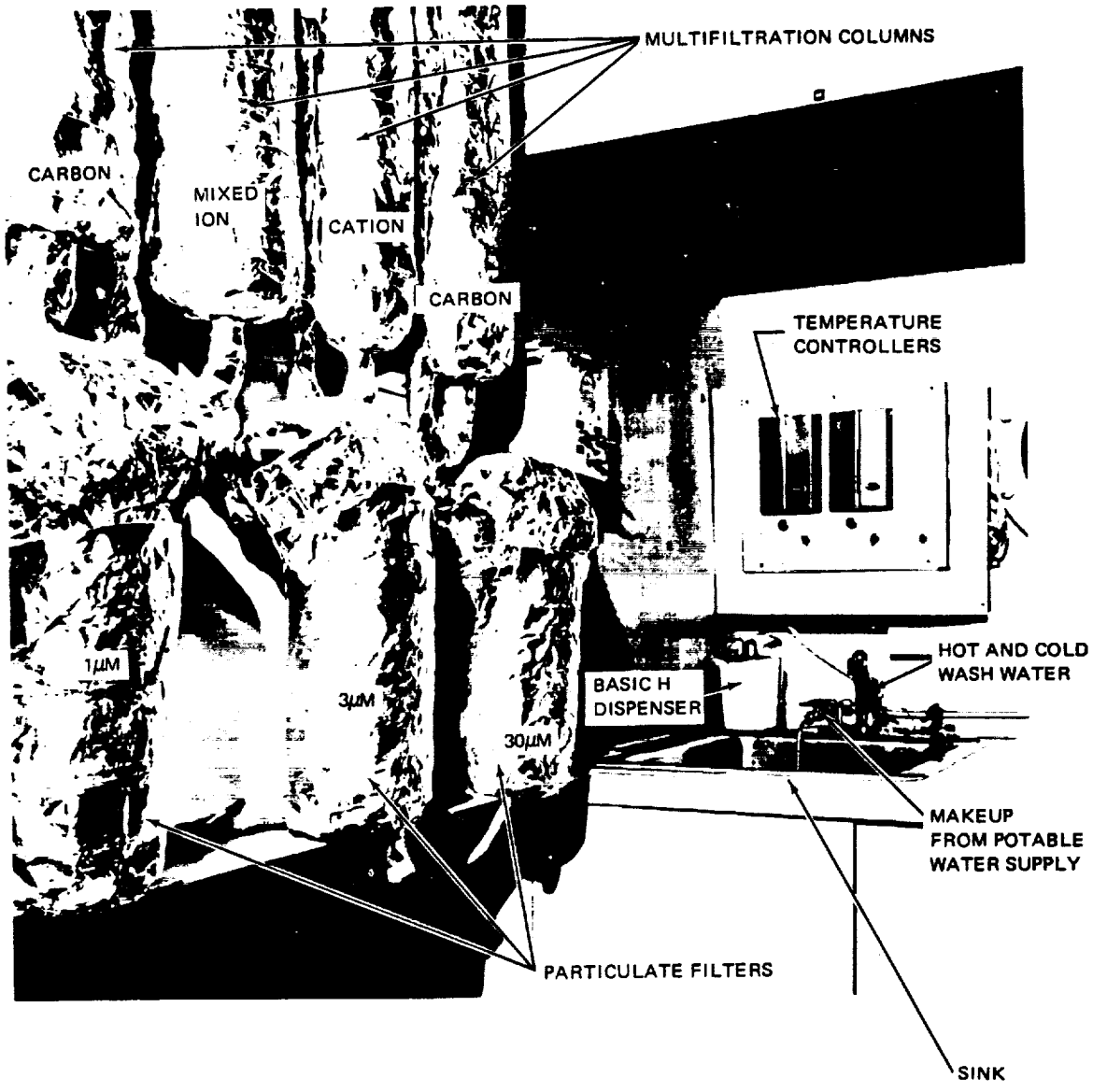


Figure 2-41. Wash Water Recovery Unit–Multifiltration Columns and Sink

Table 2-18

POTABLE WATER CHEMICAL PRETEST AND BIWEEKLY ANALYSIS (ALL VALUES IN PPM)

DATE	TEST DAY	TANK NO	SOURCE	As	Be	B	Cd	Cl	Cr	Cu	F	Pb	Se	Ag	SO_4	TDS	NO_3 As N	NO_2 As N	TOTAL N	Al	Ba	Bi	Ca	Co	Fe	Li	Mg	Mn	Hg	Ni	K	Si	Na	Sn	Zn	Mo
STANDARD				0.5	2.0	5.0	0.05	460	N.S.	3	2	0.2	0.05	0.5	250	1,000	N.S.	N.S.	10	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
5-25	10	1	DISTILLED	<0.001	<1.0	<1.0	<0.02	<0.04	13.5	<0.001	0	<0.1	<0.05	0.0007	<1.0	140	<0.1	0.13	<0.23		<0.002	<1.0	0.004	<0.01	<0.002	<0.001	0.02	<0.01	<0.1	<0.05	0.02	0.3	0.22	<0.25	<0.01	<0.01
5-26	10	3	DISTILLED + WICK EVAP M-F FROM TANK 2	<0.001	<1.0	<1.0	<0.02	<0.04	16.3	<0.001	0	<0.1	<0.02	0.0007	4.5	10	<0.1	0.13	<0.23		<0.002	<1.0	0.05	<0.01	<0.002	<0.001	0.14	<0.1	<0.01	<0.05	0.04	1.0	0.38	<0.25	<0.014	<0.01
5-26	10	4	VD-VF, REJECTED*	<0.001	<1.0	<1.0	0.48*	0.2	21.3	0.11	0	0.16		0.001	1.5		6.4	0.13	6.53	0.53	<0.002	<1.0	0.03	<0.01	1.76	0.001	0.04	0.16	<0.1	0.9	0.03	0.8	0.43	<0.25	0.27	<0.01
5-26	10	5	VD-VF, REJECTED*	<0.001	<1.0	<1.0	0.05*	0.2	9.8	0.008	0	<0.1	<0.05	0.002	2.0		5.1	0.10	5.2	0.47	<0.002	<1.0	0.02	<0.01	1.5	<0.001	0.02	0.62	<0.1	0.9	0.04	<0.03	0.18	<0.25	0.24	<0.01
5-26	10	6	DISTILLED	<0.001	<1.0	<1.0	<0.02	<0.04	30.2	<0.001	0	<0.1	<0.05	0.003	<1.0	10	<0.1	0.07	<0.17		<0.002	<1.0	0.008	<0.01	<0.002	<0.001	0.02	<0.01	<0.1	<0.05	0.01	0.3	0.2	<0.25	<0.01	<0.01
5-26	10	BACKUP	IODINE TREATED	<0.001	<1.0	<1.0	<0.02	<0.04	6.0	<0.001	0	<0.1	<0.25	<0.0002	26.0	10	0.88	0.43	9.08		<0.002	<1.0	0.009	<0.01	<0.002	<0.001	0.02	0.08	<0.1	<0.05	1.2	<0.03	0.3	<0.25	0.024	<0.01
5-21	-12	BOILER 1	VD-VF				<0.05																		0.1										
6-2	10	CONDENSATE	VD-VF				<0.01																												
6-2	-9	4	VD-VF	<0.05	<0.075	<0.075	<0.05	<0.075	8.1	<0.045	0.08	0.022	<0.05	<0.02	<0.5	155	0.55	0.38	0.93	0.038	<0.0001	0.038	0.10	<0.003	<0.38	<0.0075	0.045	<0.075	<0.038	0.38	<0.038	0.2	<0.075	0.02	0.08	0.003
6-6	-5	BOILER 1	VD-VF	<0.07	<0.7	<7.0	0.008	0.05		0.03		<0.7	<0.7	0.03						0.07	<0.03	0.02	0.1	<0.03	0.1	<0.0007	0.05	1.8	<1.5	1.3	0.03	0.2	0.2	0.07	0.02	<0.02
6-9	-3	CATALYST	VD-VF	<0.04	<0.4	<4.0	<0.005	0.005		0.04		<0.4	<0.4	0.001						4.0	<0.02	<0.008	0.3	<0.02	0.04	0.001	0.07	0.1	<0.75	0.01	0.08	0.1	1.0	0.08	0.02	<0.01
6-10	-2	COLD TRAP	VD-VF	<0.04	<0.7	10.0	3.5	1.0	22	0.6		0.45	<0.7	<0.03			1.2			1.3	<0.0007	<0.008	0.8	0.03	12	0.001	0.3	0.5	<0.2	2.2	24	0.5	1.2	<0.4	0.8	0.03
6-16	4	6	VD-VF				<0.05																												
6-30	18	6	VD-VF	<0.02	<0.02	<0.3	0.009	0.01	0.41	0.008		0.01	<0.14	0.004		0	0.78	0.08	0.84																
7-13	31	5	WICK EVAP M-F	<0.03	<0.08	<0.3	0.0015	0.005	0	0.015			<0.075	0.004		5	1.0	0.004	1.004	1.7	<0.0003	0.002	0.3	<0.002	0.08	0.0002	<0.08	0.004	<0.075	0.05	0.21		0.2			
7-15	35	2	WICK EVAP M-F	<0.03	<0.07	<0.3	0.004	0.002	0	0.04		<0.003	<0.08	0.005		0	<0.1	0.05	<0.15	0.05	<0.0003	0.004	0.04	<0.003	0.03	<0.0002	0.02	0.13	<0.08	0.37	0.04	0.12	0.05	<0.02	0.008	0.008
7-21	38	CONDENSATE	VD-VF	<0.025	<0.1	<1.2	0.003	0.005	0	0.002		<0.002	<0.38	0.008		0	<0.1	0.035	<0.135	0.01	<0.005	<0.053	0.004	<0.008	0.014	0.00008	0.008	0.0044	<0.04	0.003	0.029	<0.04	0.13	<0.01	0.012	<0.004
7-28	45	6	VD-VF M-F		<0.03	<1.5	0.0008	0.003	0	0.01		<0.008	<0.3	0.003		0	<0.1	0.1	<0.2		<0.005				0.044											
8-11	60	9	VD-VF M-F	<0.013	0.019	0.08	0.002	0.001	0	0.013		0.008	<0.013	0.011		0	0	0.03	0.03		0.0031														
8-26	74	6	VD-VF M-F	<0.014	<0.083	0.08	0.002	0.002	0	0.031		0.008	0.013	0.004		10.0	0	0.003	0.003																
8-7	87	3	WICK EVAP M-F						0							28.0	0	0.008	0.008																
9-24	POST TEST	1	W. EVAP + HUMID. COND.	<0.07	<0.4	<0.012	<0.003	0.002		0.05		<0.004		<0.001						<0.02	<0.001	<0.006	0.10	<0.004	0.004	<0.0006	0.007	0.012	<0.2	0.023		1.3	0.23		0.03	<0.014
9-24	POST TEST	2	W. EVAP + HUMID. COND.	<0.07	<0.4	<0.012	<0.003	0.002		0.05		0.013		<0.001						0.04	0.001	<0.006	0.10	<0.004	0.005	<0.0006	0.014	0.009	<0.2	0.027		<0.1	0.22		0.05	<0.014
9-24	POST TEST	3	WICK EVAP M-F	<0.07	<0.4	<0.012	<0.003	0.002		0.07		<0.004		<0.001						0.02	<0.001	0.008	0.07	<0.004	0.005	<0.0006	0.006	<0.001	<0.3	<0.004		1.3	0.17		0.02	<0.014
9-24	POST TEST	4	WICK EVAP M-F	<0.08	<0.4	<0.013	<0.004	0.004		0.07		0.008		<0.001						0.02	<0.001	<0.008	0.08	<0.005	0.006	<0.0006	0.007	<0.001	<0.3	<0.004		1.3	0.24		0.03	<0.015
9-24	POST TEST	5	VD-VF M-F	<0.07	<0.4	<0.012	<0.003	0.005		0.08		0.015		0.023						0.04	<0.001	<0.006	0.07	<0.004	0.01	<0.0006	0.007	0.001	<0.3	<0.004		1.0	0.24		0.02	<0.014
9-24	POST TEST	6	WICK EVAP M-F	<0.08	<0.4	<0.013	<0.004	0.003		0.08		0.004		<0.001						0.02	<0.001	<0.006	0.08	<0.005	0.005	<0.0006	0.013	<0.001	<0.3	<0.004		0.2	0.28		0.02	<0.015

Table 2-19

PRETEST QUALIFICATION MICROBIOLOGICAL RESULTS

Date	Raw Urine	MDAC Dispenser	VD-VF Condensate Tank	T1	T2	T3	T4	T5	T6	TB*
5-2-70		0 |								
5-20-70			0 | 0 / 0							
5-21-70	0 | 0 / 6		0 | 0 / 0		(1) 299 | 0 / 0		0 | 0 / 0			
5-22-70			0 | 0 / 0		0 | 0 / 0		0 | 0 / 0			
5-27-70								(2) 16 | 0 / 0		
6-2-70				0 | 0 / 0		0 | 0 / 0			0 | 0 / 0	0 | 0 / 0
6-3-70			0 | 0 / 0			0 | 0 / 0	0 | 0 / 0	0 | 0 / 0		
6-9-70		0 |								

KEY: A | B / D | C — A = Aerobes, No./ml; B = Anaerobes, No./ml; C = Fungi, No./ml; D = Viruses, No./ml

*Backup tank

(1) Pseudomonas, Klebsiella, Aerobacter

(2) Klebsiella, Aerobacter, Staphylococcus epidermidis

2.2.2.1 Testing Procedure for Bacteria, Fungi, and Viruses

Each sample was aseptically collected in sterile "Whirl-Pak" bags and labeled for collection date and site. Aliquots from serial dilutions of each sample were used to prepare duplicate sets of pour plates. For bacterial counts, one set of plates was incubated at 310°K (37°C) for 48 hours, while the other set was held at 295°K (22°C) for 7 days, for fungal counts.

The microbiological procedures used to qualify the system and produce the results shown in Table 2-19 were in accordance with the National Academy of Sicences ad hoc Committee's recommendations for qualification of spacecraft water recovery systems (Reference 2-3). This committee recommended that microbiological sampling during system qualification include testing for aerobic organisms, anaerobic organisms, fungi, and viruses. The assay procedure used for bacteria and fungi was that recommended in Reference 2-4. All isolated organisms were subcultured to differential media for identification as shown in Figures 2-42 and 2-43.

A presumptive test for coliforms, by means of lactose broth fermentation tubes, was also performed using 2 ml of the original water sample.

A portion of each water sample (1 ml) was also inoculated into Thioglycollate Medium, which permits the growth of both aerobic and anaerobic organisms. Any aerobic culture in the Thioglycollate Medium was subcultured onto plates of Blood, Eosin Methylene Blue, and Staphylococcus Medium No. 110 agar media for identification.

A. Blood Agar is a general, nonselective growth medium which will grow both gram-negative and gram-positive organisms.

B. Eosin Methylene Blue Agar is a differential medium selective for gram-negative organisms. Organisms isolated on this medium were further identified by biochemical reactions (such as citrate fermentation).

C. Staphylococcus Medium No. 110 is selective for gram-positive organisms, especially the staphylococcus group. Colonies on this medium were tested for coagulase activity, a positive reaction indicating Staphylococcus aureus.

D. Fungal colonies which grew on the pour plates were identified by colonial morphology.

Analyses for viruses were conducted at the Medical College of Virginia. During the 90-day test, all water samples were collected in sterile plastic bags from the Apollo hot water dispenser. Samples of approximately 250 ml were collected just prior to passthrough and stored outside at 203°K until shipment.

2.2.2.2 Chemical Analysis Procedure

The chemical standards used to qualify the system and determine potability during the test were also in accordance with the National Academy of Sciences

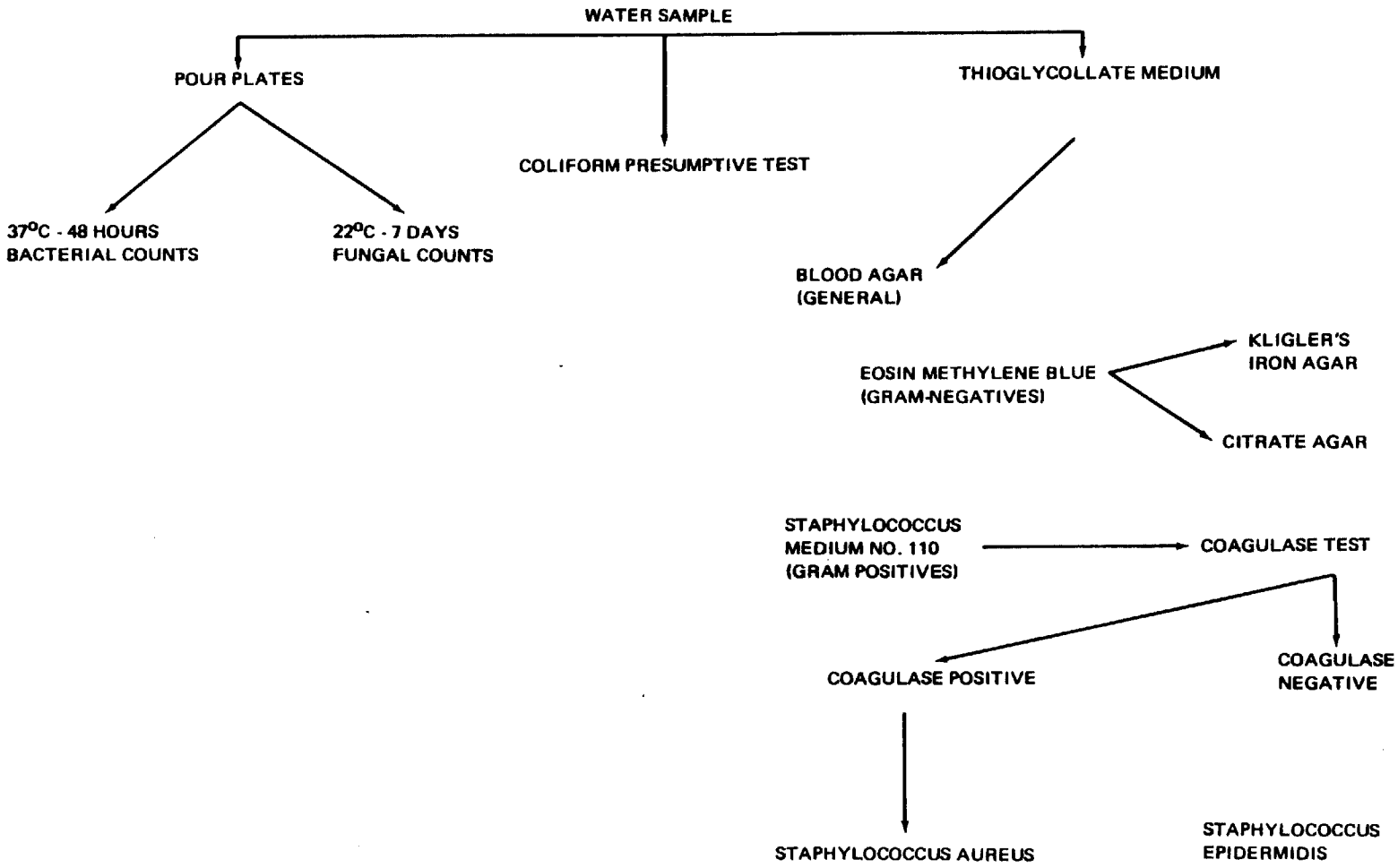


Figure 2-42. Procedures for Quantification and Identification of Microorganisms in Water Sample

EOSIN METHYLENE BLUE AGAR

LACTOSE POSITIVE	KLIGLER'S IRON AGAR	CITRATE	LACTOSE NEGATIVE	KLIGLER'S IRON AGAR	CITRATE
ESCHERICHIA COLI	A/AG	-	PSEUDOMONAS	ALK/NC	+
ESCHERICHIA FREUNDII	A/AG	V	PARACOLOBACTRUM	ALK/AG	-
KLEBSIELLA-AEROBACTER	A/AG	+	PROTEUS SPECIES	ALK/AG	V, -, + (DEPENDING ON SPECIES)
INTERMEDIATE COLIFORMS	A/AG	+	SALMONELLA	ALK/AG	V
			SHIGELLA	ALK/A	-
			ALCALIGENES	ALK/NC	+

KEY:

ALK: ALKALINE REACTION
NC: NO CHANGE IN INDICATOR
A: ACID REACTION
G: GAS FORMATION

\+ : POSITIVE REACTION
\- : NEGATIVE REACTION
V : VARIABLE REACTION

Figure 2-43. Identification Scheme for Gram Negative Organisms

ad hoc Committee's (Reference 2-3) recommendations with one exception. The exception was the replacement of chemical oxygen demand (COD) with total organic carbon (TOC) as a working criteria for potability. TOC determinations were done on every batch of water consumed, with periodic spot checks by the COD method to insure correlation.

The COD procedure is based on the oxidation of organic material and oxidizable inorganic material by a standard potassium dichromate solution. The oxidation is carried out by refluxing the sample containing potassium dichromate in a glass reflux distillation apparatus for 2 hours. The unreacted potassium dichromate is then back-titrated with a standard ferrous ammonium sulfate solution. The TOC determination is made by subtracting the indication of an inorganic carbon analyzer from that of a total carbon analyzer. These instruments are provided in an automated console which results in a considerable reduction in the time required for an analysis compared with the COD method.

The total carbon analyzer consists of a catalyst-packed combustion tube housed in a high-temperature furnace operating at 1, 223 °K (950 °C). Carrier gas consists of breathing air which continuously flows through the combustion tube. When samples are injected into the carrier gas stream all compounds

containing carbon are oxidized to carbon dioxide. A nondispersive infrared analyzer sensitized to carbon dioxide is used to measure the CO_2 generated by the sample. The total carbon analyzer does not distinguish between organic and inorganic carbon.

The second channel determines the inorganic carbon content of a sample. It consists of a low-temperature furnace operating at 423 °K (150 °C). Inorganic carbon compounds such as dissolved carbon dioxide as well as carbonates and bicarbonates injected into this low-temperature tube is converted into free CO_2, while the organic compounds are left unreacted. The difference between the total carbon found in the 1, 223 °K (950 °C) channel and the inorganic carbon in the low-temperature channel provides a measure for the total organic carbon.

It is obvious that the two procedures are based on different analytical principles. The COD method measures only those constituents that can be oxidized. An organic compound which is inert is only partially measured by this method, or not at all.

The TOC method provides a complete measure of the total carbon of the sample since all of it is converted into CO_2.

A good correlation between the COD and TOC determinations exists as long as the sample is obtained from the same source or has a fairly constant composition. If the composition of the sample is highly variable, the correlation between the two determinations breaks down. This is hardly surprising since there is not inherent similarity in the concepts of the two methods.

This is further demonstrated in Tables 2-20 and 2-21. In Table 2-20, the samples contained 25. 0 to 220 ppm of potassium acid phthalate. They were analyzed by the COD and TOC methods. Since the origin of the samples was the same, the correlation factor was fairly constant, 2. 5 to 2. 7. In Table 2-21, the sample sources were from different locations in the potable water recovery subsystem, during the test. As a result, the correlation factor varied from 1. 2 to 4. 6.

The measurement of TOC as an index of water pollution has been gaining favor over the COD analysis. This is based not only on the rapidity of the method and accuracy and reproducibility but also on the fact that the entire carbon content of the sample is determined and distinctions between organic and inorganic compounds can be readily made.

2. 2. 2. 4 Water Acceptability Tests

Three separate tests of water acceptability were made in conjunction with the 90-day manned test. The first and second tests were a series of taste comparisons completed before the 90-day manned test started. The third acceptability test took the form of a questionnaire after the completion of the 90 days. The results of the first test point out that the subjects did not care for the VD-VF water and the backup water. The second test showed that wick evaporator water was the least desired water and distilled water the most favored. The final acceptability questionnaire verified the crew verbal statements that the actual 90-day manned test water was quite acceptable with one exception.

Table 2-20

COMPARISON OF COD AND TOC DETERMINATIONS
(Solution of Potassium Acid Phthalate)

Sample Concentration (ppm)	COD (ppm)	TOC (ppm)	Correlation Factor
25.0	68.7	25.0	2.75
50.0	129.0	51.0	2.53
75.0	192.1	74.0	2.59
100.0	256.4	100.0	2.56
200.0	503.5	200.0	2.52

Table 2-21

COMPARISON OF COD AND TOC DETERMINATIONS
(Different Sample Sources of Reclaimed Water)

Date	Sample Source	COD (ppm)	TOC (ppm)	Correlation Factor
7-24-70	VD-VF Cond.	8.0	3	2.7
7-21-70	VD-VF Cond.	8.0	7	1.2
7-16-70	VD-VF Cond.	10.8	8	1.3
7-13-70	Tank No. 8	556	224	2.5
7-13-70	Tank No. 7	350	172	2.0
7-21-70	Tank No. 8	769	242	3.1
7-21-70	Tank No. 7	147	97	1.5
5-25-70	Backup Tank	7.5	2	3.7
5-25-70	Tank No. 3	15.3	4	3.8
5-25-70	Tank No. 4	18.4	4	4.6
5-25-70	Tank No. 5	7.5	4	1.9
5-25-70	Tank No. 6	5.1	3	1.7
5-25-70	Tank No. 1	3.9	2	2.0
5-25-70	MDAC Dispenser	3.9	2	2.0
5-25-70	Tap Water	2.0	1	2.0
5-5-70	Tank No. 3	60.0	22	2.7
5-5-70	Tank No. 4	24.0	6	4.0
5-5-70	Tank No. 6	28.5	7	4.0

First Acceptability Test

The object of this test was two-fold: (1) to determine if the water recovered by the water system could be detected from other, nonrecovered water; and (2) to check the effect of certain tanks on the taste of the water stored in the tanks.

Eight types of water were tested in eight tests of six subjects each. The eight types of water, and abbreviations to be used throughout the discussion of the tests, were:

A. T Tap water

B. D Distilled water

C. DT2 Distilled water that had been stored in tank No. 2 (heated)

D. DT3 Distilled water that had been stored in tank No. 3 (heated)

E. DT4 Distilled water that had been stored in tank No. 4 (heated)

F. WE Water from the wick evaporator

G. VD-VF Water from the VD-VF

H. B Backup water (distilled water with I_2)

Eight tests of three kinds of water each using the above types of water, were given to the 48 subjects to taste; the subjects being crewmen, MDAC engineers and NASA personnel. Tap water was used as a control in each of the eight tests.

Each subject was allowed to taste the three types of water with only an experimenter present. The subject was then asked: "Which of the cups of water has the most objectionable taste?" The experimenter then recorded the subject's response, and if the subject had any comments about the taste of any water, they were also recorded.

The chi-square test was used to determine if a significant number of subjects chose one of the types of water in each test as being most objectionable. The chi-square test is essentially a test of how much the values from an experiment differ from the expected values. The expected values are normally based on the null hypothesis that the different types of water chosen as objectionable will have no effect on the results. Both the expected and the actual experimental values are substituted into the chi-square formula and the resulting value is checked in a significance table.

The eight tests and the results are shown in Table 2-22. It can be seen that only VD-VF water and the backup water (B) were picked as being significantly objectionable by the subjects. The chi-square, where p is less than 0.05, means that only one person in 20 would not choose as the subjects chose. It will be further noticed that in test 6, where the backup water and the VD-VF water were tested against tap water, there was no significant difference between the subject's choices of backup water and VD-VF water.

Table 2-22

RESULTS OF FIRST WATER ACCEPTABILITY TEST

	Water Type	Subjects' Responses (6 Subjects)	Chi-Square Test	Subjects' Comments
Test 1	T	0	$p < 0.05$	(VD-VF) with oil taste; bitter but drinkable; bromine taste
	D	1		
	VD-VF	5		
Test 2	T	1		(D) metallic
	D	2		
	DT2	3		
Test 3	T	2		
	D	1		
	DT3	3		
Test 4	T	2/3*		
	D	2/3		
	DT4	4 2/3		
Test 5	T	0	$p < 0.05$	(VD-VF) worst by far, but would drink; not as bad as B (with I_2)
	WE	1		
	VD-VF	5		
Test 6	T	0		(B) objectionable, but could drink; don't like; B is worst
	B	4		
	VD-VF	2		
Test 7	T	1		(WE) rubber hose odor; alkaline; halogen
	D	1		
	WE	4		
Test 8	T	0	$p < 0.005$	(B) smells; worse than others; would drink
	D	0		
	B	6		

*Two subjects reported no difference.

In summary, it is clear from the first acceptability test that the subjects definitely did not care for either the backup water or the VD-VF water, with a slight tendency toward selecting the backup water as being the least acceptable.

Second Acceptability Test

This test, like the first acceptability test, was run before the 90-day manned test, but after the 5-day checkout test. The intention of this test was two-fold. It was to verify the reports of the crew of the 5-day manned checkout test concerning bad-tasting water; specifically of a water that had a strong metallic taste. The second goal was to measure the acceptability of all the recoverable water to be used for the 90-day manned run.

This acceptability test differed from the first acceptability test, in that a longer time duration for consuming the water was incorporated into the experimental design. To that end, the subjects carried home approximately 0.946 liters (1.0 quart) of the water which they were to drink for a 24-hour period. In the instructions given to them, the subjects were asked to drink most, if not all of the water, given to them. The subjects for this acceptability test were all eight crewmen in training for the 90-day manned run.

There were six types of water to be evaluated during this acceptability test and each of the eight crewmen was to taste each of the water types. Because of logistic difficulties, some of the crewmen did not get all of the water types. Thus, the results and impressions of some of the types of water are based on reports of only seven crewmen instead of eight.

The results of the second acceptability test are shown in Table 2-23. It is interesting to note that those crewmen who would hesitate to drink certain types of water for the 90 days were all scheduled as outside crewmen. The crewmen who were to form the outside crew had been identified several weeks previous to this water test. The inside crewmen stated that they would drink any of the waters for 90 days. This cleavage between the inside and the outside crew on their responses suggests a division of responses based on motivation. All eight crew members wanted to participate in the 90-day manned test as inside crewmen, thus the motivation of those chosen to remain outside may not have been quite as high as the others.

The results of ranking the water indicate that distilled water got the highest rating (the higher the number, the better the crewmen liked the water) and the wick evaporator water rated lowest. Both of these scores, the distilled water at 6.7 and the wick evaporator water at 3.5, were significant at the 0.01 level. That is, there is only one chance in 100 that these scores would happen in this manner at random. Or to put it more generally, it can be said with considerable confidence that the crewmen judged the distilled water and the wick evaporator water to be different from the other waters.

The comments given in answer to Question 6 give some indication of a lack either in the precision of the experiment or, more likely, in the ability of people to easily differentiate one control water from the other, given this experimental context. The crewmen easily identified the water with the metallic taste (DT and WE water). It is likely that the crewmen were sensitive to that taste from the 5-day manned checkout test which preceded this

Table 2-23

RESULTS OF SECOND WATER ACCEPTABILITY TEST

Summary of Responses to:

Question 1: Did you drink the water given to you?

Response: All of the subjects drank the water assigned them for each day.

Question 2: Would you drink this water for 10 days?

Response: All of the subjects would drink all of the water for 10 days.

Question 3: Would you drink this water for 90 days?

Response: Three subjects would hesitate to drink wick evaporator water for 90 days. One subject would hesitate to drink the backup water (B) and one subject said he would not like to drink VD-VF water for 90 days.

Question 4: Rank the water on a 9-point scale: 9 = liked extremely, 5 = neither like nor dislike and 1 = dislike extremely.

Response:

Water Type	Avg Rank
D	6.7
B	5.3
VD-VF	5.0
DT	5.0
T	5.0
WE	3.6

Question 5: If you have drunk other test water, rate how this water compares with the other water?

Response: The unstructured nature of this question did not prompt replies from the subjects. Almost without exception they left it blank.

Question 6: Any comments about water?

Response:

T. Bland, but better than my home tap water

D. Tastes ok while drinking, but a bit of an aftertaste

D. Palatable; better than home tap water

DT. Water tastes metallic though not as bad as that of 5-day test. Tastes exactly like the first bottle (thermos) of water I tasted.

30

Table 2-23 (Page 2 of 2)

RESULTS OF SECOND WATER ACCEPTABILITY TEST

Question 6: (Continued)		
	WE.	This water has the same smell and taste as the silver nitrate water we had inside (5-day test) except it is not as bad as the water we had inside. However, I could get use to the taste or I could increasingly dislike it if I had to drink it for a long period of time.
	WE.	It's like the 5-day test water.
	VD-VF	Leaves palate with taste.
	VD-VF	Tastes of "rubber."
	B	Medicine.

acceptability test and thus put their comments in terms of a metallic taste. The VD-VF water and the backup water (B) were tagged with their characteristic taste.

Third Acceptability Test

The goal of this acceptability test, which was administered after the 90-day manned test was completed, was to get the crewmen's subjective impressions of the water they drank during the entire 90 days. This test assumed the form of a questionnaire. Several of the initial questions inquired if the taste of water (assuming the water did have a bad taste) interferred with the drinking of the water or with the taste of the food which had to be reconstituted using the water.

Another question listed seven ways of using the water (e. g., chilling the water, heating it and making coffee) in a manner to reduce the taste of the water if the taste was objectionable. The crewmen were asked to rate the methods of treating the water to reduce the bad taste. Finally, the crewman was asked to compare the taste of the 90-day manned test water with the water they tasted before the 90-day duration started. A tabular summary of the results are shown in Table 2-24.

Each crewman mentioned independently that water during the 90-day test had a bad taste immediately before the filter pack in the multifiltration system was changed. This was because the filter had reached its capacity in its ability to hold the solutes to be filtered out and any filtering beyond that point was not up to the usual standards. When asked if they ever refused to drink the water because of the taste, only one crewman said frequently he would not drink the water because of bad taste. The crewmen were split in their opinions of whether the unacceptable water interferred with the flavor of the reconstituted foods they ate.

Table 2-24

RESULTS OF THIRD WATER ACCEPTABILITY TEST
(Given after 90-Day Manned Test)

	Questions	Responses of Crew
1.	For water that tasted bad, what was cause?	VD-VF water immediately before multifilter element change.
2.	Did you ever not drink water because of its taste?	Never (1 crewman) Rarely (2 crewmen) Frequently (1 crewman)
3.	Did (unacceptable) water interfere with flavor of food?	No (2 crewmen) Yes (2 crewmen)
4.	What was best method for improving taste of room temperature glass of water?	
	Chill, add Koolaid and sugar	1st
	Heat, add coffee	2nd
	Heat, add tea	3rd
	Chill, eat snack with it	4th
	Chill, add tea	5th
	Add ice cubes	6th
	Chill only	7th
5.	Considering your expectations based on water tasted before 90-day test, how did test water taste?	CM1: 90-day test water was better (it improved during the run). Rubber diaphragms still gave water some taste. CM2: Better than I expected; better than pre-90-day test water. CM3: Quite good except for some bad VD-VF water. Sometimes much better, sometimes worse (than pre-90-day test water). CM4: Better! Better!
6.	Was the water you drank during 90-day test better than the backup water (containing I_2)?	Yes (4 crewmen)

When asked the best method for improving the taste of a room-temperature glass of water, they preferred to chill the water and add Koolaid with sugar. The second choice for improving the water was to heat it and add coffee. The least desirable way to handle water with an unpleasant taste was to merely add ice cubes or to chill it alone.

The crew was unanimous in their judgment of the 90-day test water being better than the pre-90-day test water, although they still had some comments about the water. For example, crewman 1 stated there was a rubber taste in the water and crewman 3 remarked again about bad VD-VF water. The crewmen were unanimous in favoring the 90-day test water to the backup water (B). As was noted in acceptability test 1, the backup water was one of the least liked waters of any that the crewmen drank but ranked second during test 2. It is also interesting to note the absence of adverse comments on wick evaporator water, which ranked last during test 2.

2.2.2.5 Operating Procedure

The procedure for certifying and keeping track of the status of the potable water system with respect to units in operation, inventory of certified water, and status of chemical and microbial testing was as follows: water samples were taken by the inside crew, passed out, and delivered to the laboratory for analysis along with a chemical and physical analysis checkoff sheet (see Figure 2-44). At the same time a Millipore Field Monitor was processed by the inside crew for bacterial analysis. The tank fill date and sample date were noted on a tank status card (see Figure 2-45) and as soon as available the chemical and microbiological results were also noted on the card. The medical director then certified or rejected the tank for consumption. The operational status of units and progression of water tanks from initial fill to certification standby and use was kept current on a system status board as shown in Figure 2-46.

The Millipore Field Monitors that were used for the enumeration and preliminary isolation of microorganisms were 0.45-μm black, grid-type filters. Samples of water for microbial analysis were aseptically collected from each sampling port in a sterile disposable plastic bag after first flushing the sample port by drawing 100 to 200 ml of water and returning this to the system via the urinal or sink. A fresh sterile field monitor and sampling tube assembly was used for each water sample cultured. After identifying the field monitors as to sample port, date, time, and volume of sample filtered (usually 10 ml), ampouled medium (Millipore M-TGE Broth) was added to each monitor and they were immediately incubated at 35°C for 48 hours. Following incubation the field monitors were opened and the membrane filters examined under illuminated low-power magnification for characteristic colonial growth. The total number of colonies present on each filter was counted and this count, divided by the volume of sample filtered, was recorded as the number of viable cells/ml of water. All field monitors showing growth at 48 hours were stored onboard at ambient temperature for weekly pass-out. After pass-out, representative colonies were selected and subcultured from each monitor for identification of genus and species in the outside laboratory. Field monitors showing no growth onboard were returned to the original storage container and held at ambient temperature for the duration of the test.

TO: Dr. P. Mader

FROM: Medical Director 90-Day Run

SUBJECT: CHEMICAL AND PHYSICAL WATER ANALYSIS

ACTION: Perform the analyses checked below

Date of Sample _____

Location of Sample _____

Sample Number _____

Source of Water: [ ] VD-VF
[ ] Humidity Condensate
[ ] Air Evaporation

Actual Sample Size _____ mℓ

Total plate count – 24 Hr _____ per mℓ

– 48 Hr _____ per mℓ

[ ] Certified to use.

Signed: _____
Medical Director Date

MEASURED EVERY TANK

		Amount	Standard
[ ]	Turbidity	_____	(10) Jackson Units
[ ]	Color	_____	(15) Cobalt Units
[ ]	Taste	_____	(none objectionable)
[ ]	Odor	_____	(none objectionable)
[ ]	Foaming	_____	(none persistant >15 sec)
[ ]	pH	_____	(no std)
[ ]	K	_____	(no std) μmho-cm^{-1}

MEASURED EVERY 2 WEEKS

		Amount	Standard
[ ]	As	_____	(0.5) mg/ℓ
[ ]	Ba	_____	(2) mg/ℓ
[ ]	B	_____	(5) mg/ℓ
[ ]	Cd	_____	(0.05) mg/ℓ
[ ]	Cl	_____	(450) mg/ℓ
[ ]	Cr	_____	(no std) mg/ℓ
[ ]	Cu	_____	(3) mg/ℓ
[ ]	F	_____	(2) mg/ℓ

MEASURED TO INITIALLY QUALIFY SYSTEM PRIOR TO START OF 90-DAY TEST

		Amount	Standard
[ ]	Al	_____	(no std) mg/ℓ
[ ]	Be	_____	(no std) mg/ℓ
[ ]	Bi	_____	(no std) mg/ℓ
[ ]	Ca	_____	(no std) mg/ℓ
[ ]	Co	_____	(no std) mg/ℓ
[ ]	Fe	_____	(no std) mg/ℓ
[ ]	Li	_____	(no std) mg/ℓ
[ ]	Mg	_____	(no std) mg/ℓ
[ ]	Mn	_____	(no std) mg/ℓ
[ ]	Hg	_____	(no std) mg/ℓ
[ ]	Ni	_____	(no std) mg/ℓ
[ ]	K	_____	(no std) mg/ℓ

		Amount	Standard
[ ]	NH_3	_____	1, pH >7 10, pH <7 mg/ℓ
[ ]	TOC	_____	(no std) mg/ℓ
[ ]	COD	_____	(100) mg/ℓ
[ ]	Br	_____	(1) mg/ℓ
[ ]	$C_r{}^{+6}$	_____	(0.05) mg/ℓ

		Amount	Standard
[ ]	Pb	_____	(0.2) mg/ℓ
[ ]	Se	_____	(0.05) mg/ℓ
[ ]	Ag	_____	(0.5) mg/ℓ
[ ]	$SO_4^{=}$	_____	(250) mg/ℓ
[ ]	TDS	_____	(1,000) mg/ℓ
[ ]	NO_3 as N	_____	(no std) mg/ℓ
[ ]	NO_2 as N	_____	(no std) mg/ℓ
[ ]	Total NO_3 and NO_2 as N	_____	(10) mg/ℓ

		Amount	Standard
[ ]	Si	_____	(no std) mg/ℓ
[ ]	Na	_____	(no std) mg/ℓ
[ ]	Sn	_____	(no std) mg/ℓ
[ ]	Zn	_____	(no std) mg/ℓ
[ ]	P	_____	(no std) mg/ℓ
[ ]	Mo	_____	(no std) mg/ℓ

Figure 2-44. Checkoff Sheet

TANK NO. 3

		MO	DAY	HOUR	SIGNED
START FILL	9 LB	7	25	2210	GW
END FILL	80 LB	7	26	0200	ECT
SAMPLES TAKEN		7	26	1400	R mallin
CERTIFIED: YES	✓	7	29	0500	[illegible]
START USE	80	7	31	2200	[illegible]
	49	8	1	23:15	[illegible]
AMT IN TANK:	23	8	2	23:30	[illegible]
AMT IN TANK:	9	8	3	2359	[illegible]
AMT IN TANK:					
AMT IN TANK:					
END USE	8	8	3	0100	ECT
CERTIFIED: NO					
REPROCESSED					
EMPTY, READY FOR REFILL		8	3		ECT

pH	6.55	COLOR	1	HEAT: ___ YES ✓	NO ___
K	34	ODOR	FLAT	IODINE: ___ YES ___	NO ✓
TOC	9	TURBIDITY	3	SOURCE: VD-VF	
NH_3	3.1	TASTE	—	VIA TANK 1	
TPC	NEG	FOAMING	NONE	M/F	

Figure 2-45. Potable Water Tank Status Card

2. 2. 3 Subsystem Performance

The overall water balance is fully described in Section 2. 1. 2. A tabulated summary is shown in Table 2-25. It is significant that less than one-half of the reclaimed water was actually consumed by the crew. About one-fourth of the water was required to operate the solid amine unit and the remaining one-fourth was required for operation of the VD-VF unit, wash water makeup and samples.

The potable water daily inventory is shown in Figure 2-47. The initial storage of 127 kg (280 lb), not including the backup supply, dropped to a low of 64 kg (140 lb) on day 35 but gradually increased to 159 kg (350 lb) by the end of the run. The depletion was primarily due to supplying the wash water system with 39. 9 kg (88 lb) of phase-changed water from the holding tanks and 2 days without VD-VF unit or wick evaporator operation. The latter occurred when a VD-VF boiler failure during changeover delayed water recovery processing.

There were a total of 35 tanks of reclaimed water that were certified potable and three tanks that were rejected. One tank full was rejected because of objectionable odor and taste and two were rejected because of excessive NH_3 content (over 10 ppm). The potable water chemical analysis data are shown on Figure 2-48 and are detailed in Tables 2-26 and 2-18. A summary of the mean and maximum observed values of the physical and chemical properties are compared to the NAS/NRC standards in Table 2-27. All measured values were well below the standard limits, except for the three rejected tanks.

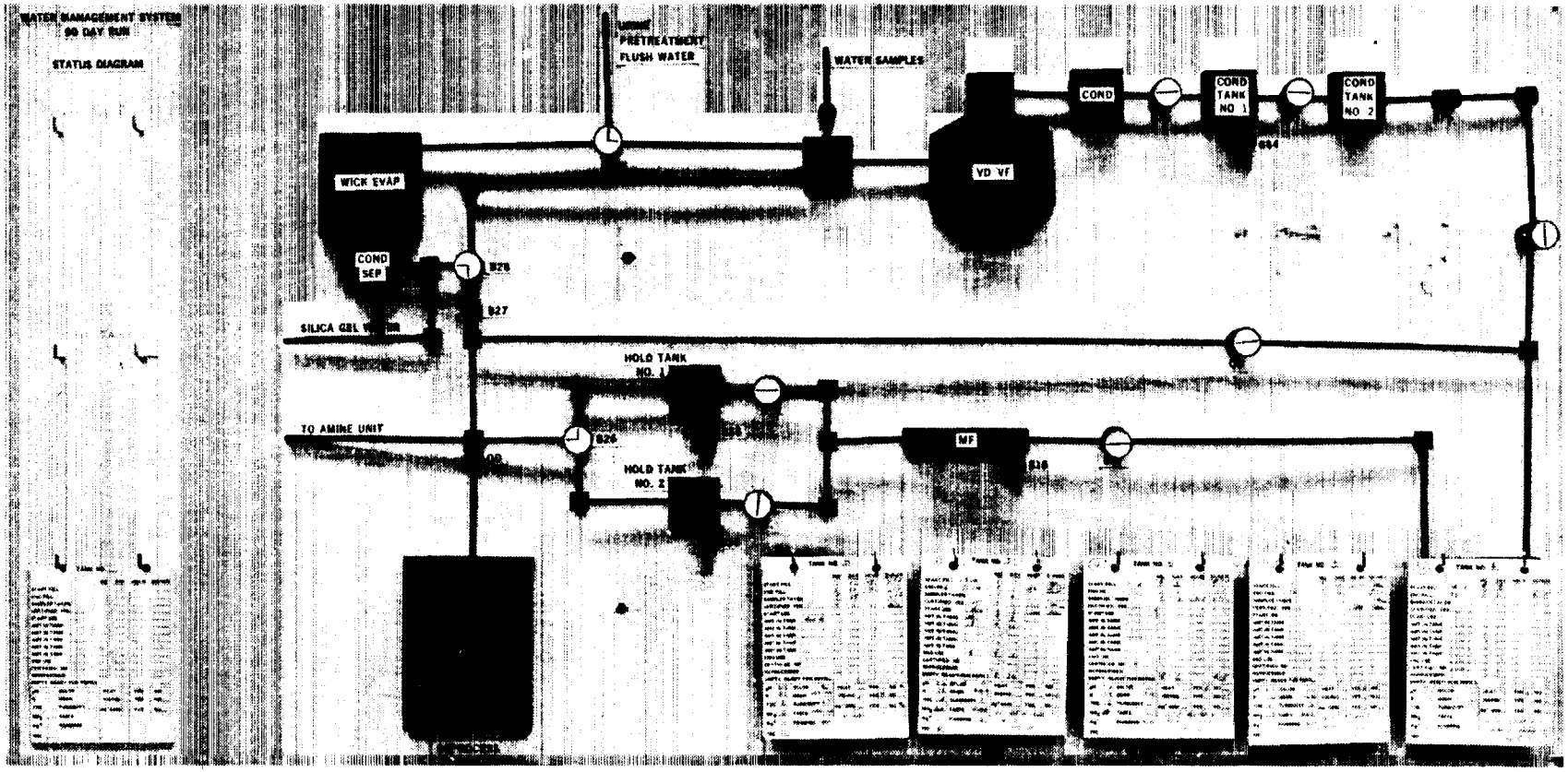


Figure 2-46. System Status Board

Table 2-25

POTABLE WATER SUBSYSTEMS SUMMARY
WATER BALANCE (4 MEN, 90 DAYS)

		kg (pounds)	kg (pounds)
Water Produced			
Humidity control			1, 215 (2, 676)
VD-VF			614 (1, 353)
Wick evaporator			308 (680)
Water Used			
Consumed by crew		928 (2, 045)	
Feed to solid amine		521 (1, 148)	
Feed to VD-VF		292 (644)	
Wash water makeup and phase change		270 (594)	
Samples, inventory gain, losses, etc.		126 (278)	
		2, 137 (4, 709)	2, 137 (4, 709)
Source of Water Consumed			
VD-VF		367 (809)	
Without post-filtration	204 (450)		
With post-filtration	163 (359)		
	367 (809)		
Wick evaporator		141 (310)	
Humidity condensate		420 (926)	
		928 (2, 045)	

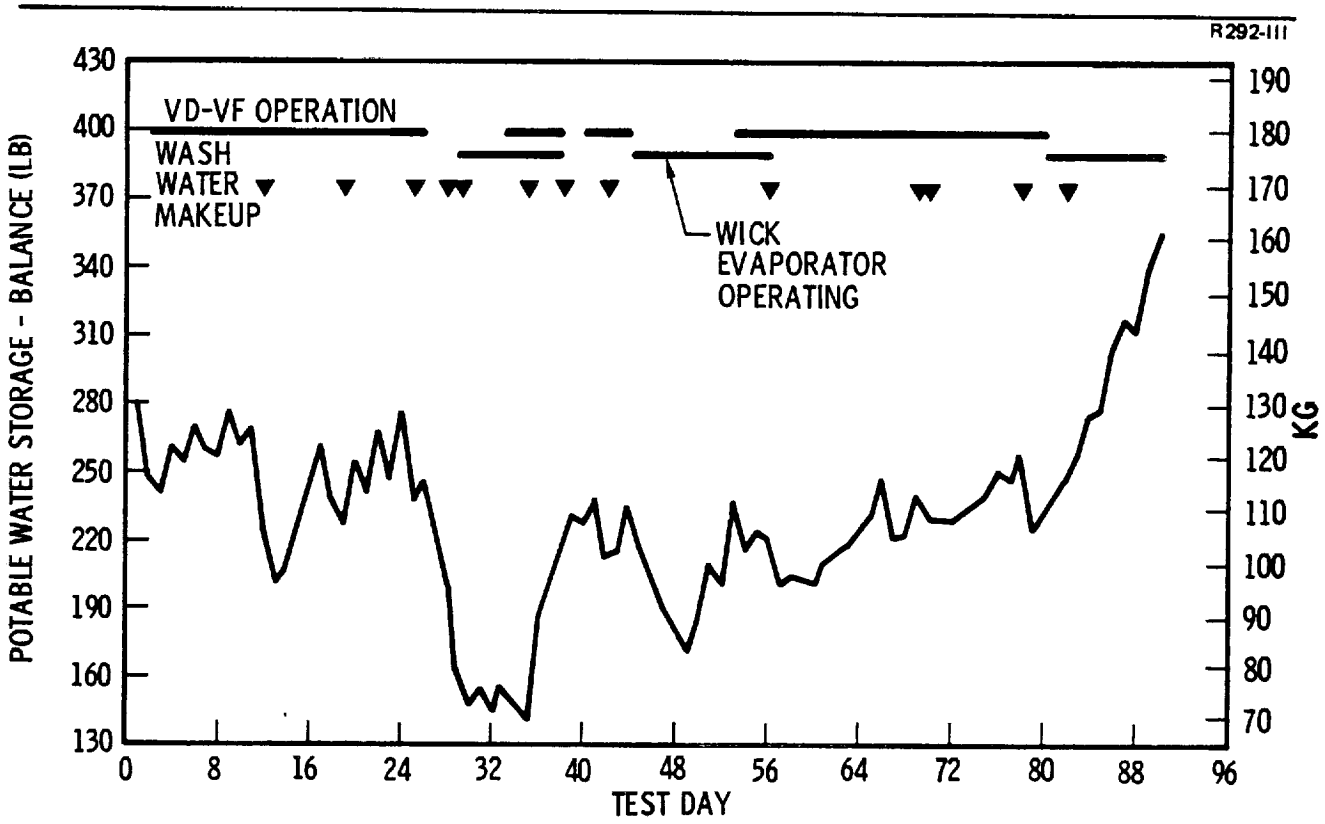


Figure 2-47. Potable Water Daily Inventory

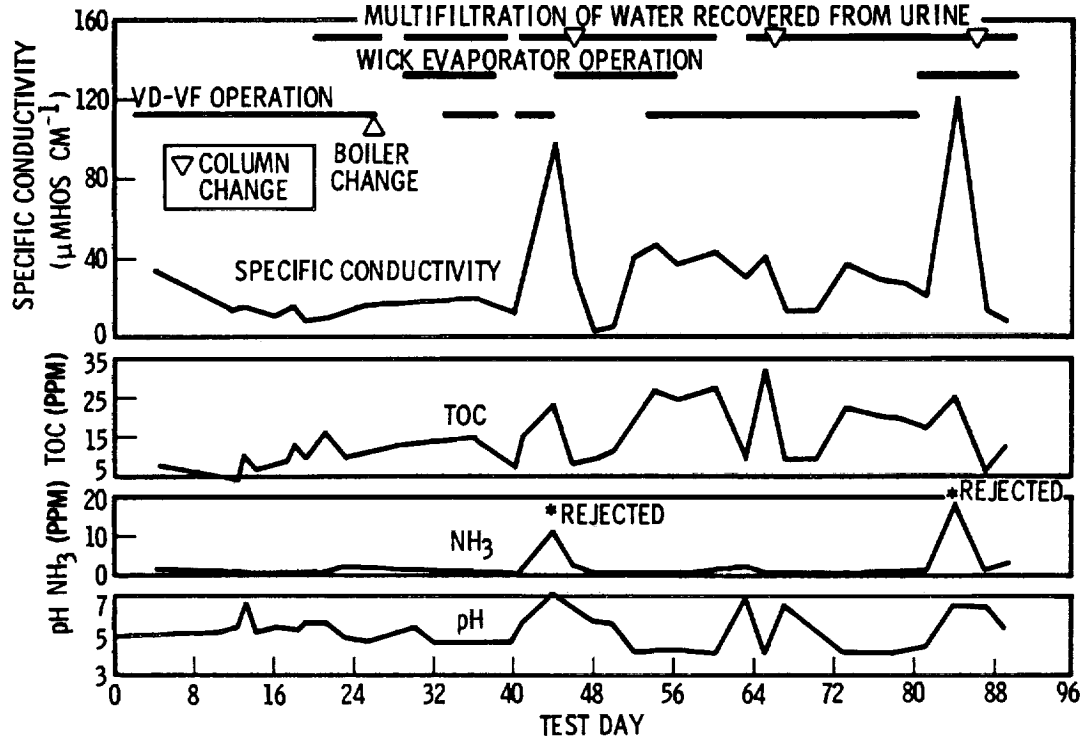


Figure 2-48. Reclaimed Potable Water Analysis

Table 2-26

POTABLE WATER CHEMICAL ANALYSIS

Date	Tank No.	Source	pH	Specific Conductivity (μmho-cm^{-1})	TOC (ppm)	NH_3 (ppm)	Color (Cobalt units)	Odor	Turbidity (Jackson units)	Taste	Foaming	Date Certified
			No std	No std	No std	1, pH>7 10, pH<7	15	None objectionable	10	None objectionable	None persistent >15 sec	
6-9-70	3	W. Evap + dist H_2O	6.1	2.5	7	0	0	Very slight	<5	Slight medicinal	0	6-11-70
6-9-70	4	VD-VF + dist H_2O	6.4	5.0	5	0	5	Bland	0	Medicinal	0	6-11-70
												6-13-70 Start test
6-16-70	6	VD-VF	5.1	38	7.7	1.4	1	Slight	0	Slight	0	6-18-70
6-18-70	5	VD-VF	4.9	18	5	0.6	0	Slight	0	Very slight	0	Retested
6-19-70	5	VD-VF										6-21-70
6-20-70	3	VD-VF	5.2	15	4	0.5	8	Slight	<5	Slight	0	6-24-70
6-22-70	6	VD-VF	5.2	16	5	0.6	2	Slight	4	Slight	0	6-24-70
6-22-70	4	H. Cond. -MF	6.7	16	11	1.0	1	Slight	0	Flat	0	6-25-70
6-25-70	5	VD-VF	5.4	14	3.5	0.6	2	Slight	3	Slight	0	6-27-70
6-27-70	3	VD-VF-MF	5.2	15	7	0.8	5	Slight medicinal	2	Medicinal	0	6-29-70
6-29-70	6	VD-VF-MF	5.5	11	9	1.0	4	Slight medicinal	4	Medicinal	0	7-1-70
6-30-70	4	VD-VF						Objectionable		Objectionable		Rejected
7-1-70	4	Process T4 through MF	5.3	16	14	1.1	-	-	2	Strongly medicinal	0	7-4-70
7-4-70	5	VD-VF-MF	5.7	10	17	1.4	3	Slight medicinal	3	Slight medicinal	0	7-6-70
7-5-70	3	VD-VF-MF	5.0	14	10	3.0	0	Slight	2	Slight medicinal	0	7-8-70
7-7-70	6	VD-VF-MF	4.8	17	12	2.9	1	Slight	0	Slight	0	7-11-70
7-11-70	5	W. Evap-MF	5.5	19	14	2.0	0	Slight	2	Slight	0	7-13-70
7-14-70	3	W. Evap-MF	4.7	19	15	2.1	-	Slight	0	Slight	0	7-16-70
7-15-70	6	W. Evap-MF	4.7	21	16	1.3	0	Slight	0	Flat	0	7-18-70
7-18-70	4	W. Evap + VD-VF-MF	4.9	18	12	0.5	0	Flat	0	Flat	0	7-22-70
7-22-70	5	VD-VF-MF	4.8	13	8	0.6	1	Flat	3	Flat	0	7-24-70
7-23-70	6	VD-VF-MF	5.9	37	16	3.0	2	Flat	3	Flat	0	7-27-70
7-26-70	3	VD-VF-MF	7.3	101	24	12.4	2	Flat	3	Flat	0	Rejected

Table 2-26 (Cont)

POTABLE WATER CHEMICAL ANALYSIS

Date	Tank No.	Source	pH	Specific Conductivity ($\mu mho\text{-}cm^{-1}$)	TOC (ppm)	NH_3 (ppm)	Color (Cobalt units)	Odor	Turbidity (Jackson units)	Taste	Foaming	Date Certified
			No std	No std	No std	1, pH>7 10, pH<7	15	None objectionable	10	None objectionable	None persistent >15 sec	
7-28-70	3	Recycle T3 through MF	6.6	34	9	3.1	1	Flat	3	-	0	7-29-70
7-30-70	4	W. Evap-MF	5.9	4.5	10	1.0	2	Flat	3	Flat	0	8-1-70
8-1-70	5	W. Evap-MF	5.7	7.5	12	1.0	2	Slight	4	Slight	0	8-4-70
8-3-70	6	W. Evap-MF	4.3	42	21	1.2	0	Flat	0	Flat	0	8-5-70
8-5-70	3	W. Evap-MF	4.3	48	27	1.4	0	Flat	0	Flat	0	8-8-70
8-7-70	4	W. Evap-MF	4.4	38	25	1.0	2	Slight	4	-	0	8-10-70
8-10-70	5	VD-VF-MF	4.2	44	28	1.8	0	Slight	2	Slight	0	8-12-70
8-13-70	6	VD-VF	7.0	31	9	2.8	0	Bland	2	Bland	0	8-17-70
8-16-70	3	VD-VF-MF	4.2	42	33	1.0	0	Bland	0	Bland	0	8-20-70
8-18-70	4	VD-VF-MF	6.7	15	10	1.3	0	Bland	3	Bland	0	8-20-70
8-20-70	5	VD-VF-MF	5.5	15	10	1.2	1	Bland	2	Bland	0	8-24-70
8-24-70	6	VD-VF-MF	4.3	38	23	1.4	-	Bland	2	Bland	0	8-27-70
8-27-70	3	VD-VF-MF	4.3	32	21	2.2	2	Bland	4	Bland	0	8-30-70
8-30-70	4	VD-VF-MF	4.3	29	20	1.7	0	None	2	Bland	0	9-2-70
9-1-70	5	VD-VF-MF	4.6	22	18	2.2	0	Bland	2	Bland	0	9-5-70
9-4-70	6	W. Evap-MF	6.7	124	26	19.0	1	Bland	3	-	0	Rejected
9-6-70	3	W. Evap-MF	6.5	15	7	2.5	1	Bland	3	Bland	0	9-9-70
9-9-70	4	W. Evap-MF	5.4	9	13	4.0	0	Bland	2	Bland	0	9-11-70 End test
9-24-70	3	W. Evap-MF	6.5	20	9	0.04	1	Bland	0	-	0	
9-24-70	4	W. Evap-MF	5.1	15	24	0.04	1	Bland	0	-	0	
9-24-70	5	VD-VF-MF	5.2	10	19	0.12	1	Bland	0	-	0	
9-24-70	6	W. Evap-MF	6.6	100	27	0.04	1	Bland	0	-	0	

KEY: TOC = Total organic carbon
MF = Multifiltered

Table 2-27

SUMMARY OF POTABLE WATER ANALYSIS

	Mean Observed Value	Maximum Observed Value	Standard Value
Turbidity (Jackson units)	1.9	<5	<10
Color (Plat.—Cobalt units)	1.3	8	<15
Taste	Slight	Objectionable	None objectionable
Odor	Slight	Objectionable	None objectionable
Foaming	None	None	None persistent more than 15 sec
Chemical Standards (ppm)			
Arsenic	0.022	0.03	0.5
Barium	0.044	<0.009	2.0
Boron	0.45	<1.5	5.0
Cadmium	0.003	0.009	0.05
Chloride	0.07	0.41	450.0
Chromium (Cr^{+6})	0.004	0.01	0.05
COD	N. T. +	N. T.	100.0
Copper	0.016	0.031	3.0
Fluoride	N. T.	N. T.	2.0
Lead	0.007	0.01	0.2
Nitrate and nitrite (as nitrogen)	0.21	1.00	10.0
Selenium	<0.11*	<0.3*	0.05
Silver	0.005	0.011	0.5
Sulfate	N. T.	N. T.	250.0
Total solids	5.5	28.0	1000.0
Ammonia	2.1	19.0	10.0
pH	5.4	4.2 to 7.5	N. E.Δ
Specific Conductivity ($\mu mho\text{-}cm^{-1}$)	28.4	124	
TOC (ppm)	14.9	33	

\+ Not tested (see text)
Δ No established limit
* Lowest detectable limit with sample size provided (see text)

The tests for fluoride and sulfate were omitted because of the extremely low levels found during qualification testing (see Table 2-18). The level of selenium was also found below the standard of 0.05 ppm during qualification testing. During the 90-day test there was insufficient sample available to determine selenium to this low a level. A minimum of 3 liters of water is required to provide selenium sensitivity below 0.05 ppm.

The microbiological results are shown in Table 2-28. Positive counts were observed on only two occasions in the potable storage tanks. These were counts of 0.6 organisms/ml on day 60 and 0.1 organisms/ml on day 66. The earlier high counts on days 6 and 8 were determined as incorrect sampling technique. Since storage tank was connected to its sample point with plumbing lines at ambient temperature, it was found necessary to flush each line with 100 to 200 ml before drawing the sample for microbial analysis. No further problems were encountered after this technique was instituted.

2.2.3.1 VD-VF Unit

Two VD-VF boiler units were used during the test for a total of 63 days of operation. The first boiler was used for 25 days and the second boiler was used for 38 days, of which only the last 27 days were continuous operation. A total of 666 kg (1,467 lb) of urine and humidity condensate were fed to the units, which produced 615 kg (1,353 lb) of water for a water recovery efficiency of 94.3 percent. The net usable product was reduced to 594 kg (1,309 lb) because of sampling requirements and some substandard water that was rejected and reprocessed. Of this, 236 kg (518 lb) were used without multifiltration and 360 kg (791 lb) required multifiltration due to either poor taste or microbiological contamination.

The mass and energy balance and the expendable requirements for VD-VF boiler 1 are shown in Table 2-29. The requirements for VD-VF boiler 2 are shown in Table 2-30. Water quality and boiler temperature profiles are shown in Figure 2-49 and chemical analysis in Table 2-31.

Boiler 1 operated normally for approximately 17 days. The water produced met all chemical and bacteriological requirements for potability until test day 15, when the water suddenly had an objectionable odor and taste. Figure 2-49 shows all measured chemical parameters to be acceptable at this time. However, the TOC level began to increase significantly on day 13. It appears that the catalyst had ceased to function at this point. This boiler and catalyst had been used prior to the 90-day test for system checkout and certification. Thus, this boiler had 25 operating days with urine feed prior to the 90-day test. It may be concluded from these data that the catalyst life is approximately 40 days. Operation with this boiler was continued using multifiltration of the product to meet potability standards for consumption. Additional problems with boiler 1 appeared on test day 21. It appeared that the float switch controlling the feed to the boiler was sticking, thus allowing the liquid level to fall and significantly increase the solids concentration. This is indicated in the temperature excursions shown for days 21 through 26 in Figure 2-49. The effect of the temperature instability is evident in all the parameters shown in Figure 2-49. It is significant to note that all water produced by the first boiler was sterile.

Table 2-28

WATER MANAGEMENT SUBSYSTEM MICROBIOLOGICAL DATA
Millipore Field Monitors, No. of Organisms per ml

Test Day	Date	T1	T2	T3	T4	T5	T6	VD-VF Cond Tank	MDAC Dispenser	Apollo Dispenser (Hot)	Apollo Dispenser (Cold)	T7	T8	Wash Dispenser (Hot)	Wash Dispenser (Cold)	Viruses Apollo Dispenser (Hot)
3	6-15-70	O						O	TNTC*	O	TNTC*					
4	6-16-70						O	O								
5	6-17-70							O								
6	6-18-70	210**				TNTC**		O								
7	6-19-70	7**				O		O								
8	6-20-70		3.5**	TNTC**	TNTC**			O		O		TNTC**	TNTC**			
9	6-21-70							O								
10	6-22-70			O	O		O	O								
11	6-23-70							4.2								O
12	6-24-70					O	O	O								
13	6-25-70							O								
14	6-26-70			O		O		O	170	O						
15	6-27-70							0.1								
16	6-28-70			O			O	O								
17	6-29-70						O	O				0.1	O			
18	6-30-70				O		O	0.4								
19	7-1-70				O			O								
20	7-2-70				O			O								
21	7-3-70					O		O								
22	7-4-70					O		O		O						
23	7-5-70			O				O								
24	7-6-70			O				O								
25	7-7-70							0.4		O						O
26	7-8-70						O	O								
28	7-10-70						O			O						
29	7-11-70					O										
31	7-13-70					O										
32	7-14-70			O		O										
34	7-16-70						O	0.2								
35	7-17-70							0.3								
36	7-18-70				O		O	9.6								
37	7-19-70							TNTC								
38	7-20-70				O			TNTC								
39	7-21-70							TNTC								O
40	7-22-70					O										
41	7-23-70						O	7.6								
42	7-24-70					O	O	300		O						
43	7-25-70							100								
44	7-26-70			O			O	25								
45	7-27-70													O	O	
47	7-29-70			O												

* Too numerous to count
** Incorrect sampling technique (see text)

Table 2-28 (Cont)

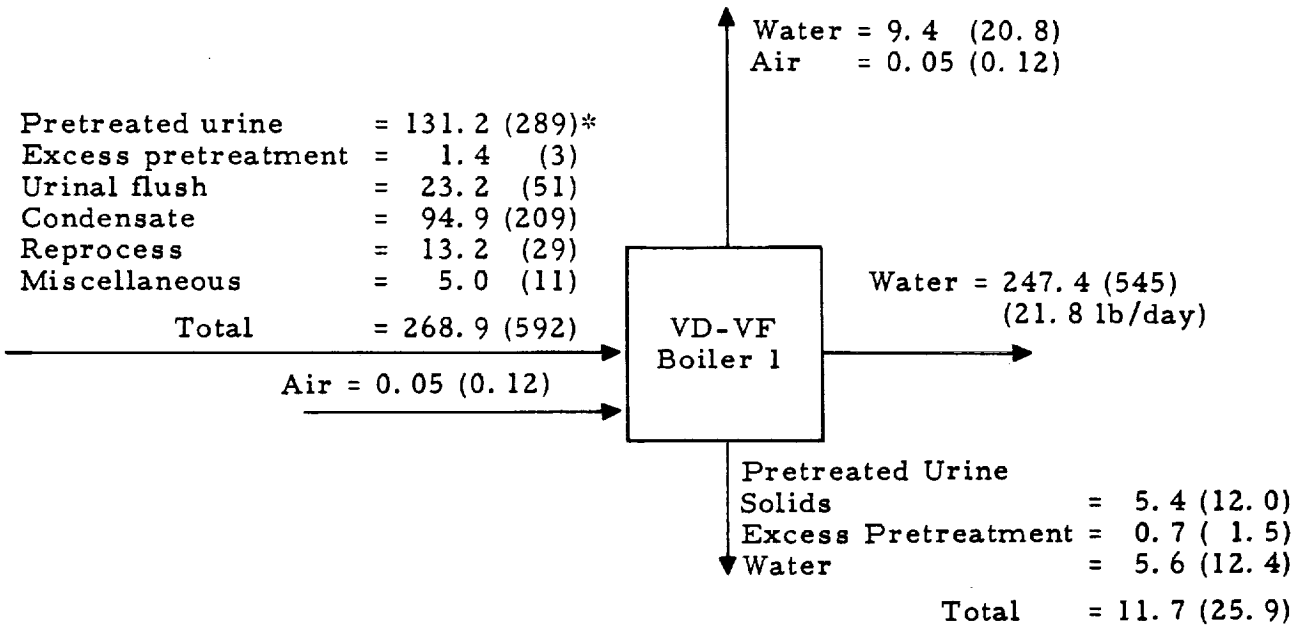
WATER MANAGEMENT SUBSYSTEM MICROBIOLOGICAL DATA
Millipore Field Monitors, No. of Organisms per ml

Test Day	Date	T1	T2	T3	T4	T5	T6	VD-VF Cond Tank	MDAC Dispenser	Apollo Dispenser (Hot)	Apollo Dispenser (Cold)	T7	T8	Wash Dispenser (Hot)	Wash Dispenser (Cold)	Viruses Apollo Dispenser (Hot)
48	7-30-70				O											
50	8-1-70				O	O				O						
52	8-3-70					O	O									
53	8-4-70							10.7								O
54	8-5-70			O				0.1								
55	8-6-70							O								
56	8-7-70			O	O			O		O						
57	8-8-70							O								
58	8-9-70				O			O								
59	8-10-70					O		2.6								
60	8-11-70					O	0.6	O		0.1				O		
61	8-12-70							O								
62	8-13-70							0.3								
63	8-14-70						O	O								
64	8-15-70			O				37		O						
65	8-16-70							TNTC								
66	8-17-70			0.1				TNTC								
67	8-18-70				O			12.6						0.2	0.6	O
68	8-19-70				O			43								
69	8-20-70							TNTC								
70	8-21-70					O		TNTC		O						
71	8-22-70							TNTC								
72	8-23-70					O		TNTC								
73	8-24-70						O	TNTC								
74	8-25-70						O	490						O	0.3	
75	8-26-70							TNTC								
76	8-27-70			O				TNTC								
77	8-28-70							TNTC								
78	8-29-70			O				TNTC		O						
79	8-30-70				O			TNTC								
80	8-31-70				O			O								
81	9-1-70													O	O	O
82	9-2-70					O										
83	9-3-70					O										
84	9-4-70						O									
85	9-5-70						O			O						
86	9-6-70			O												
87	9-7-70			O												
88	9-8-70													O	O	
89	9-9-70				O											

Table 2-29

VD-VF BOILER 1 MASS AND ENERGY BALANCE

25 days of operation
17 days without multifiltration
8 days with multifiltration



Overall water recovery efficiency $\left(\frac{\text{Water out}}{\text{Water in}}\right)$ = 94.3%

Expendables:

Pretreatment solution	=	1.00 (2.2)
Boiler	=	24.70 (54.4)
Catalyst	=	1.82 (4.0)
MF Carbon	=	0.05 (0.11)
MF Resin	=	0.05 (0.11)
Antifoam	=	0.02 (0.055)
Air bleed	=	0.05 (0.121)
Total	=	27.69 (60.996)

Isotope heat:

Boiler = 268.6 joules/sec (916.8 Btu/hr)
Catalyst = 75.6 joules/sec (257.9 Btu/hr)

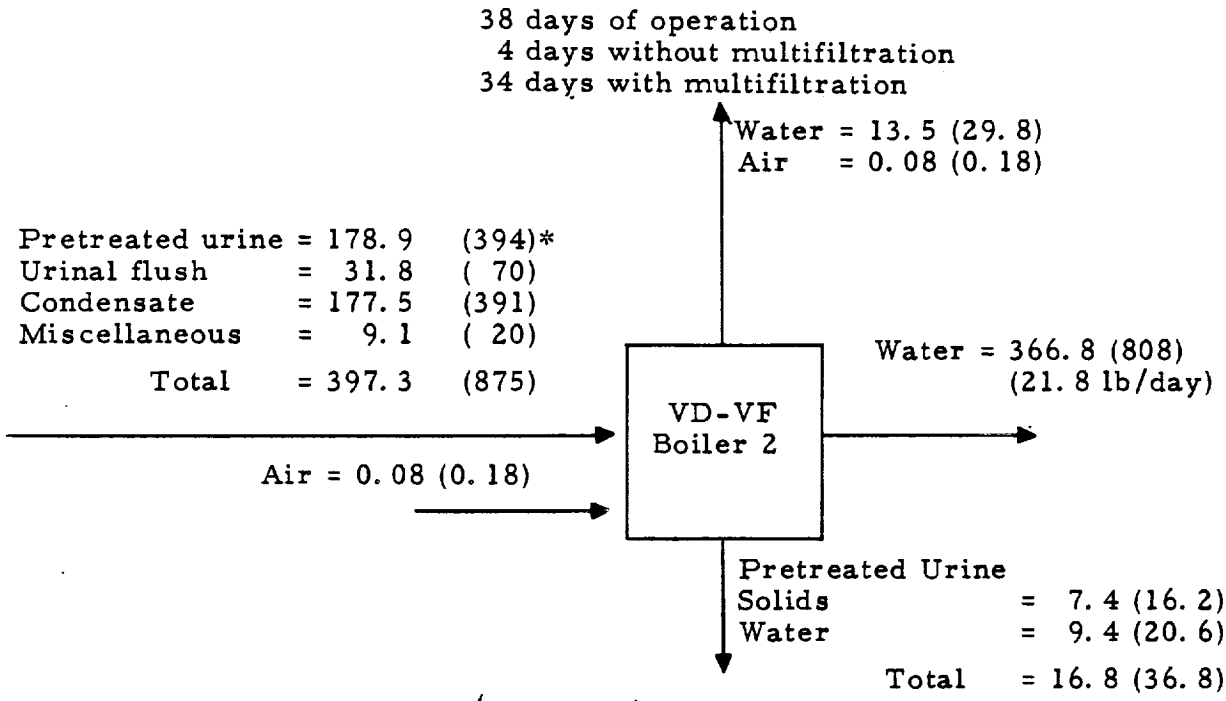
Condenser cooling (average) = 362.7 joules/sec (1,238 Btu/hr)

Pumping power (average) = 9 watts

*All weights in kg (lb)

Table 2-30

VD-VF BOILER 2 MASS AND ENERGY BALANCE



Overall recovery efficiency $\left(\frac{\text{Water out}}{\text{Water in}}\right)$ = 94.1%

Expendables:

Pretreatment solution	= 1.36	(3.0)
Boiler	= 26.11	(57.5)
Catalyst	= 1.82	(4.0)
MF Carbon	= 0.21	(0.47)
MF Resin	= 0.21	(0.47)
Antifoam	= 0.04	(0.084)
Air Bleed	= 0.08	(0.184)
Total	= 29.83	(65.708)

Isotope heat:

Boiler = 294.3 joules/sec (1,004.6 Btu/hr)
Catalyst = 47.8 joules/sec (163.2 Btu/hr)

Condenser cooling (average) = 362.7 joules/sec (1,238 Btu/hr)

Pumping power (average) = 9 watts

*All weights in kg (lb)

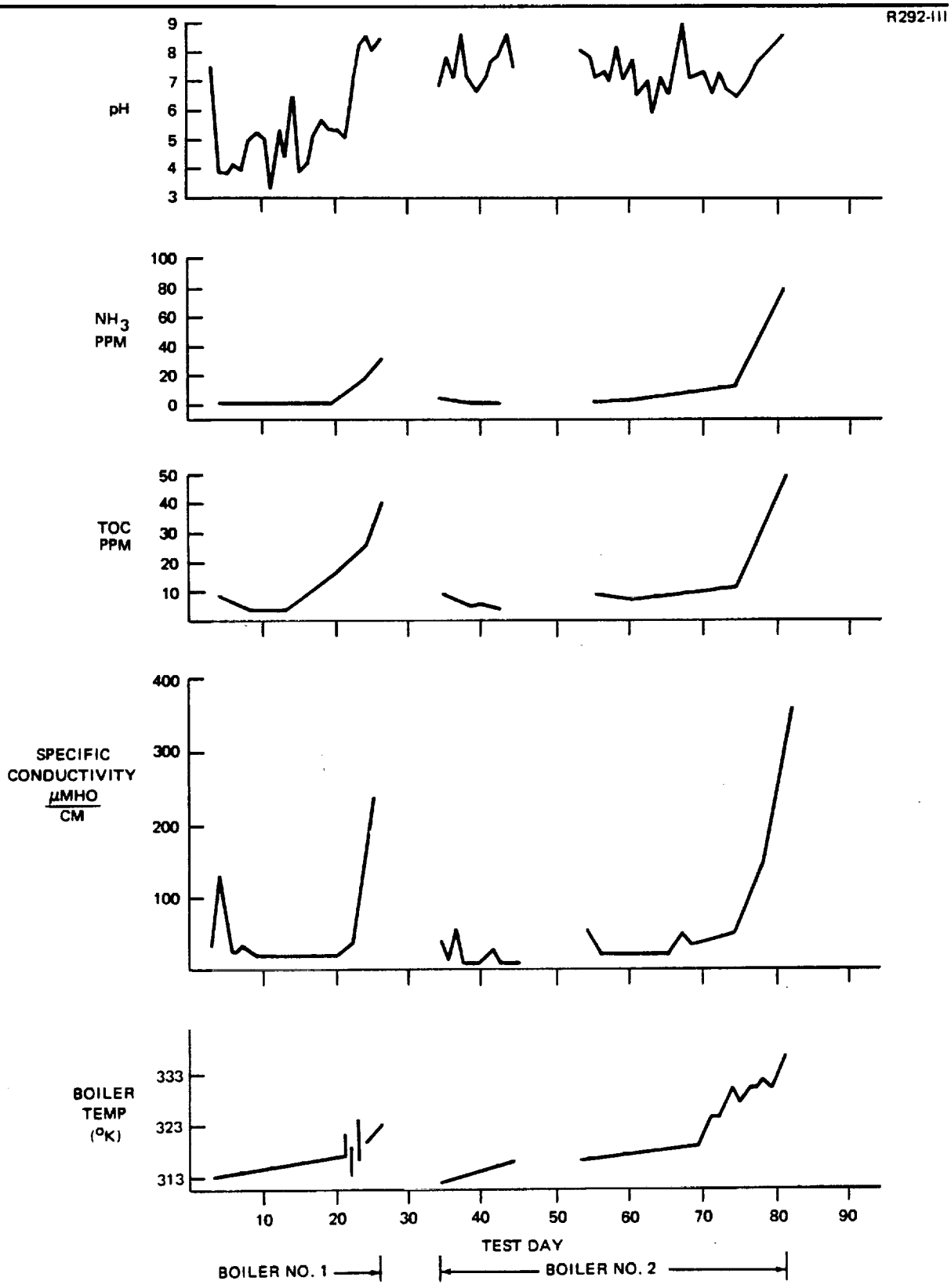


Figure 2-49. VD-VF Product Water Analyses and Boiler Temperature at Condenser

Table 2-31

VD-VF CONDENSATE CHEMICAL ANALYSIS

Date	Day	Turbidity, Jackson Units	Color, Cobalt Units	pH	Specific Conductivity (μmho/cm)	NH_3 (ppm)	TOC (ppm)	Br (ppm)	Cr^{+6} (ppm)	
7-1	19	4	3	5.3	18	1.24	14	0	0	Boiler 1
7-6	24	2	3	8.5	150	20	26	0	Off color	
7-8	26	N. T. *	N. T.	8.4	270	32	40	N. T.	N. T.	
7-16	34	15	Cloudy	6.8	39	5	8	.04	.02	Boiler 2
7-20	38	2	2	7.0	8	0.7	5	0	0	
7-21	39	2	2	7.0	6.6	0.48	7	0	0	
7-24	42	2	1	6.8	13	1.42	3	0	0	
8-6	55	2	N. T.	7.3	31	4	8	0	0	
8-11	60	2	0	6.8	23	3.6	7	0	0	
8-26	74	2	0	7.3	53	7.6	12	0	0	
9-1	81	2	0	8.6	370	80	49	0	0	

*Not tested

Boiler2 was installed on test day 28. During the filling sequence, it was observed that the float switch was not operating properly. The boiler was drained and disassembled, revealing that the float had come off its shaft. This was corrected and the boiler reassembled. During the next fill sequence, a short circuit occurred in the float switch wires. This was caused by insulation chafing at the feedthrough. This was corrected and the fill sequence continued. It appeared that the system was functioning normally; however, the feed solenoid valve did not close at the proper time and the boiler was flooded, causing urine to penetrate the membrane and contaminate the catalyst. The boiler was disassembled, and the catalyst rinsed with successive aliquots of potable water until stable specific conductivity readings of the rinse water showed the catalyst to be clean. This malfunction was thought to be caused by an error in reconnecting the level control circuits. After reassembly, a fill sequence was restarted; however, flooding occurred again. It was subsequently determined that the previous short circuit had fused the contacts in the float switch. The boiler was again disassembled, the float switch replaced with a spare, the catalyst washed, and the system reassembled. The subsequent filling and startup procedures went smoothly and the system operated normally for 5 days. At this time it was determined that the product water was contaminated with bacteria. The system was shut down, and the condenser and collecting tanks were steam-sterilized at cabin pressure. After restart, the system operated normally for 5 more days. During the last restart sequence, the humidity condensate diverter switch which automatically maintained a minimum volume in the urine accumulator was inadvertently left in the manual mode. On the sixth day, the urine accumulator ran dry, allowing cabin air to be pulled into the boiler at a high rate which blew urine up into the catalyst. The boiler was again disassembled, cleaned, and restarted. The system then operated satisfactorily, with the exception of temporary shutdowns for attempts at sterilizing the system, for 28 days. The product water was pasteurized and multifiltered due to continuous bacteria contamination, although the majority of the product water met the chemical standards. Figure 2-49 shows the deterioration of the water quality as the boiler temperature increased. This was due in part to boiling-point rise caused by the increasing solids concentration in the liquid. However, a direct measurement of the pressure drop across the membrane toward the end of the boiler life showed approximately 3.9 kN/m^2 (30 mm Hg) thus causing a relatively high evaporation pressure. The flooding failures, which forced urine through the membrane, probably caused clogging thus increasing the pressure drop. Figure 2-50 shows boiler 2 prior to disassembly and in Figures 2-51 and 2-52 after disassembly.

Examination of the corrugated membrane, shown in Figure 2-53, revealed the folds to be filled with solids, thus confirming the increasing pressure drop theory. The expended catalyst bed is shown in Figure 2-54.

2.2.3.2 Wick Evaporator and Humidity Control Unit

The wick evaporator operated a total of 31 days as a backup to the VD-VF unit. The humidity control portion of the unit operated for the entire 90-day test.

The wick evaporator was fed 318 kg (700 lb) of pretreated urine, flush water and miscellaneous input, and produced 309 kg (680 lb) of water for a recovery



Figure 2-50. VD-VF Boiler 2 Prior to Disassembly

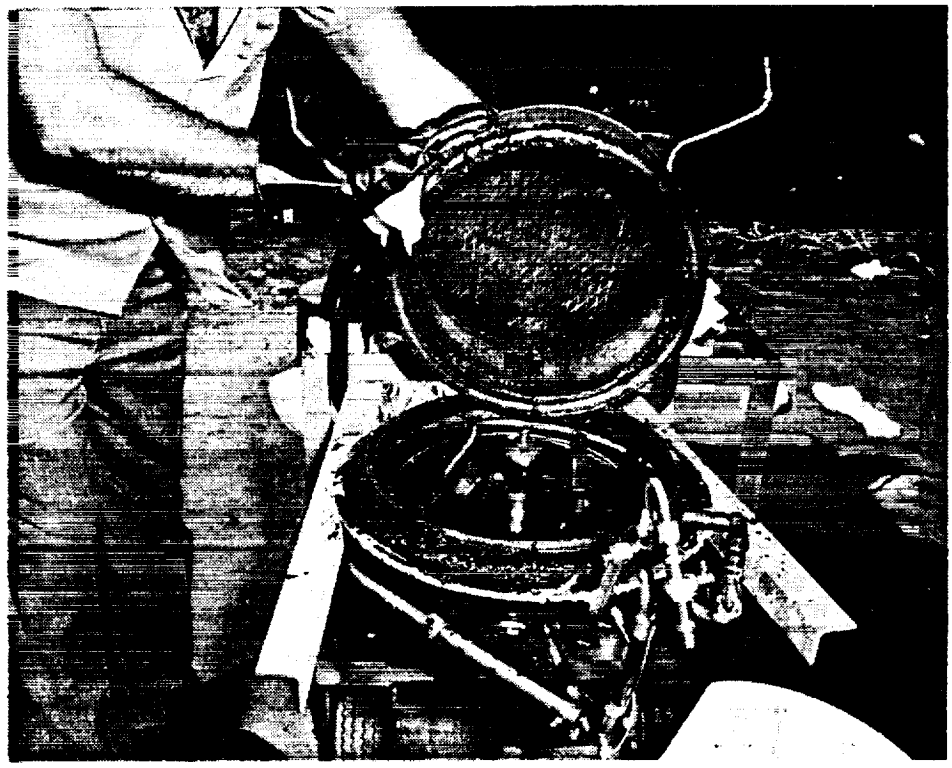


Figure 2-51. VD-VF Boiler 2 After Disassembly

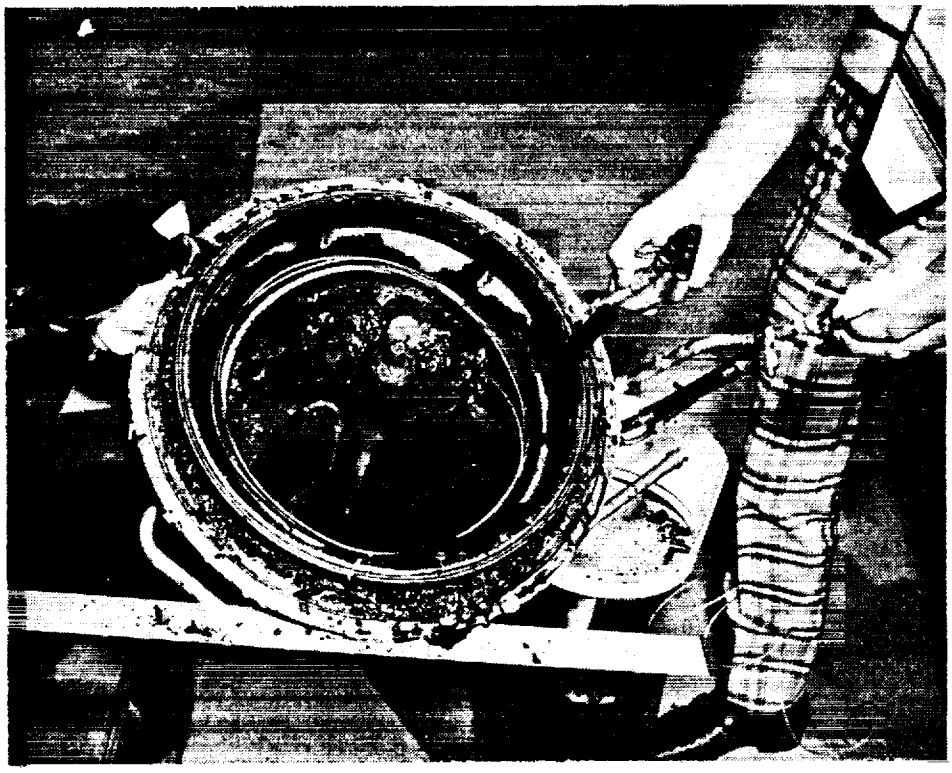


Figure 2-52. VD-VF Boiler 2 Interior View

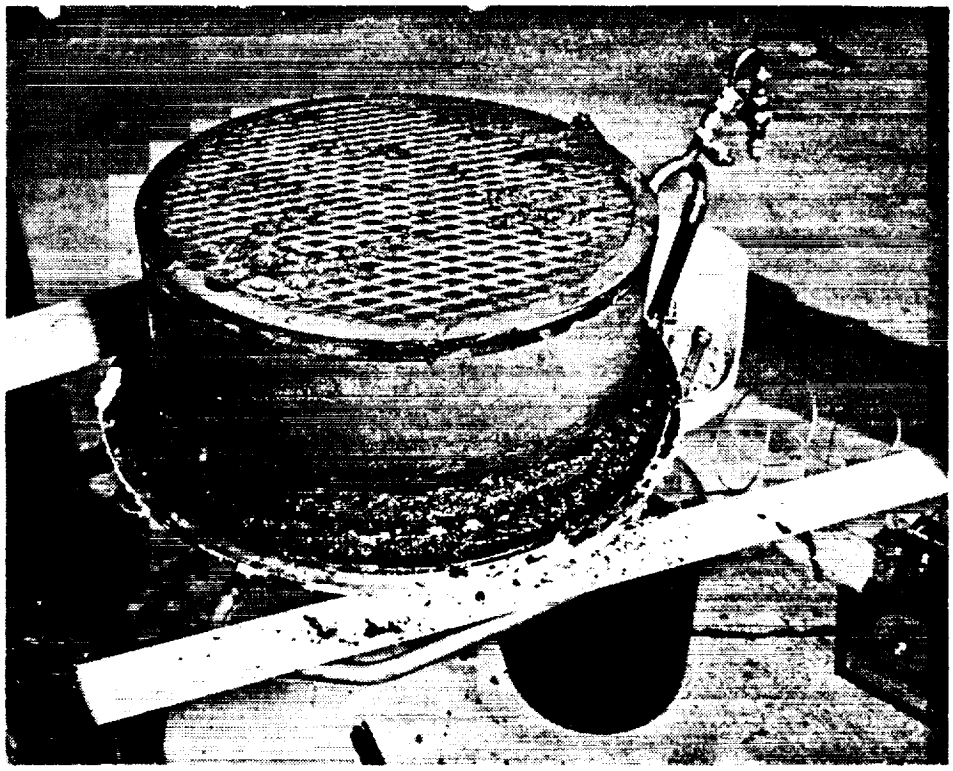


Figure 2-53. VD-VF Membrane Filter

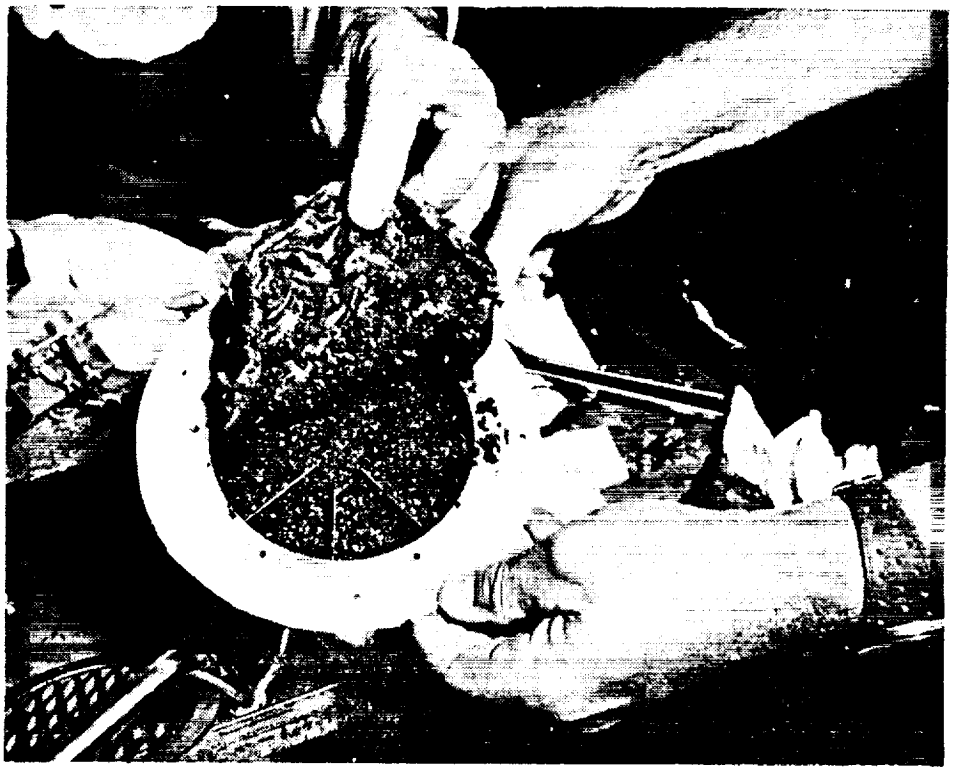


Figure 2-54. VD-VF Expended Catalyst

efficiency of 100 percent. A mass and energy balance and the expendable requirements are shown in Table 2-32. Five wick packages were used and a summary of their performance is shown in Table 2-33.

Premature flooding occurred in the first two wicks. The flooding was caused by a combination of (1) a higher feed rate than normal, and (2) unusually high humidity in the inlet air to the wick evaporator caused by the solid amine CO_2 removal unit. The high feed rate, which was more than double that required to process the daily urine production, was used in an attempt to deplete the accumulation of urine created during VD-VF unit shutdown.

The planned method of urine feeding was to pump directly from the urinal to the wick package after each micturition. This was not possible because of the urine phase separator failure, so the urine transfer pump was connected to the urine accumulator outlet. This required manual pump operation and batch process feeding during the use of wick 1 and 2 and part of wick 3. A 90-minute cam timer was found by the crew in the spare parts inventory (for the electrolysis unit) and installed in the pump circuit on day 50. Automatic batch feeding was used for the remaining wick evaporator operation. Figure 2-55 shows one of the used wick packages disassembled after the 90-day test.

The 11-kg (24-lb) air carbon canister satisfactorily removed all urine odors during the entire 90 days and was not considered expended at the end of the test. The zero-g condenser/separator removed 1, 440 kg [3, 172 lb (35. 2 lb/day)] of humidity condensate and wick evaporator produced water. There were 239 kg (525 lb) of this total that overflowed the separator and were processed from an overflow catch basin, which results in a water separation efficiency of 83. 5 percent. This efficiency is excellent considering the separator was handling more than 200 percent of its design capacity. The hydrophilic screen sumps (three installed in unit) required frequent removal and cleaning to minimize the amount of overflow. The frequency of cleaning varied, but averaged about every 3 days. Visual observation of the removed sumps did not reveal the cause of clogging.

The alternate method of separator water removal, using the system supplied with the unit, as described in CR111882, was required when the negative pressure cylinder spring failed on day 83. This method operated satisfactorily the remainder of the test.

The relative humidity and dew point temperatures during the test are reported in Section 2. 3. 3.

2. 2. 3. 3 Detoxification-Multifultration Unit

The detoxification-multifiltration unit processed 835 kg (1, 839 lb) of reclaimed water and humidity condensate. The contributions to this total were 188 kg (414 lb) from the VD-VF unit, 162 kg (358 lb) from the wick evaporator, and 484 kg (1, 067 lb) of humidity condensate. A performance summary of this unit is shown in Table 2-34.

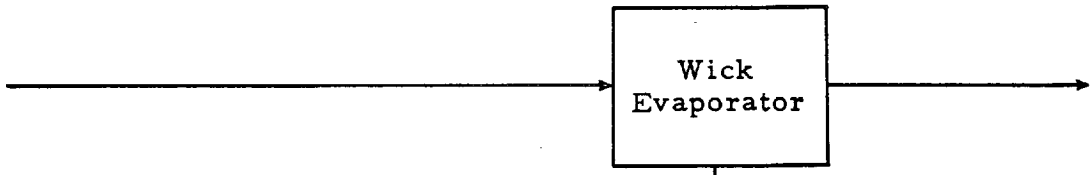
The chemical analysis results performed on the input of this unit are shown in Table 2-35. In general, the specific conductivity, TOC, and NH_3 levels in the holding tanks gradually increased over the period of the test.

Table 2-32

WICK EVAPORATOR MASS AND ENERGY BALANCE
31 DAYS OF OPERATION

Pretreated urine	=	219.3	(483)*
Urinal flush	=	39.0	(86)
Condensate	=	8.6	(19)
Reprocess from VD-VF	=	19.5	(43)
Miscellaneous	=	31.3	(69)
Total	=	317.7	(700)

Water = 308.7 (680)
(21.9 lb/day)



Pretreated urine solids	=	9.1	(20.0)
Water	=	0	(0.0)
Total	=	9.1	(20.0)

Overall Recovery Efficiency $\left(\frac{\text{Water out}}{\text{Water In}}\right)$ = 100%

Expendables:

Pretreatment solution	=	1.68	(3.7)
Wicks	=	7.72	(17.0)
MF Carbon	=	0.20	(0.44)
MF Resin	=	0.20	(0.44)
Air carbon (24 lb) installed Not expended	=	- - -	
Total	=	9.80	(21.58)

Heat (average) = 101.7 joules/sec (347 Btu/hr)

Condenser cooling (average) = 105.5 joules/sec (360 Btu/hr)

Blower power = 307 watts (includes humidity control)

Pumping power (average) = 0.7 watts

*All weights in kg (lb)

Table 2-33

WICK PERFORMANCE SUMMARY

Wick No.	Test Day	Operating Hours	Urine Processed (liters)
1	29 to 31	43.5	19.5
2	31 to 37 49 to 51	171.5	88.7
3	45 to 49	117.0	71.9
4	52 to 57	113.0	49.2
5	81 to 90	213.5	81.7
	Total	658.5	311.0

The carbon and resin columns were changed three times during the test on days 46, 66, and 86 (see Figure 2-48). The columns were packaged as a unit for ease of replacement, so each change contained a complete new charge of materials. Each unit contained 0.2 kg (0.4 lb) of activated carbon (0.1 kg in each column), 0.1 kg (0.2 lb) of mixed resin, and 0.1 kg (0.2 lb) of cation resin. This totaled 0.5 kg (1.2 lb) of carbon and 0.5 kg (1.2 lb) of resin expended. The first and last changes were made because of high NH_3 levels and the second change was made because of rapidly increasing TOC. Each change lowered the levels to satisfactory values.

2.2.3.4 Potable Water Storage and Distribution Unit

This unit operated satisfactorily for the entire test with the exception of the cold water supply ports in the dispensing unit, which became bacterially contaminated and were not used after test day 3 (see Table 2-28).

The heated zero-g bladder storage tanks required two minor adjustments: (1) occasional venting of trapped gases, and (2) adjustments of temperature control settings during nearly empty conditions. At the conclusion of the test, very small amounts of water were found on the gas pressurized side of seven of eight bladders. The exception was tank 5 which contained 2.4 liters. The leakage path in this tank was probably through the bolt holes in the bladder at the bolted flange connection.

2.2.3.5 Backup Potable Water Supply

The backup potable water supply was not required during the test. Weekly checks of the iodine content were made and the result of these analyses and a few microbiological checks are shown in Table 2-36.

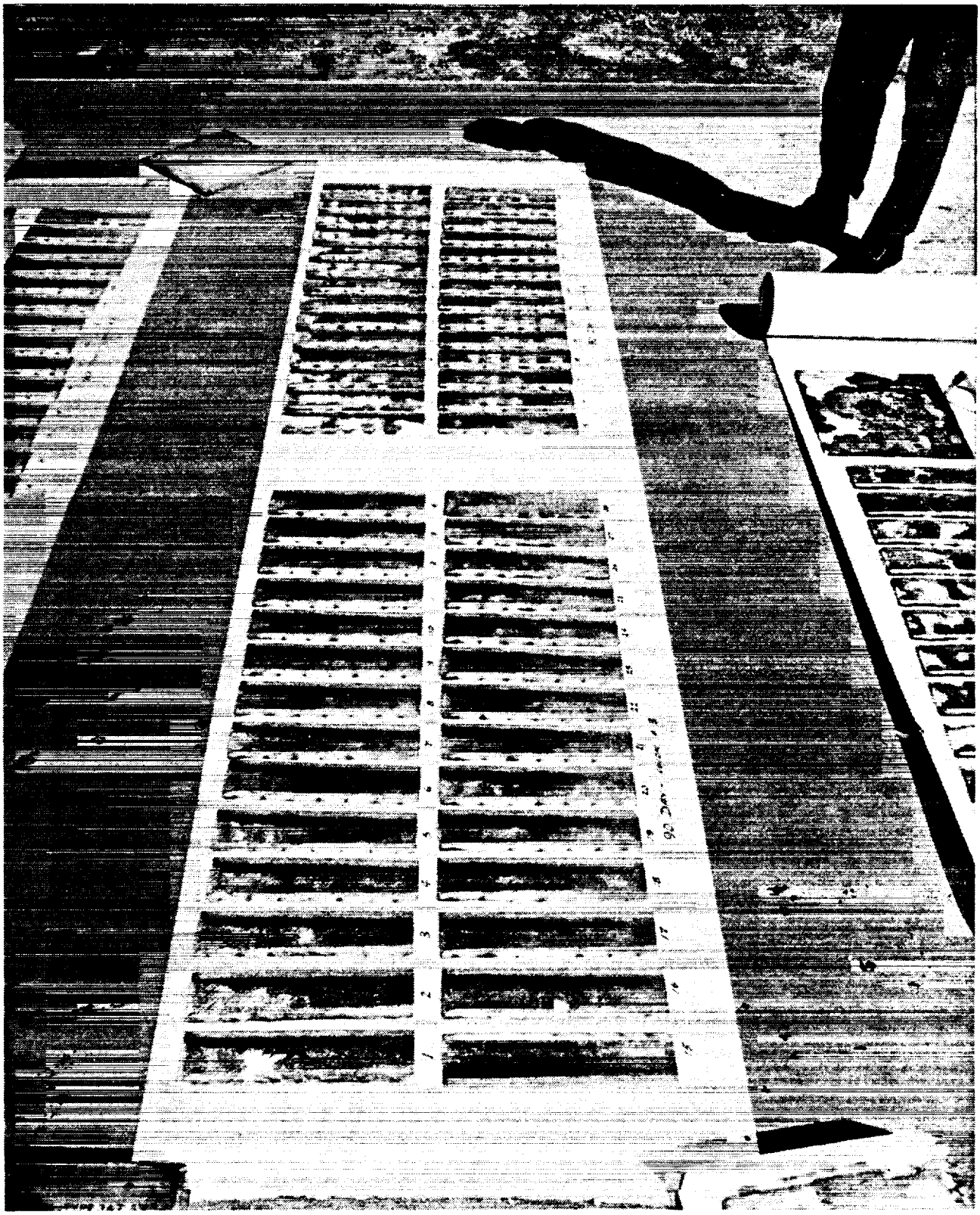


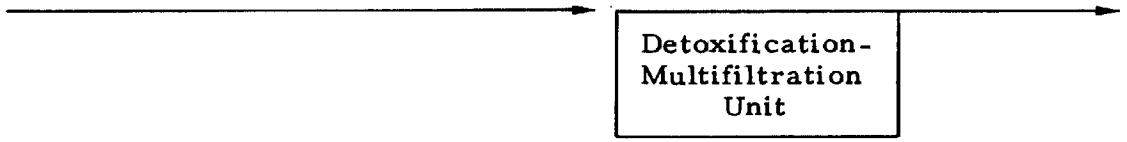
Figure 2-55. Diasssembled Wick Package

Table 2-34

POTABLE WATER DETOXIFICATION-MULTIFILTRATION UNIT 85 DAYS OF OPERATION

VD-VF 1	= 35.9	(79)*
VD-VF 2	= 152.1	(335)
Wick evaporation	= 162.5	(358)
Humidity condensate	= 484.4	(1,067)
Total	= 834.9	(1,839)

Water = 834.9 (1,839)
(21.6 lb/day)



Overall water recovery efficiency $\left(\frac{\text{Water out}}{\text{Water in}}\right)$ = 100%

Expendables:

Carbon	=	0.54 (1.2)
Resin	=	0.54 (1.2)
Total	=	1.08 (2.4)

Hold tank heating (T_1 and T_2): 162.9 joules/sec (556 Btu/hr)

*All weights in kg and (lb)

Table 2-35

DETOXIFICATION-MULTIFILTRATION UNIT INPUT CHEMICAL ANALYSIS

Date	Test Day	Water Source	Turbidity, Jackson Units	Color, Cobalt Units	pH	Specific Conductivity (μmho/cm)	NH_3 (ppm)	TOC (ppm)	Br (ppm)	Cr^{+6} (ppm)
Input										
7-6	24	Humidity condenser	8	Cloudy	7.6	170	20	38	0.0032	Off Color
7-6	24	VD-VF + humidity condenser	3	3	7.9	140	19	27	0.0024	0
7-15	33	Wick evaporator and humidity condenser	1	1	8.3	270	44	44	0	0
8-6	55	Wick evaporator and humidity condenser	3	0	8.0	245	31	52	0	0
8-25	74	Thermal control condensation	0	0	7.9	475	N. T.	83	N. T.	N. T.
8-29	78	VD-VF and humidity condenser	3	0	7.9	345	44	55	0.002	0
9-5	85	Wick evaporator and humidity condenser	3	1	7.6	280	46	42	0	0
9-24	Post Test	Wick evaporator and humidity condenser (tank 1)	0	1	7.1	370	0.2	70	0	0
9-24	Post Test	Wick evaporator and humidity condenser (tank 2)	0	1	7.5	.340	0.08	61	0	0

Table 2-36

DATA ON IODINE DISSIPATION IN BACKUP POTABLE WATER STORAGE TANK

Tank design
- Type: Cylinder with flat ends
- Size: 15 in. diameter x 66 in. - 14-gage shell, 12-gage ends
- Material: Type 304 S/S-2B Quantity: 182 kg (400 lb)

Water Chemistry
- Source: Sparkletts distilled drinking water
  Specific conductivity = 3 to 5 μmho/cm
- Treatment: Add iodine solution (40g I_2 + 52g KI + 1,000g H_2O) to reach 6 ppm I_2 as measured by the silver method (no additional solution added)

I_2 Dissipation Data

Date (1970)	Test Day	I_2 Content (ppm)	MFM††† (No./ml)	Fe (ppm)	Cr (ppm)	Ni (ppm)
*5-22	1	6				
5-25	4	5		<0.002	<0.04	<0.06
6-2	12	5	0			
6-8	18	5				
**6-18	23					
6-22	32	1***				
6-30	40	1***				
7-6	46	1***				
7-13	53	0.5***				
7-13	53	0.5***				
7-21	61	4.5				
7-21	61	5.0				
7-28	68	4.5				
8-4	75	5.0	0	0.02	<0.01	<0.06
8-11	82	5.0	0	0.02	<0.01	<0.06
8-18	89	5.0	0	0.02	<0.01	<0.06
8-25	96	5.0		0.30	<0.01	0.14
9-1	103	5.0		0.08	<0.01	<0.06
9-8	110	5.0				
9-10†	112	--				
9-24††	126	5.0				

*Filled tank
**Start 90-day SSS test
***Incorrect sampling procedure
†End 90-day SSS test
††Emptied tank
†††Millipore Field Monitor

The low levels of iodine detected during the early portion of the test were found to be due to incorrect sampling procedure. The samples were placed in sterile polyethylene bags and passed overboard during the weekly passout for analysis. It was discovered that the first samples were drawn the day before passout and not analyzed until the day after passout. This allowed sufficient time for the iodine to dissipate. The corrected procedure, followed for the remainder of the test, called for drawing the sample just prior to passout and analysis immediately after passout. An acceptable I_2 level was maintained throughout the test without adding more iodine solution.

2.2.3.6 Wash Water Recovery Unit

A summary water balance for the wash water recovery unit is shown in Table 2-37 and results of the chemical, physical, and microbiological analysis are shown on Figure 2-56 and in Tables 2-38 and 2-39.

The unit processed 5,077 kg (11,182 lb) of water and used 13.6 kg (30 lb) of expendables. A total of 362 kg (798 lb) of water from the potable water subsystem and storage cart was added as makeup to the unit. The multifiltration module required four changes of carbon column, one change of both resin columns, and replacement of five particulate filters.

The particulate filters were changed whenever the process rate dropped below 2.5 ml/sec. The filters were changed in progression, starting with the one having the highest pressure drop, until a satisfactory process rate was achieved. The 30-μm filter was changed on days 25, 52 and 78. The 1 and 3-μm filters were changed only once on day 34. Table 2-40 shows the amount of residue contained on the used filters. An additional undetermined amount of material was screened out by each filter and accumulated in the bottom of the filter housings. Figure 2-57 shows the used filters.

The carbon and resin columns were changed as dictated by crew judgment of water quality and chemical analysis results. The first signs of crew rejection, because of odor, occurred on day 35. At this time the wash water charge in the unit was replaced with 40 kg (88 lb) of humidity condensate. The objectional odor did improve some, but on day 40 a carbon column change was made and a considerable improvement in water quality was noted. The carbon column change procedure was to replace the last column with a new charge and replace the first column with the old last column. Microbial growth was found in the felt pad carbon retainer in the first column and it is felt that this growth was responsible for the objectionable odor. It was felt that water temperatures within the columns were below those required to inhibit bacterial growth because of system heat losses. The process tank temperature was subsequently occasionally raised to 366°K (200°F) before multifiltration in an attempt to inhibit this type of growth. The same objectionable odor did not occur again. However, the columns were changed twice as frequently during the last half of the test. The change in frequency was due to earlier crew rejection of the water. Also, the life of the columns estimated before the test, was based on a lower usage rate than the actual daily volume of water used.

Table 2-37

WASH WATER SYSTEM SUMMARY
WATER BALANCE AND EXPENDABLES
(4 MEN, 90 DAYS)

	kg (pounds)	kg (pounds)
Water Produced		
Multifiltration unit (Ref: Figure 2-11 for water sources)		5,077 (11,182)
Water Used		
Washing [Including evaporation loss = (560 lb) 254]	4,744 (10,448)	
Reprocess	227 (500)	
Urinal flush	94 (207)	
Phase change	40 (88)	
Miscellaneous	6 (13)	
Inventory change	-34 (-74)	
	5,077 (11,182)	5,077 (11,182)
Expendables		
Four carbon columns	(16)	7.3
Two resin columns	(8)	3.6
Five particulate filters	(2)	0.9
Cleansing agent (Basic H)	(4)	1.8
Total expendables	(30)	13.6
Heat		
Tank heaters: (817 Btu/hr) 239.4 joules/sec average		
Power		
Pump: 1,056 watts for 4.32 hours total operating time		

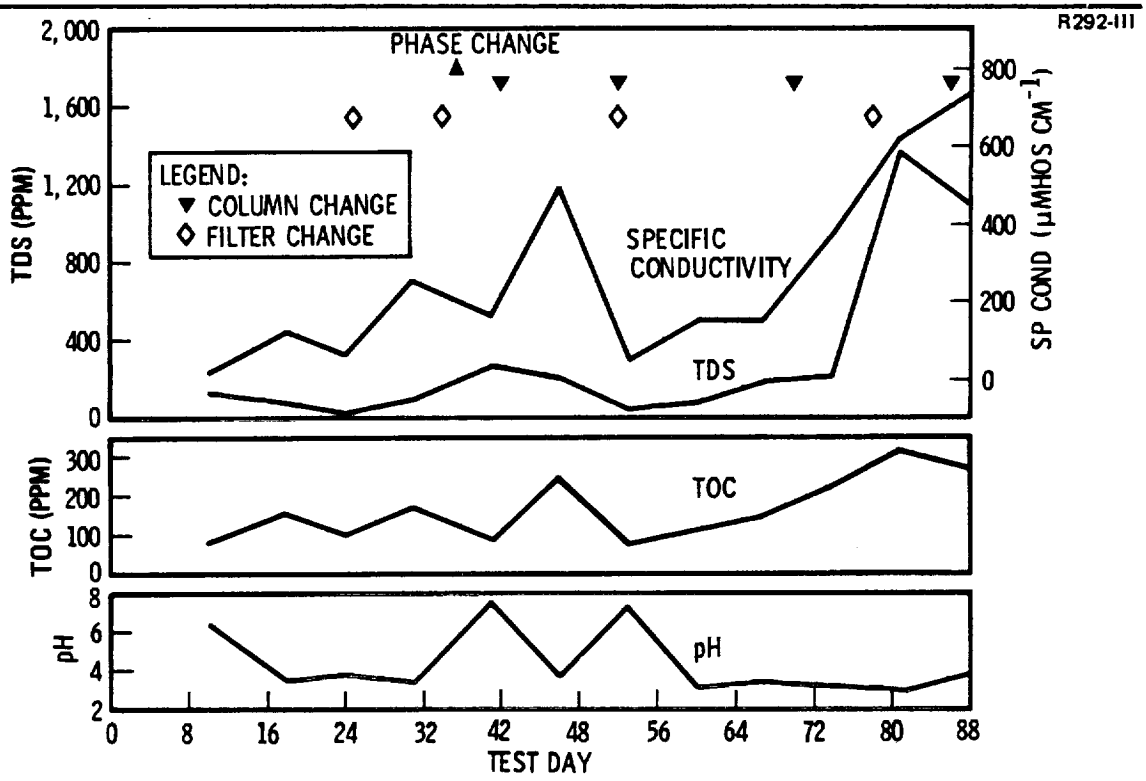


Figure 2-56. Reclaimed Wash Water Analysis

The next column change occurred on day 52. Both resin columns were changed at this time as well as the carbon column. This was done to determine what chemical changes in water quality, if any, would result. No noticeable chemical changes occurred that had not occurred after the first carbon column change as shown in Table 2-38.

Two more carbon column changes were made on days 70 and 86. The resin columns would have been changed again on day 86 had it not been so close to the end of the test.

A total of 342 g of TOC and 1,586 g of TDS were removed by the carbon and resin columns as calculated from the average removal rate between sample intervals (see Table 2-38). This results in a carbon column loading average of 37.7 g of TOC per kg of carbon and 174.7 g of TDS for each kg of carbon. The small changes in specific conductivity across the entire multifiltration module indicated that all or most of the TDS were removed by the carbon columns and not the ion exchange columns.

The washer and dryer were used to clean and dry 44 loads of wash composed of underclothing, socks, uniforms, wash cloths, towels, and bed sheets. The Basic H cleansing agent did an adequate cleaning job on all clothes except the uniforms made of Durette. The agent failed to remove the perspiration stains from this material. The crew considered Basic H undesirable for personal hygiene because they felt it left a slippery film residue, that was hard to rinse away, and an objectionable odor. The slippery feeling is typical of soft water. A shower to provide sufficient rinsing might have eliminated the problem.

Table 2-38

WASH WATER CHEMICAL AND MICROBIOLOGICAL ANALYSIS

Date	Test Day	Tank No.	Turbidity (ppm SiO_2)	Color (Cobalt Units)	Odor	Foaming	pH	Specific Conductivity ($\mu mho\text{-}cm^{-1}$)	TOC (ppm)	TDS (ppm)	Millipore Field Monitor 48-Hour Count (No. /ml) Hot (71°C)	Cold (38°C)
6-22	10	7	80		Flat	None	6.4	28	81	135		
6-22		8	123		Slight	None	6.7	92	164	428		
6-30	18	7	3	4	Slight	None	3.5	250	152	81	1	
6-30		8	55	Cloudy	Slight	None	3.7	280	190	216	0	
7-6	24	7	2		Flat	None	3.8	130	99	31		
7-6		8	35		Slight	None	4.0	180	162	469		
7-13	31	7	0		Flat	None	3.4	510	174	102		
7-13		8	16	2	Slight	None	3.3	490	174	219		
7-21	39	7	0	0	Rubber	None	7.6	330	90	273		
7-21		8	112	Cloudy	Rubber	None	7.0	380	231	579		
7-28	46	7	0	2	Flat	None	3.7	990	250	214	0	0
7-28		8	105	Cloudy	Slight	None	3.8	1,000	260	494		
8-4	53	7	3	2	Slight	None	7.4	102	82	62		
8-4		8	83	Cloudy	Slight	Slight	7.2	740	263	484		
8-11	60	7	2	0	Slight	None	3.2	300	112	86	1	0
8-11		8	78	Cloudy	Slight	Slight	3.3	285	177	726		
8-18	67	7	2	0	Bland	None	3.4	310	151	191	2	6
8-18		8	170	Cloudy	Slight	Slight	3.8	335	258	669		
8-25	74	7			Slight	None	3.2	745	233	224	0	3
8-25		8			Slight	Slight	3.5	645	275	514		
9-1	81	7	2		Slight	None	3.0	1,240	340	1,366	0	0
9-1		8	130	Cloudy	Slight	Slight	3.0	1,110	429	1,710		
9-8	88	7	2		Slight	None	3.9	1,470	275	1,088	0	0
9-8		8	93	Cloudy	Slight	Slight	4.0	1,660	300	1,500		
9-24		7	0	1	Bland	None	3.7	1,850	390			
		8	0	1	Bland	None	4.2	2,000	390			

Table 2-39

WASH WATER POST-TEST CHEMICAL ANALYSIS
(ppm)

Element	Use Tank 7	Process Tank 8
As	<0.07	<0.08
Ba	<0.4	<0.5
B	<0.012	<0.014
Cd	<0.003	<0.004
Cr	0.003	0.003
Cu	0.06	0.05
Pb	0.004	0.009
Ag	<0.001	<0.001
Al	<0.02	0.02
Be	<0.001	<0.001
Bi	<0.006	<0.006
Ca	0.08	0.06
Co	<0.004	<0.005
Fe	0.005	0.005
Li	<0.0005	<0.0006
Mg	0.013	0.013
Mn	0.001	<0.001
Hg	<0.2	<0.2
Ni	<0.004	0.004
Si	0.4	0.1
Na	0.28	1.03
Zn	0.05	0.02
Mo	<0.015	<0.017

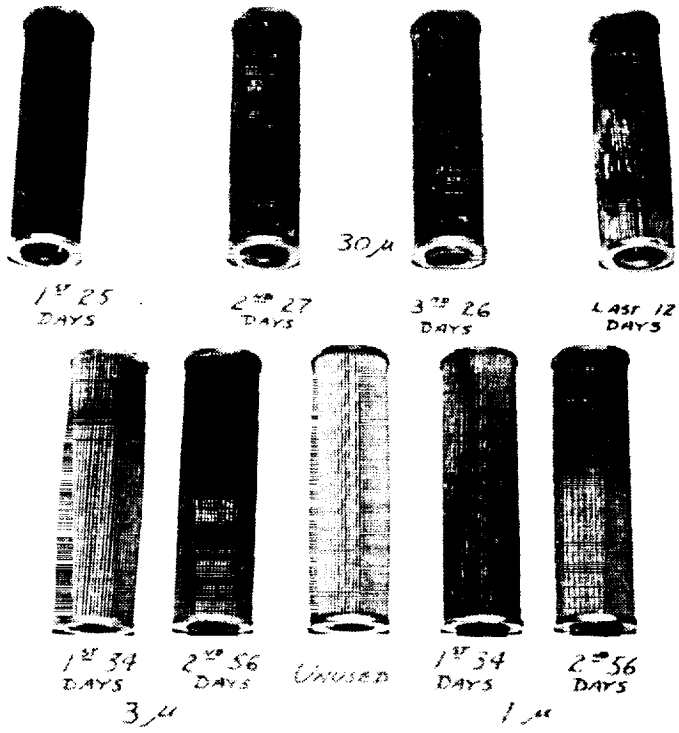


Figure 2-57. Used Wash Water Filters

2.2.3.7 Power Consumption

The water management subsystem power consumption is shown in Table 2-41. The items listed operated in a continuous mode over the entire test period unless otherwise noted. The noted values reflect only the average load over that time period. Section 2.1.4 details the peak load values for this equipment.

2.2.3.8 Maintenance Activity

The maintenance and repair activities on the water management subsystem are shown in Table 2-42. These activities have been discussed in detail in appropriate areas of this section. The overall maintenance and repair activities are summarized in Section 2.1.1.

2.2.3.9 Urine Data

The crew urine output data are shown in Figures 2-58 through 2-61. The crew total urine output over the entire 90 days is shown in Figure 2-58. The constant rate of urine production during this test correlates very well with past manned chamber test data (Reference 2-5). Figure 2-59 shows the urine output volumes as a function of time of day for each shift crew. Crewmen 3 and 4 were on the inverted work schedule. The data for crewmen 3 and 4 show that their urine output was fairly evenly distributed over the entire period of their awake hours, whereas that of crewmen 1 and 2 occurred at definite times of the day. These times were right after awaking, about midday, and again before retiring. This again substantiates past data showing that urine processing systems must be capable of handling cyclic loads.

Table 2-40

WASH WATER FILTER RESIDUE

Day	Changed	Used Water Processed kg (lb)		Residue Collected (g)	g Residue/ kg Water	Days Used	% Residue Removed
25	30 μm	985	(2,170)	23.8	0.024	25	
52	30 μm	1,456	(3,208)	70.9	0.049	27	
78	30 μm	1,218	(2,684)	69.2	0.057	26	
90	30 μm	786	(1,731)	26.8	0.034	12	
	Subtotal	4,445	(9,793)	190.7	0.041 Avg	90	82
34	3 μm	1,539	(3,391)	9.2	0.0060	34	
90	3 μm	2,906	(6,402)	32.5	0.0118	56	
	Subtotal	4,445	(9,793)	41.7	0.0089 Avg	90	18
34	1 μm	1,539	(3,391)	0			
90	1 μm	2,906	(6,402)	0			
	Subtotal	4,445	(9,793)	0			0
	Total			232.4			100

The number of micturitions each day for each crewman was fairly constant as shown in Figure 2-60. The urine volume for each micturition is shown in Figure 2-61 for the entire crew and summarized in Table 2-43 for each crewman. The crew average volume per micturition was 268 ml with a modal value of 200 ml. The volume per micturition ranged from a minimum of 16 ml to a maximum of 924 ml.

Urine properties data taken during the test are shown in Figures 2-62 to 2-74. Correlation was not obtained between the urine properties data and test day as shown in Figures 2-62, 2-63, 2-65, 2-67, 2-69, 2-71 and 2-73. Correlation was obtained between TDS and five other properties as shown in Figures 2-64, 2-66, 2-68, 2-72 and 2-74. However, correlation was not obtained between TDS and pH as shown in Figure 2-70. These results are in agreement with similar data which are presented in Reference 2-6. This is presented for comparison of long-term operational data with that of random samples collected in an industrial laboratory.

Table 2-41

WATER MANAGEMENT SUBSYSTEM POWER CONSUMPTION

	Total kW–ksec	Average Watts During Operation
Potable Water Unit		
Holding tank 1	53.3	89
Holding tank 2	43.8	74
Use tank 3	50.0	83
Use tank 4	44.7	75
Use tank 5 + circulation pump	79.4	133
Use tank 6	57.3	96
Humidity condensate pump, 67-hour operation	1.9	104
Wick evaporator heater, 1, 127-hour operation	104.0	332
110-vac Subtotal	434.4	986
Humidity control blower, 400 Hz	183.4	307
Total	617.8	1, 293
Wash Water Unit		
Use tank 7	67.8	113
Process tank 8	75.3	126
Sink pump, 4.32-hour operation	1.4	1, 056
Washer, 4-hour operation	1.1	1, 000
Dryer, 44-hour operation	22.8	1, 865
Total	168.4	4, 160

Table 2-42

WATER MANAGEMENT SUBSYSTEM MAINTENANCE AND REPAIR ACTIVITY

Unit		Spares Usage	No Times	Hours
VD-VF	Steam-sterilized condensate tanks		5	5.0
	Steam-sterilized boiler and catalyst bed		1	0.5
	Interchanged boiler and catalyst isotopes		4	0.5
	Repaired boiler level switch		2	4.5
	Replaced boiler level switch	Float switch	1	5.0
	Corrected urine pump control	Relay	1	0.2
	Replaced expended boiler*	Boiler assembly	1	4.0
	Cleaned catalyst		3	0.7
	Replaced metering pump	Pump assembly	1	1.0
	Cleaned vacuum gage		1	2.0
	Relocated sensing line to bypass boiler membrane		1	0.5
		Subtotal	21	23.9
Wick Evaporator/ Humidity Control	Transferred processing to new wick package*		4	0.3
	Cleaned sump screens*		30	15.0
	Replaced sump	Sump fitting	2	1.0
	Switched to backup pump (negative pressure device failed)		1	0.2
		Subtotal	33	16.2
Multifilter (Potable)	Replaced multifilter columns*	Column assembly	1	0.3
	Repacked multifilter columns	Carbon and resin	2	5.0
	Changed filter	Filter element	1	0.3
		Subtotal	4	5.6
Wash Water	Replaced carbon column*	Carbon column	1	0.7
	Repacked carbon column	Carbon	3	0.3
	Repacked ion exchange resin column	Resin	2	2.0
	Changed filter	Filter element	5	1.6
	Reprocessed water		8	0.2
		Subtotal	19	4.8
		Subsystem total	81	50.8
		*Maintenance Items	-37	-20.3
		Repair Items	44	30.5

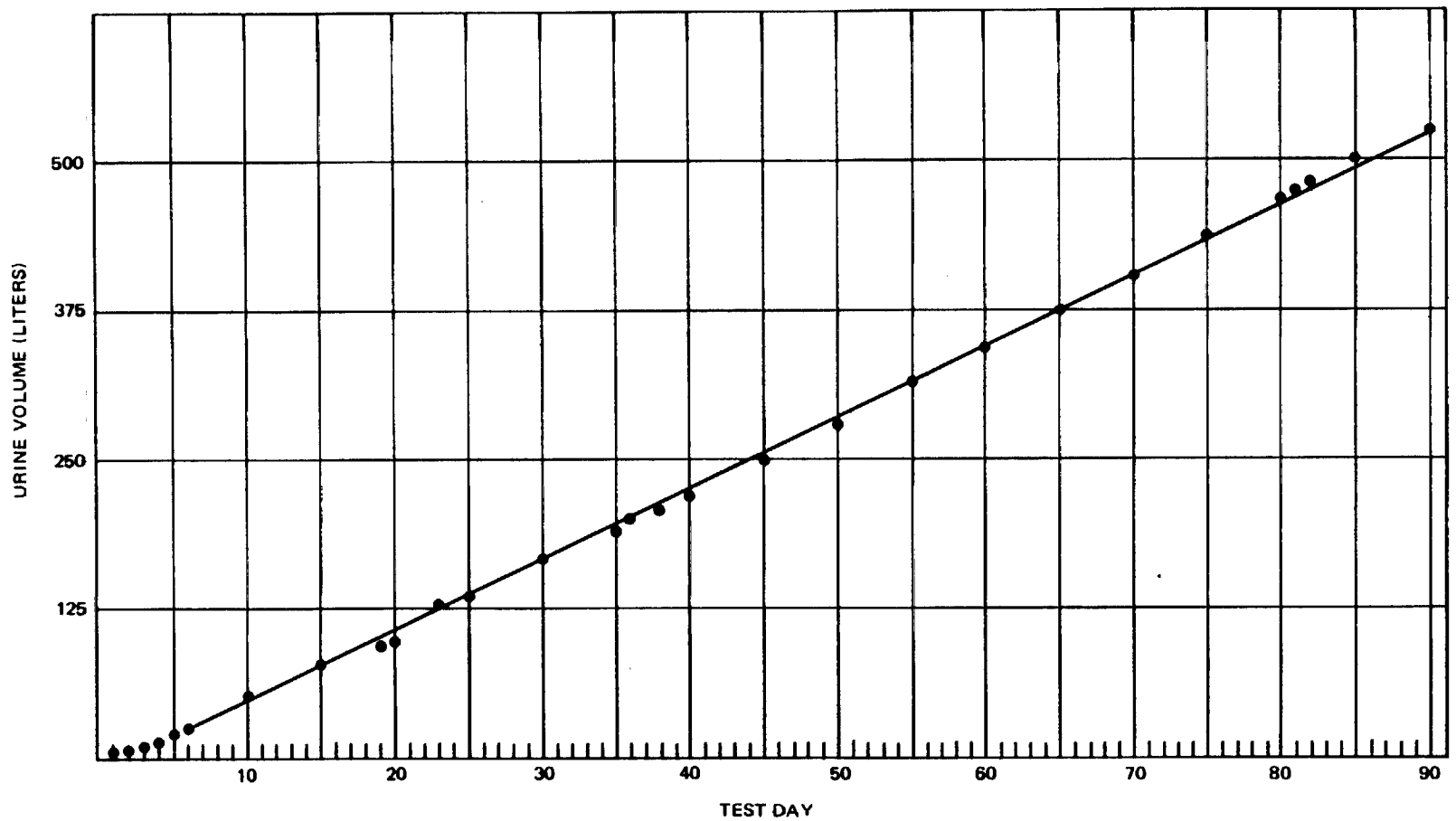


Figure 2-58. Crew Total Urine Output

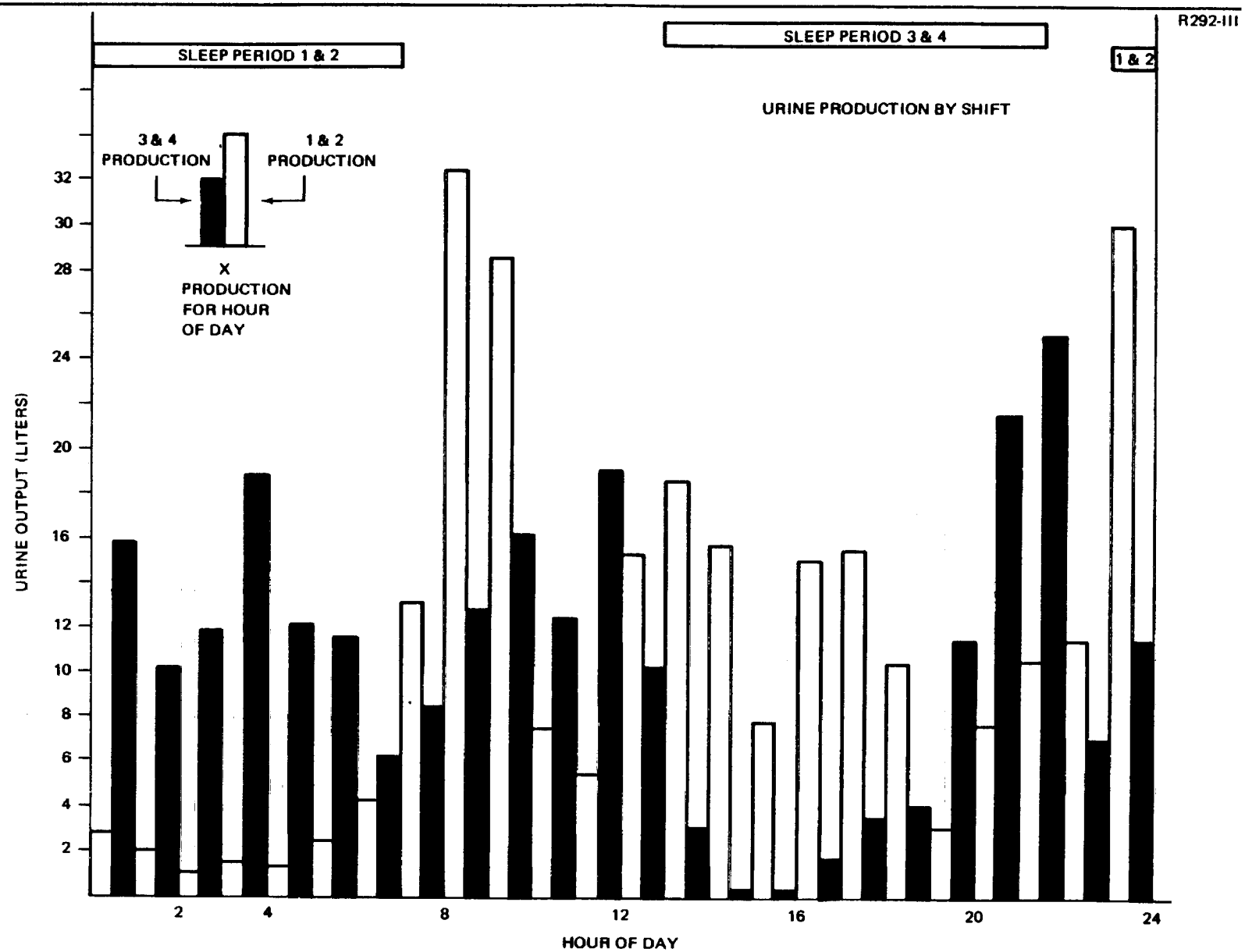


Figure 2-59. Urine Production by Shift

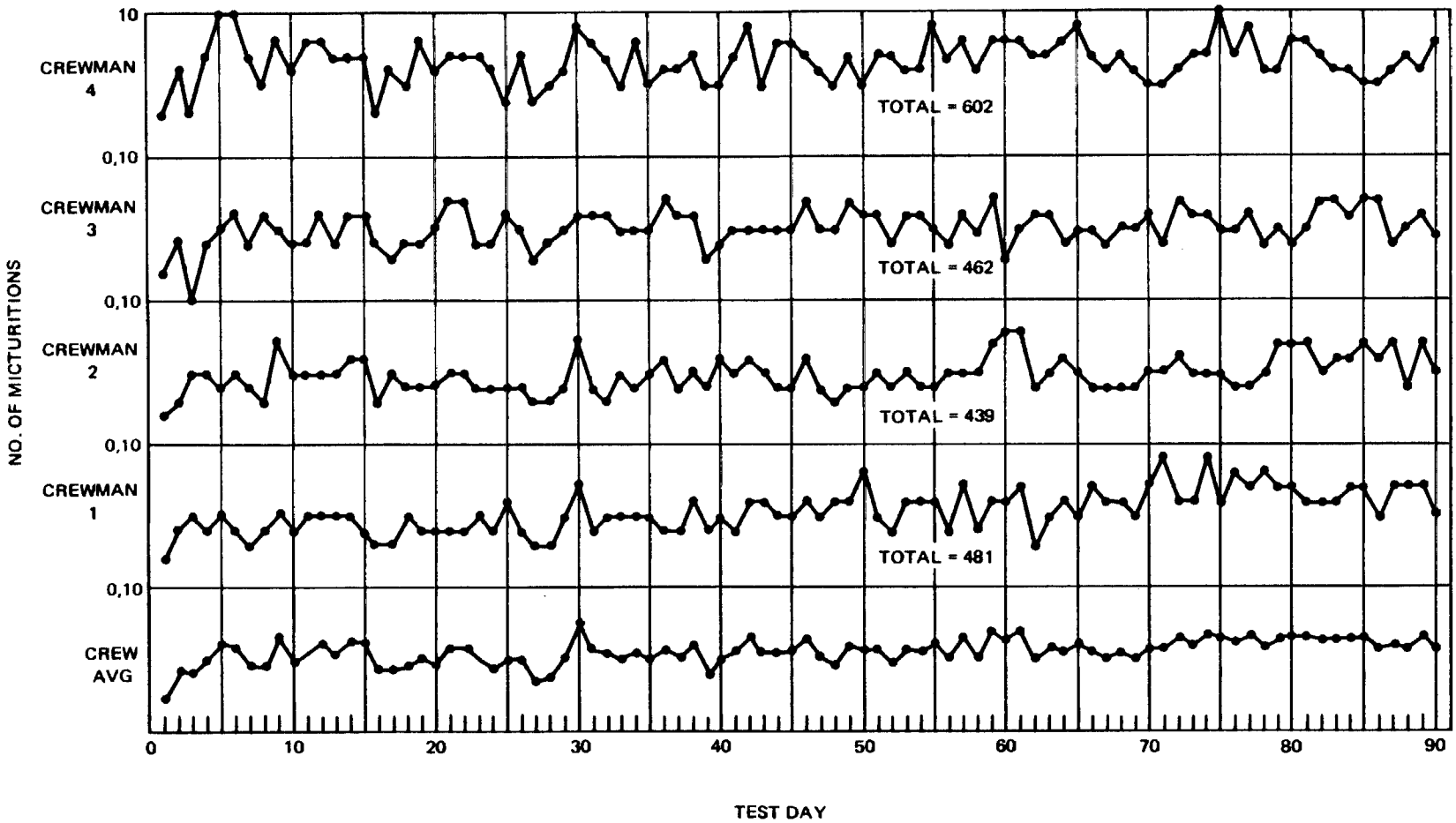


Figure 2-60. Crew Number of Micturitions per Day

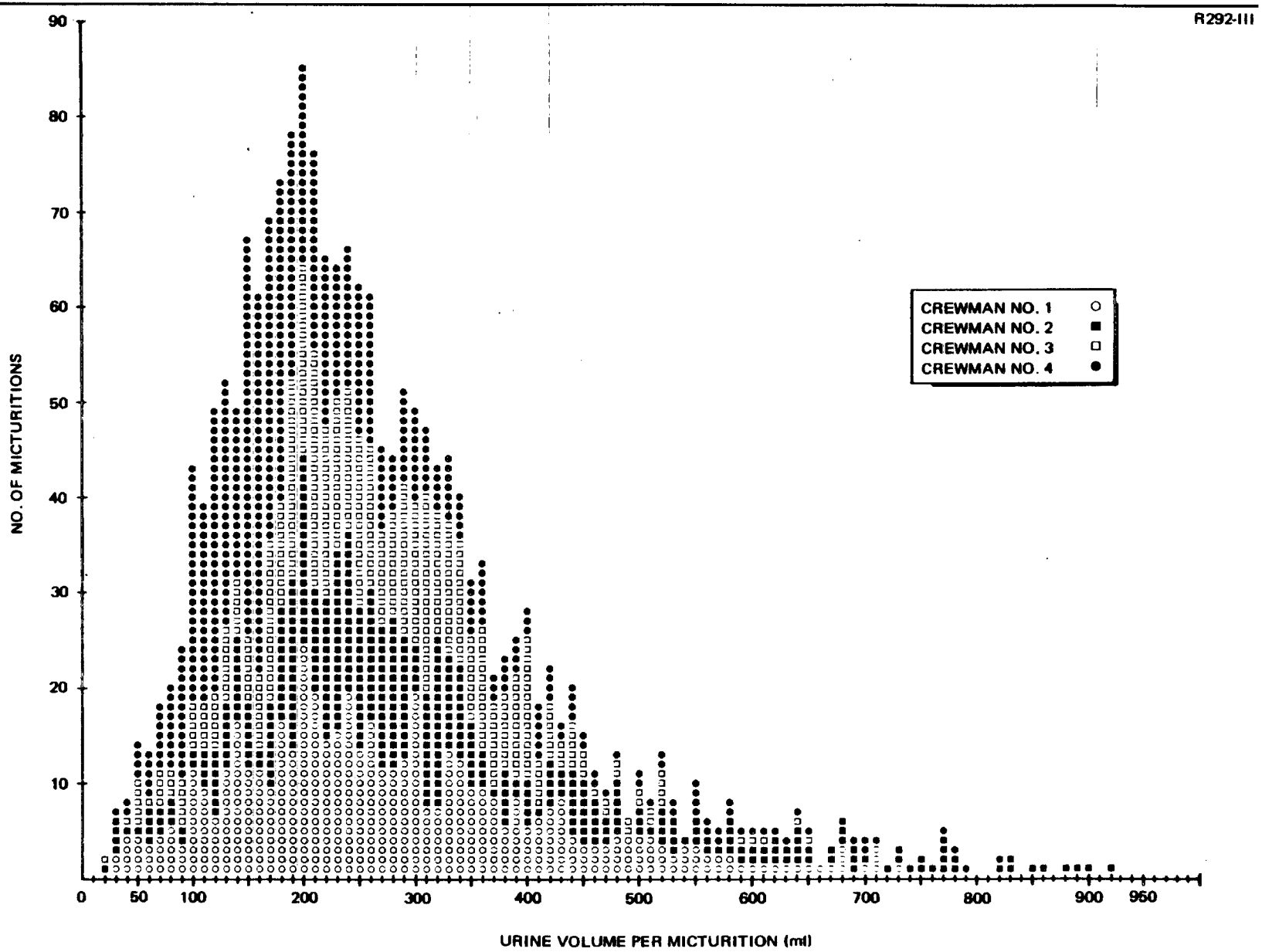


Figure 2-61. Urine Volume per Micturition

Table 2-43

CREW URINE DATA SUMMARY

Item	1	2	3	4	Total
Urine quantity, liters	133	141	125	132	531
Number of urinations	481	439	462	602	1,984
Minimum volume, ml	28	25	16	33	
Maximum volume, ml	730	924	650	820	
Micturition frequency per day, min	3	3	3	3	
Micturition frequency per day, max	9	8	7	10	
Average volume per micturition, ml	277	322	269	219	

2.3 ATMOSPHERE PURIFICATION

This portion of the final report describes performance of the CO_2 concentrators, as well as the temperature and humidity control units. Although the toxin burner contributed to atmospheric purification, it was integrated with the Sabatier reactor and its performance is discussed in conjunction with that unit in Section 2.4.1. All of these units operated satisfactorily during the 90-day test. Carbon dioxide removal from the cabin atmosphere could have been accomplished by the advanced prototype solid amine unit, the backup molecular sieve unit, or for a period of up to 5 days by the emergency lithium hydroxide CO_2 removal unit. The CO_2 concentration in the cabin over the 90-day test period was approximately 666 N/m^2 (5 mm Hg) rather than the intended 507 N/m^2 (3.8 mm Hg) primarily because of the problems with adjusting the operating conditions of the solid amine concentrator. The solid amine unit was used for CO_2 control during the majority of the first 81 days of the test. The molecular sieve unit operated approximately 20 days during the 90-day test. Operation of the lithium hydroxide emergency unit was not required during the test.

The prime function of the thermal conditioning unit was to maintain temperature levels suitable for human comfort by removing the sensible heat dissipated into the atmosphere. This heat dissipation into the SSS atmosphere was derived from occupants, high-temperature heat transfer fluid lines, electrical energy, and onboard isotope heaters. The rate of sensible heat dissipated from these sources varied as much as 40 percent and thus created a requirement for accurate and reliable modulating automatic controls.

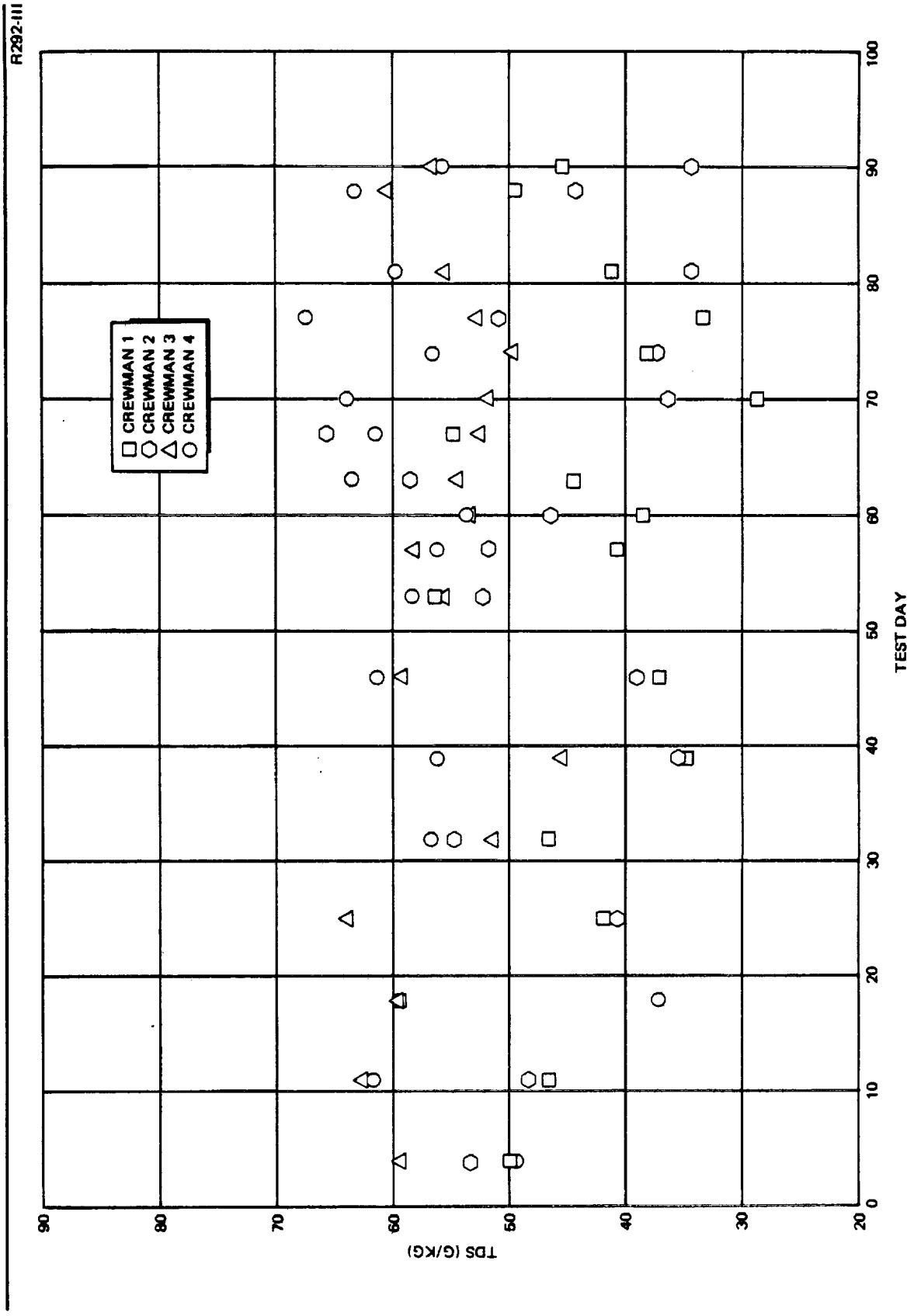


Figure 2-62. Total Dissolved Solids of Urine

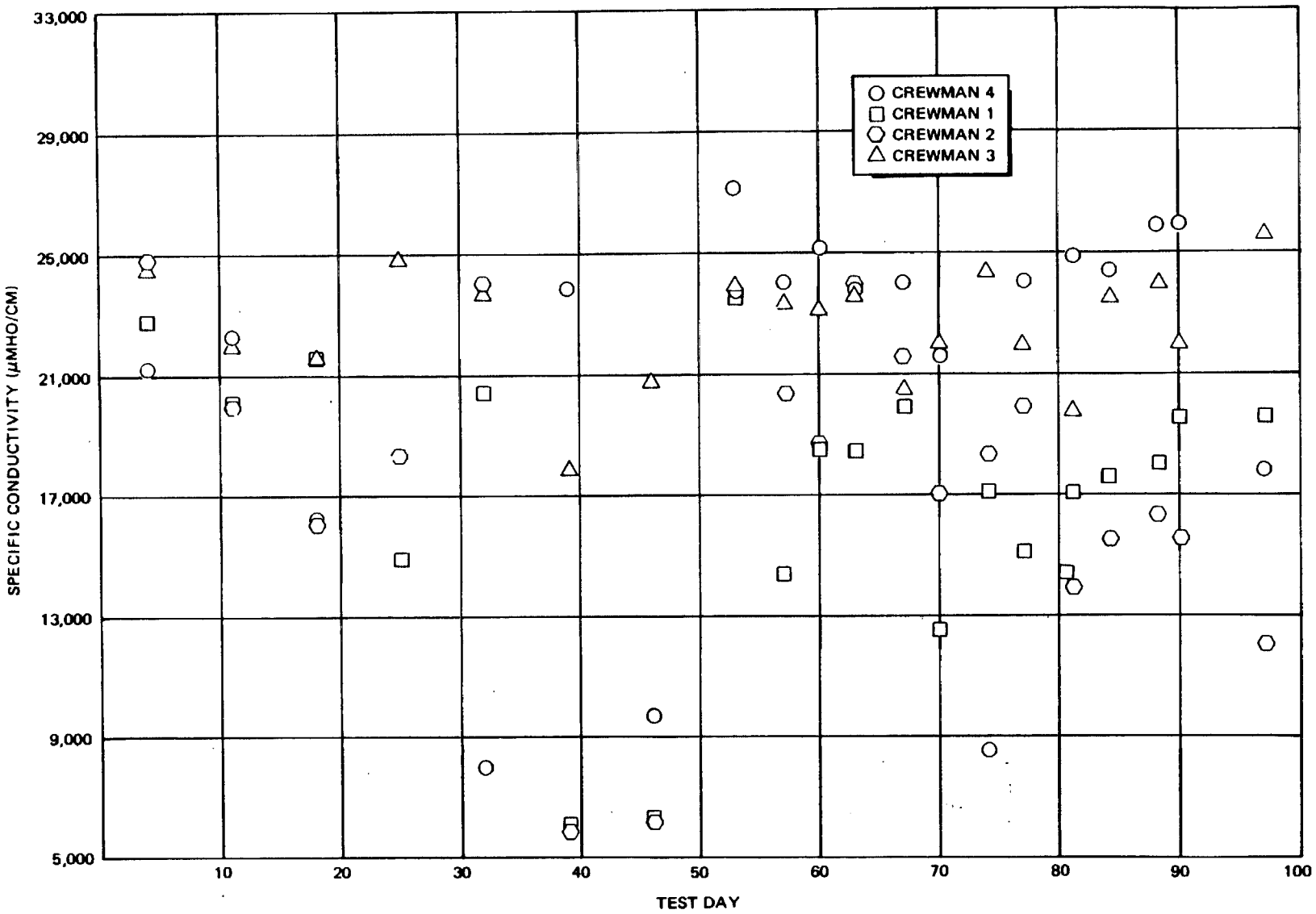


Figure 2-63. Specific Conductivity of Urine

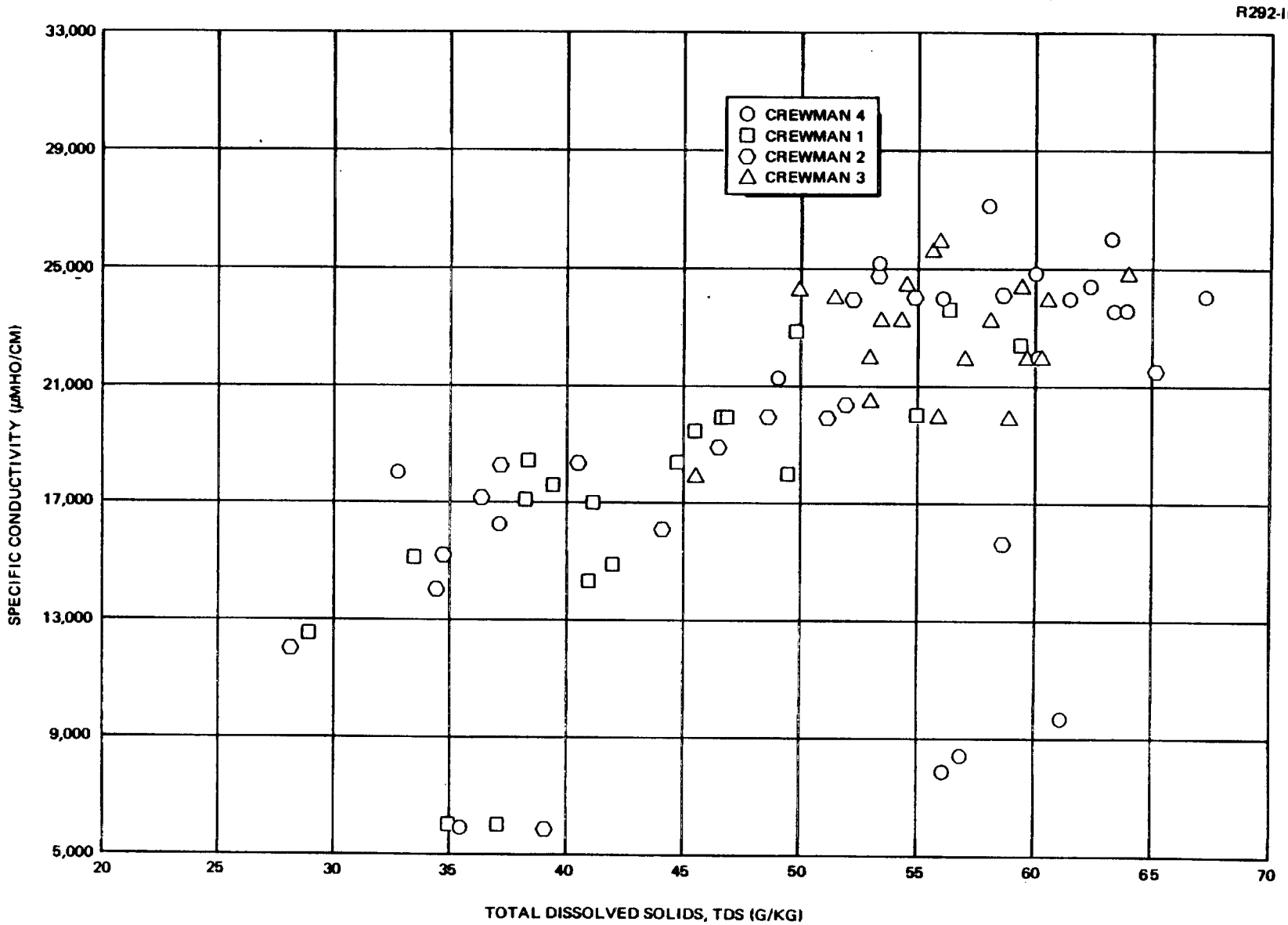


Figure 2-64. Specific Conductivity vs Total Dissolved Solids of Urine

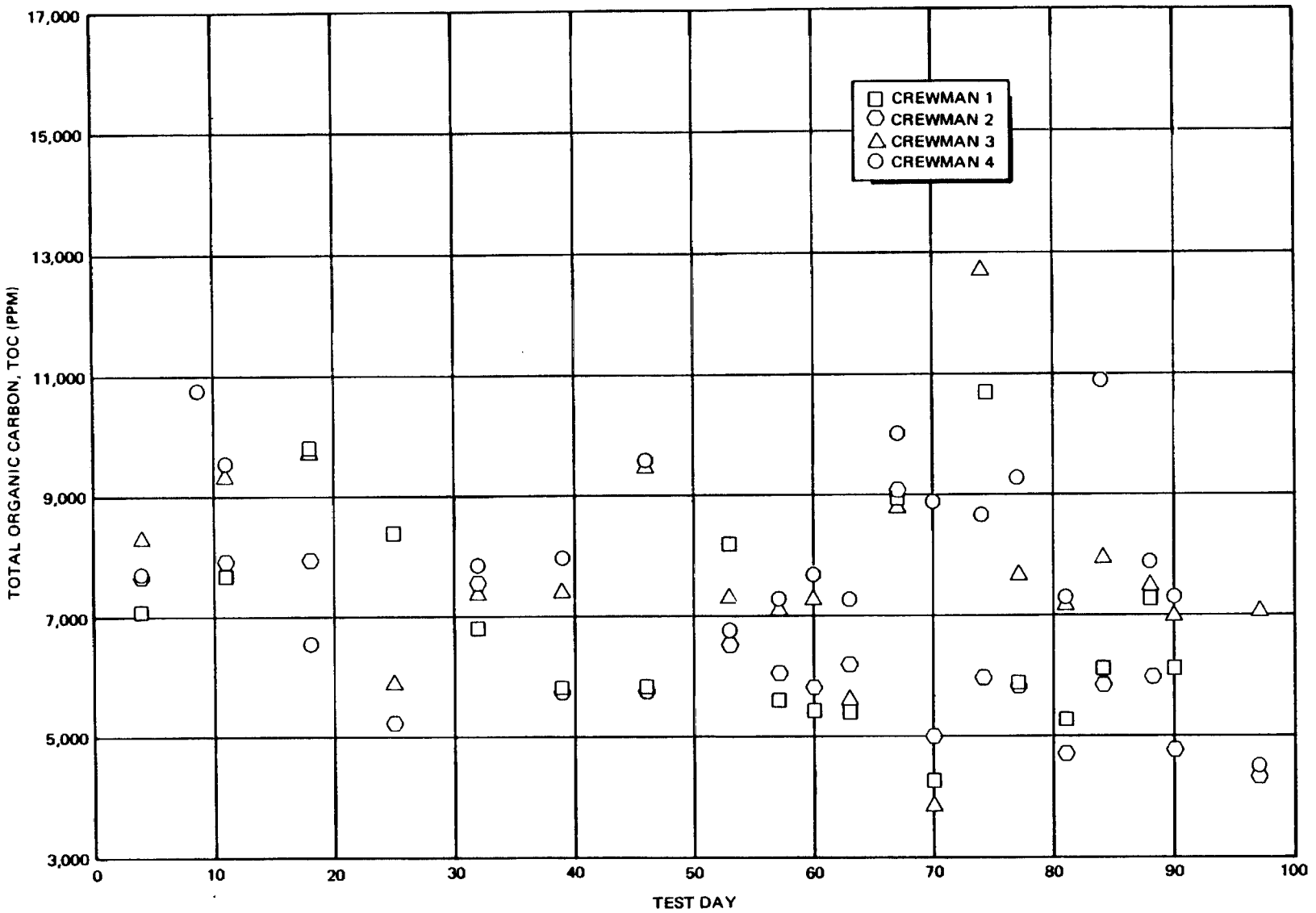


Figure 2-65. Total Organic Carbon of Urine

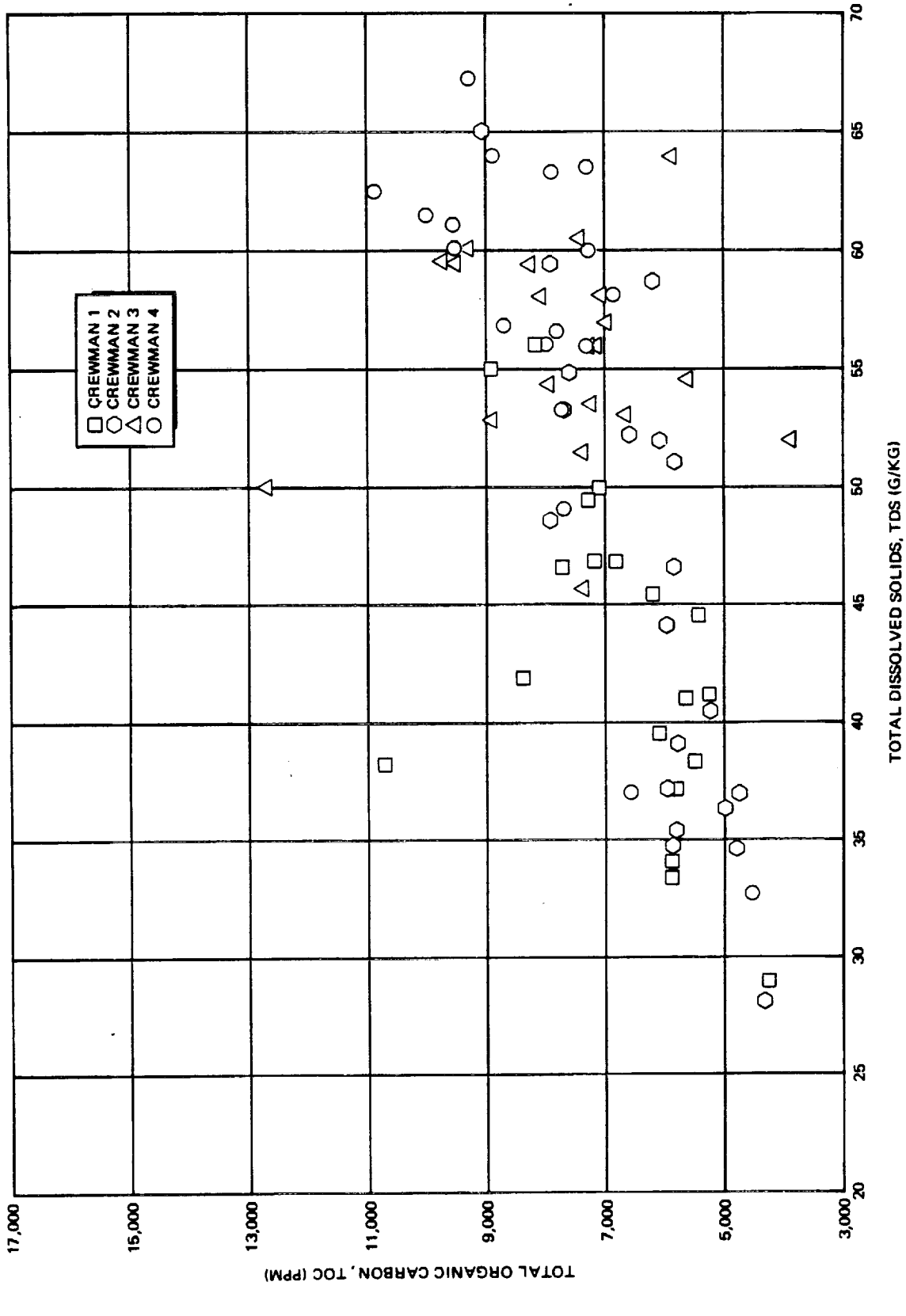


Figure 2-66. Total Organic Carbon vs Total Dissolved Solids of Urine

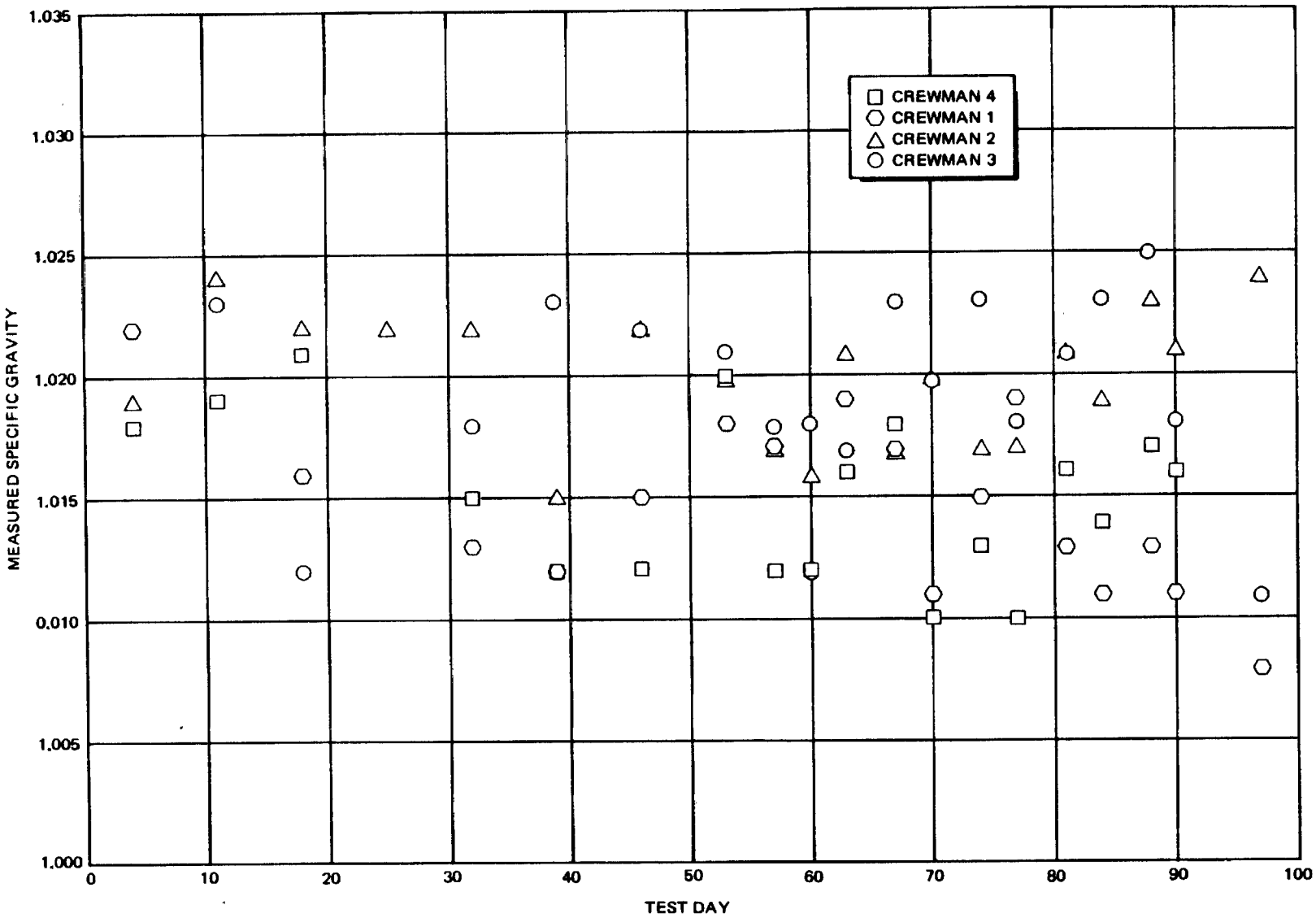


Figure 2-67. Measured Specific Gravity of Urine

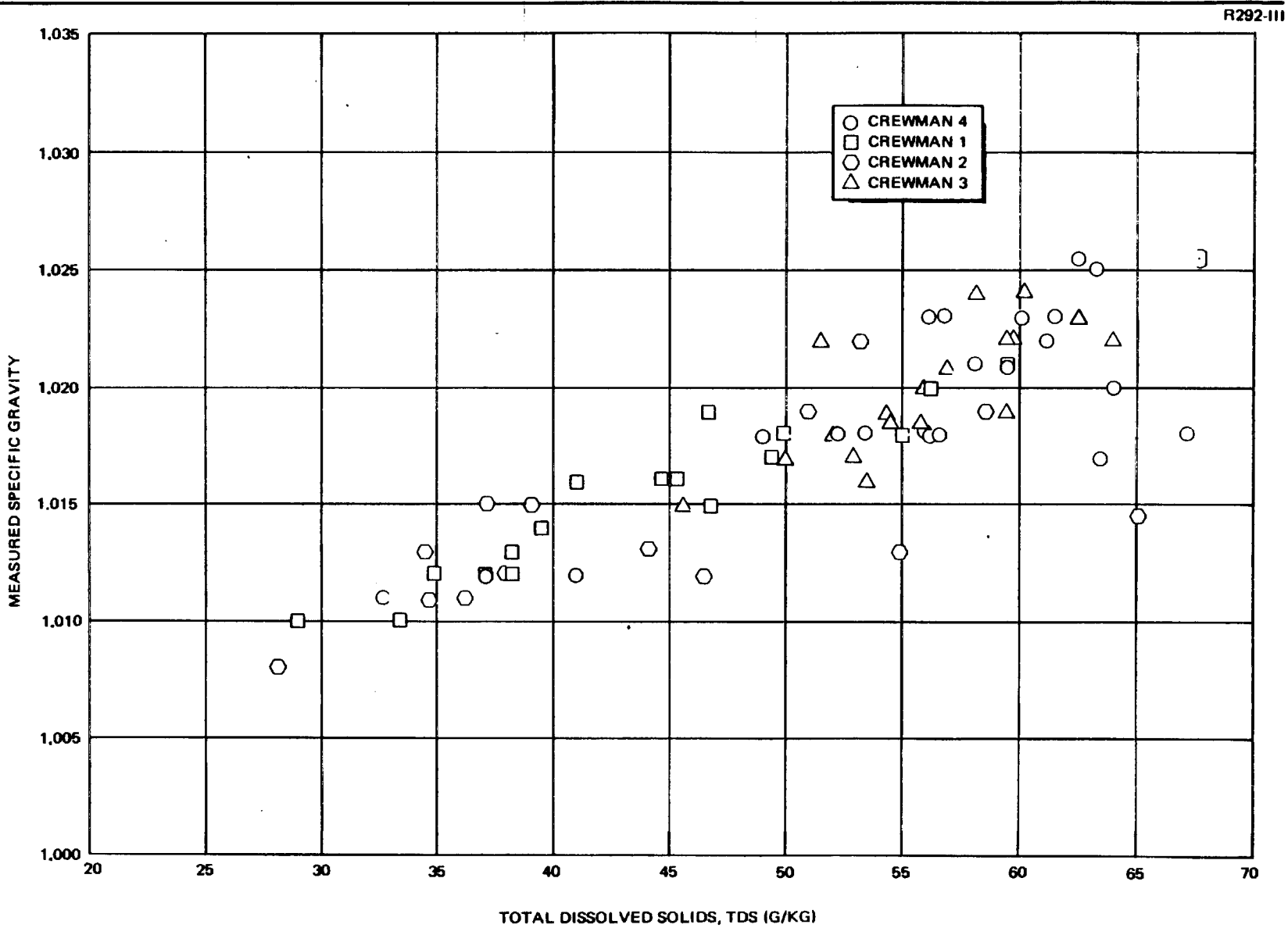


Figure 2-68. Measured Specific Gravity vs Total Dissolved Solids of Urine

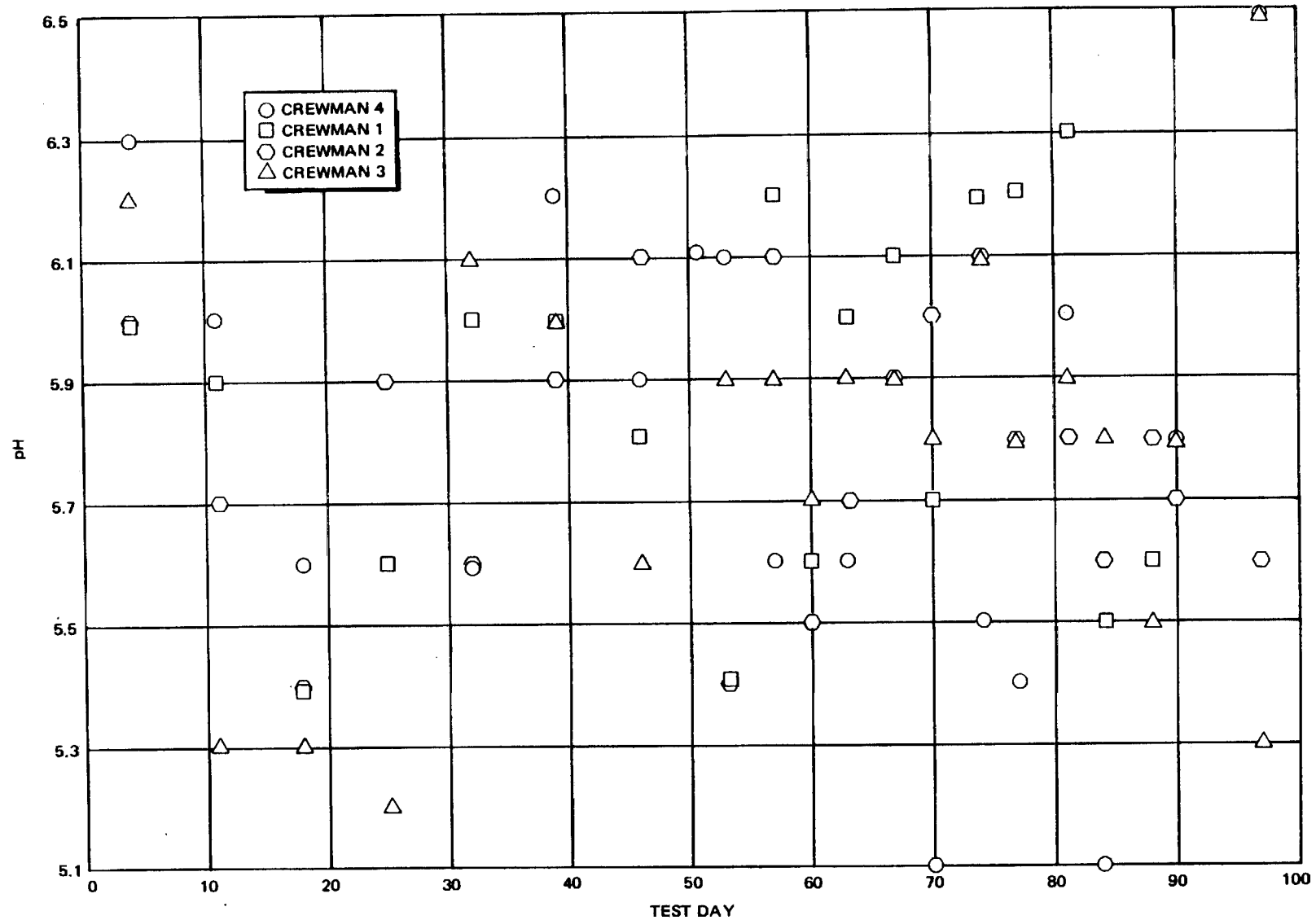


Figure 2-69. pH of Urine

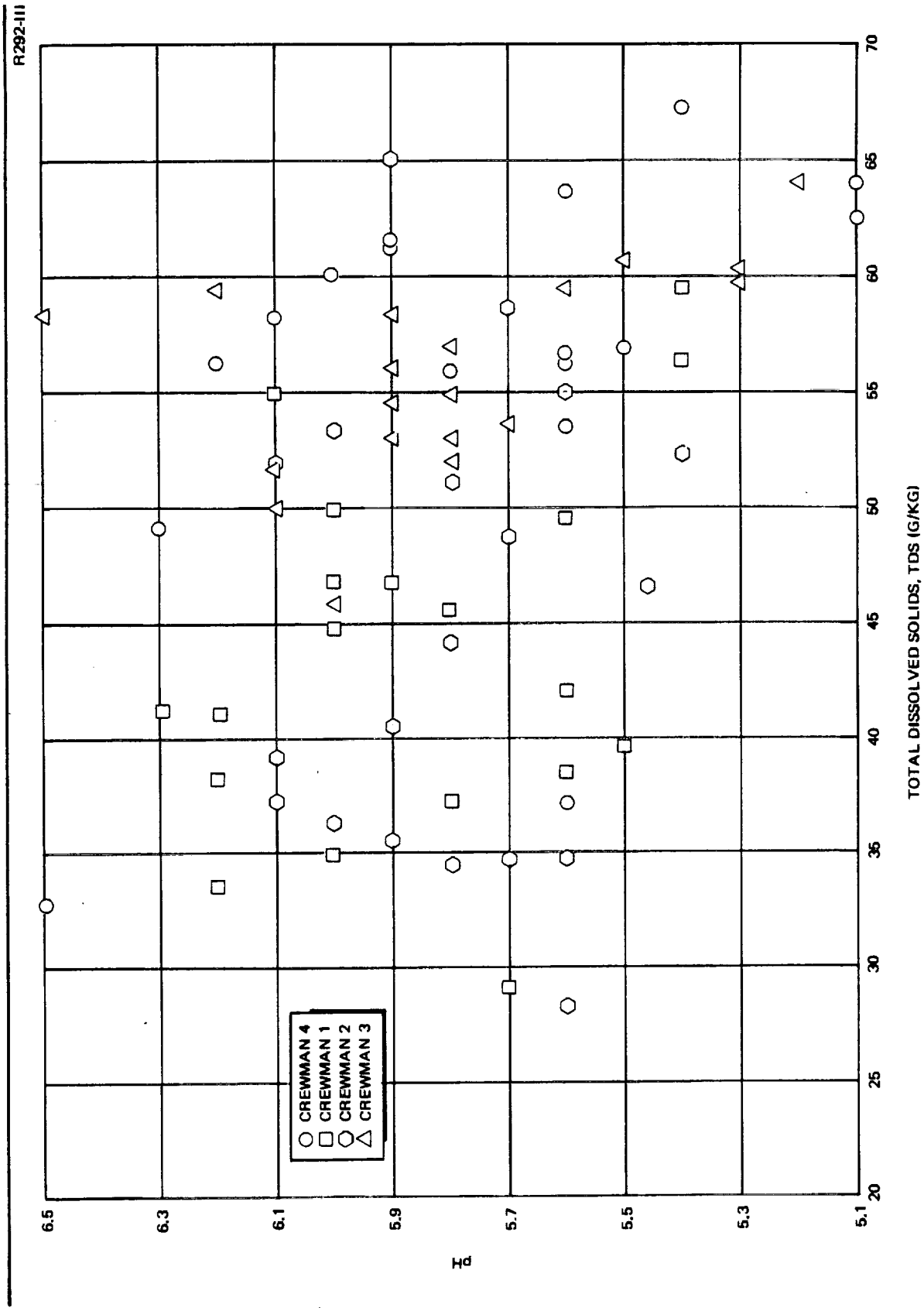


Figure 2-70. pH vs Total Dissolved Solids of Urine

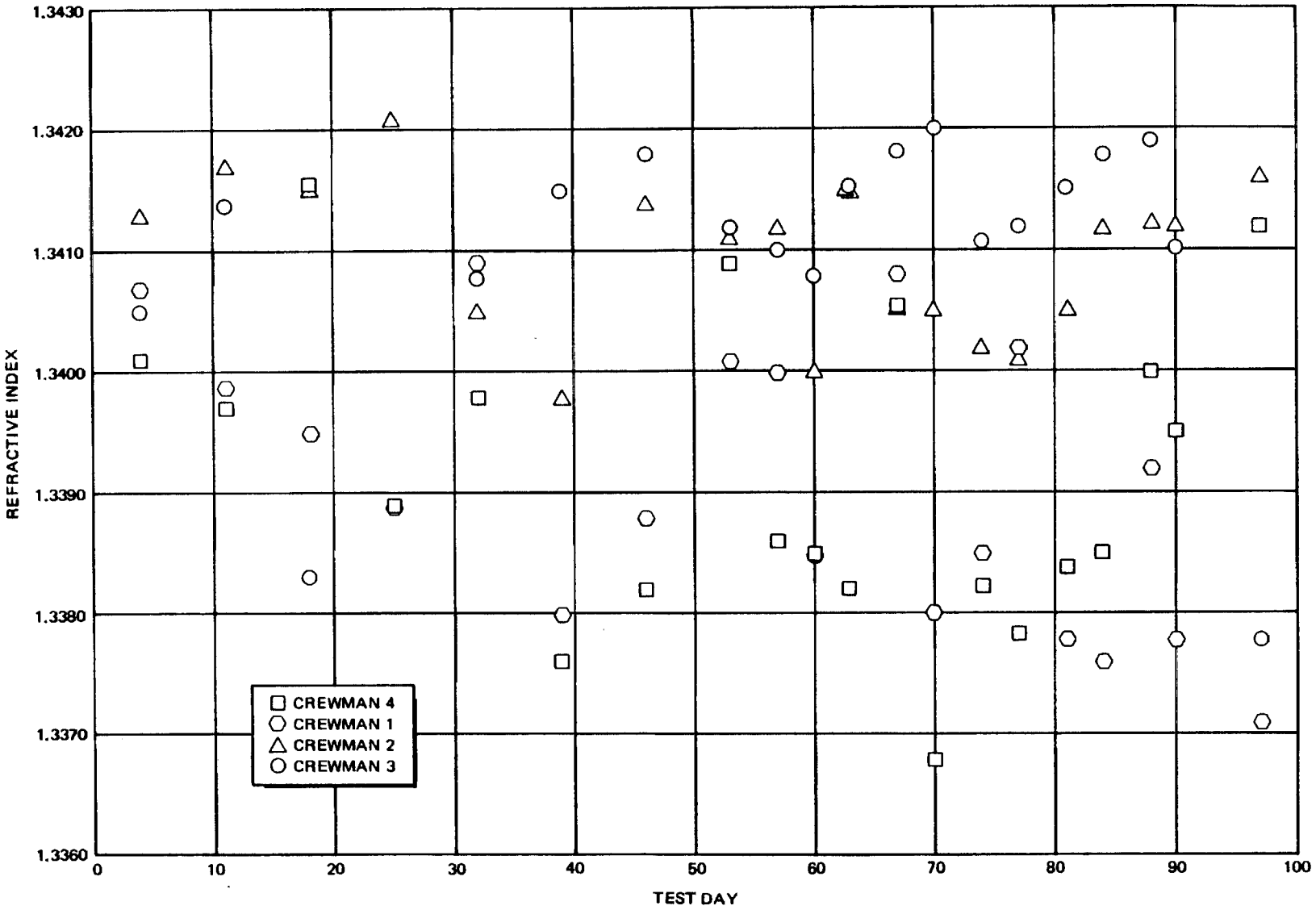


Figure 2-71. Refractive Index of Urine

R292-III

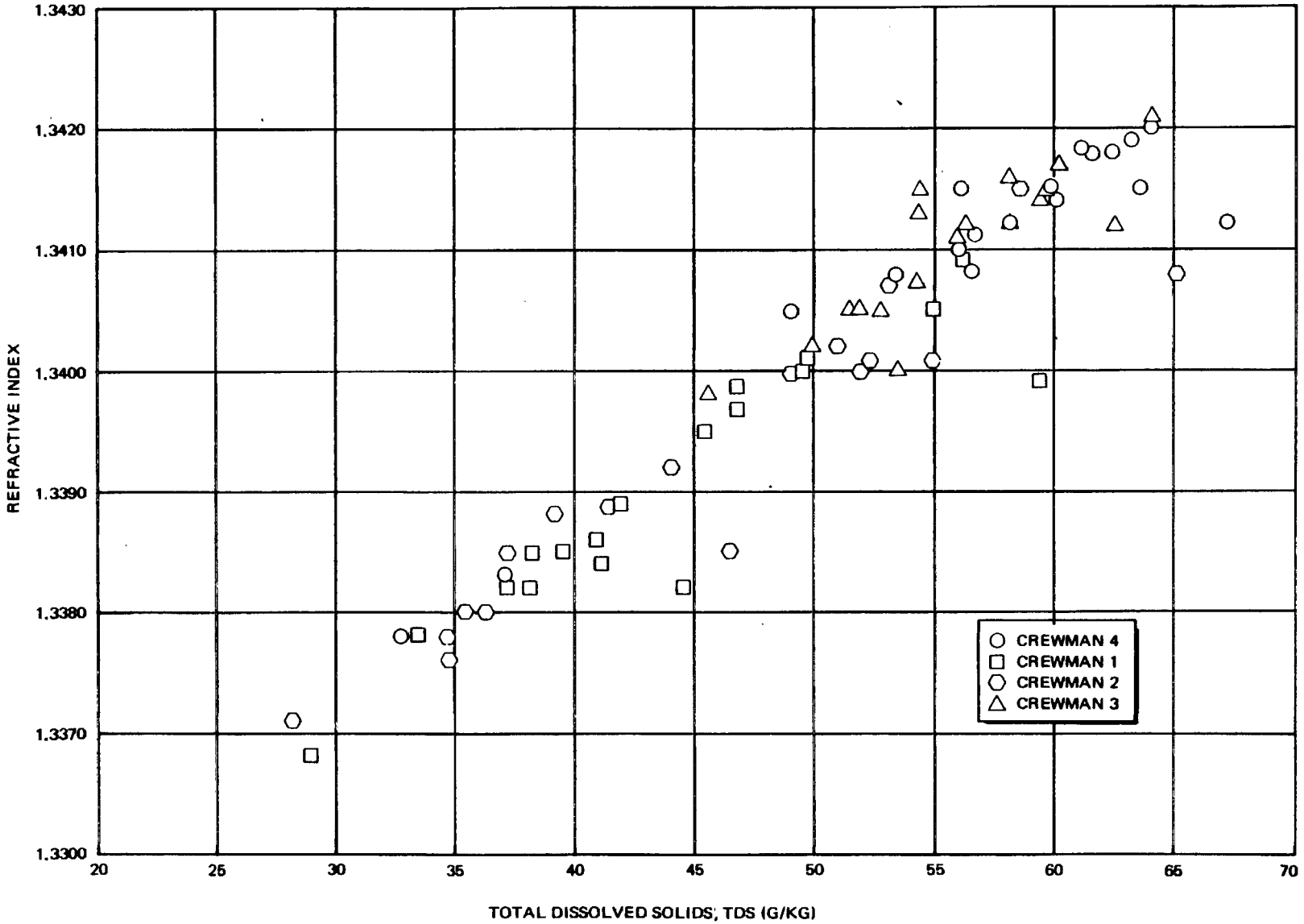


Figure 2-72. Refractive Index vs Total Dissolved Solids of Urine

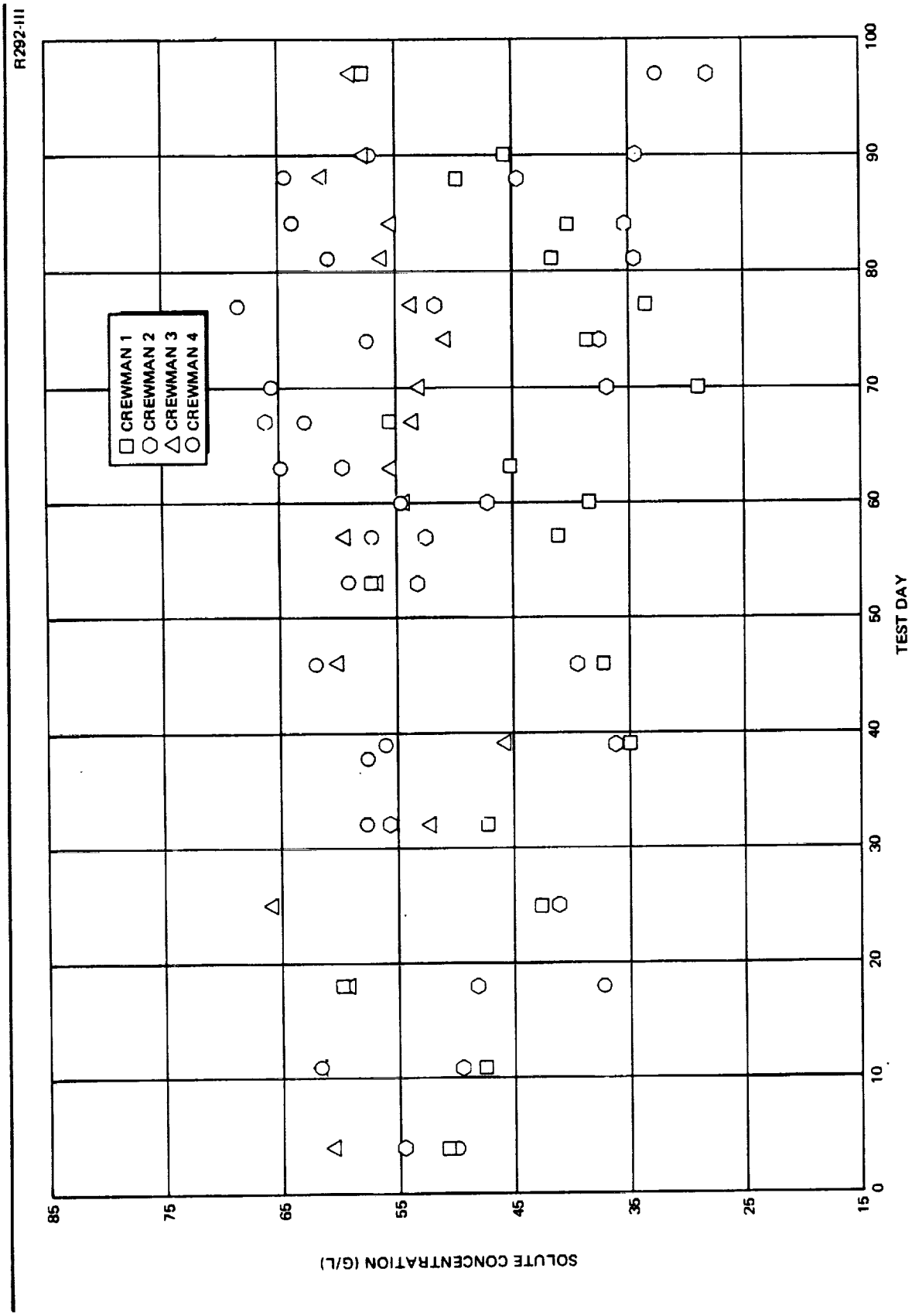


Figure 2-73. Solute Concentration of Urine

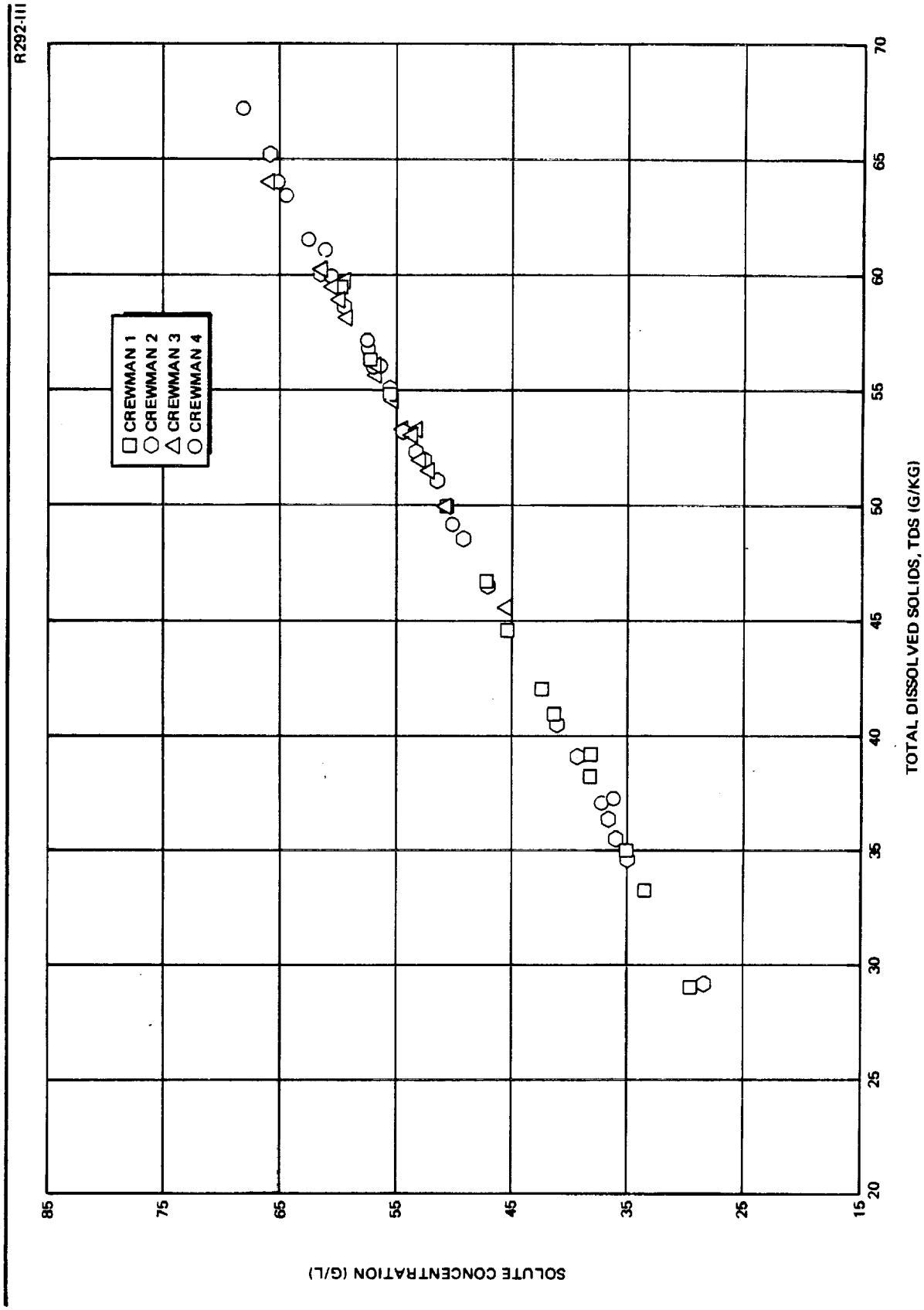


Figure 2-74. Solute Concentration Vs Total Dissolved Solids of Urine

In addition to accomplishing its prime function of sensible heat removal, the thermal conditioning unit was conceived around strict guidelines which limited designing for full optimum performance. These design guidelines included: (1) configuring to fit a predesignated minimum volume, (2) providing adequate performance over a wide range of cabin pressures, (3) fabricating from high-grade commercial or aircraft components, (4) limiting maintenance to filter changes, and (5) confining high temperatures resulting from excessive heat dissipation to the equipment area.

Humidity control was accomplished by removing atmospheric moisture in the zero-g condenser/separator of the open-loop wick evaporator unit of the water recovery subsystem. Design and performance of this unit is discussed in Section 2.2 of this report. The resulting effect on cabin humidity is presented below (Section 2.3.3).

2.3.1 Carbon Dioxide Concentrators

The function of the CO_2 concentrator is to maintain the partial pressure of CO_2 at approximately 507 N/m^2 (3.8 mm Hg) and to provide pure CO_2 for processing in the Sabatier reactor for oxygen recovery. This function was provided by an advanced solid amine unit with a molecular sieve unit as backup and an LiOH CO_2 removal unit for emergencies.

The solid amine concentrator was an experimental unit built specifically for the 90-day test from off-the-shelf hardware. It utilized a weak base amine ion exchange resin, IT-45, for CO_2 absorption. It was built by Hamilton-Standard under contract to NASA-LRC.

The molecular sieve CO_2 concentrator, used for CO_2 concentration during the 1968 60-day NASA/MDAC chamber test, was rebuilt and updated. The major changes to the unit were:

- Replacement of the two four-way electric air diverter valves isolating the silica gel beds with four three-way pneumatic valves.
- Addition of an Apollo suit compressor for circulation of cabin air through the unit.
- Replacement of the cycle timer with a more positive snap action switch, cam timer.
- Addition of a filter upstream of the CO_2 compressors to remove any dust coming from the beds.
- Complete rearrangement of component locations to obtain access for maintenance and part replacement and to meet installation space limitations.

2.3.1.1 Description of Operation

The two CO_2 concentrators used during the 90-day test are described in the following paragraphs.

Solid Amine

The basic components of the solid amine CO_2 concentrator unit are three separate beds packed with solid amine ion exchange resin particles, two circulation fans (one redundant), two condensing heat exchangers, two compressors (one redundant) to pump CO_2 to the accumulator, a boiler and superheater, water pumps, timer and cycle control unit, manifolds and sequence control valves. A schematic of the unit is shown in Figure 2-75 and the installed unit is shown in Figure 2-76.

Dehumidified cabin air from the humidity control outlet is drawn into the unit by the circulation fan. The air then passes through a filter and a condenser/heat exchanger to condition it to the desired temperature and relative humidity, and then enters the absorbing amine canister(s) where the CO_2 contained in the airstream is removed. The purified air is then returned to the cabin through the second condenser/heat exchanger. This heat exchanger cools the air and condenses the water removed from the absorbing bed during the absorption reaction. This water is returned to the water storage accumulator. The desorption of the amine beds is accomplished with superheated steam. Water is pumped from the storage accumulator to a two-stage water boiler. Heat is supplied from the Coolanol 35 heating fluid circuit. The steam generated in the boiler/superheater at 372 ± 2°K (210 ± 3°F) is passed through the amine bed where it condenses on the amine resin. The resultant heat and water release the CO_2 from the amine particles. The CO_2 is then reabsorbed downstream in the bed. After sufficient steam is condensed in the bed and the bed temperature is elevated, the

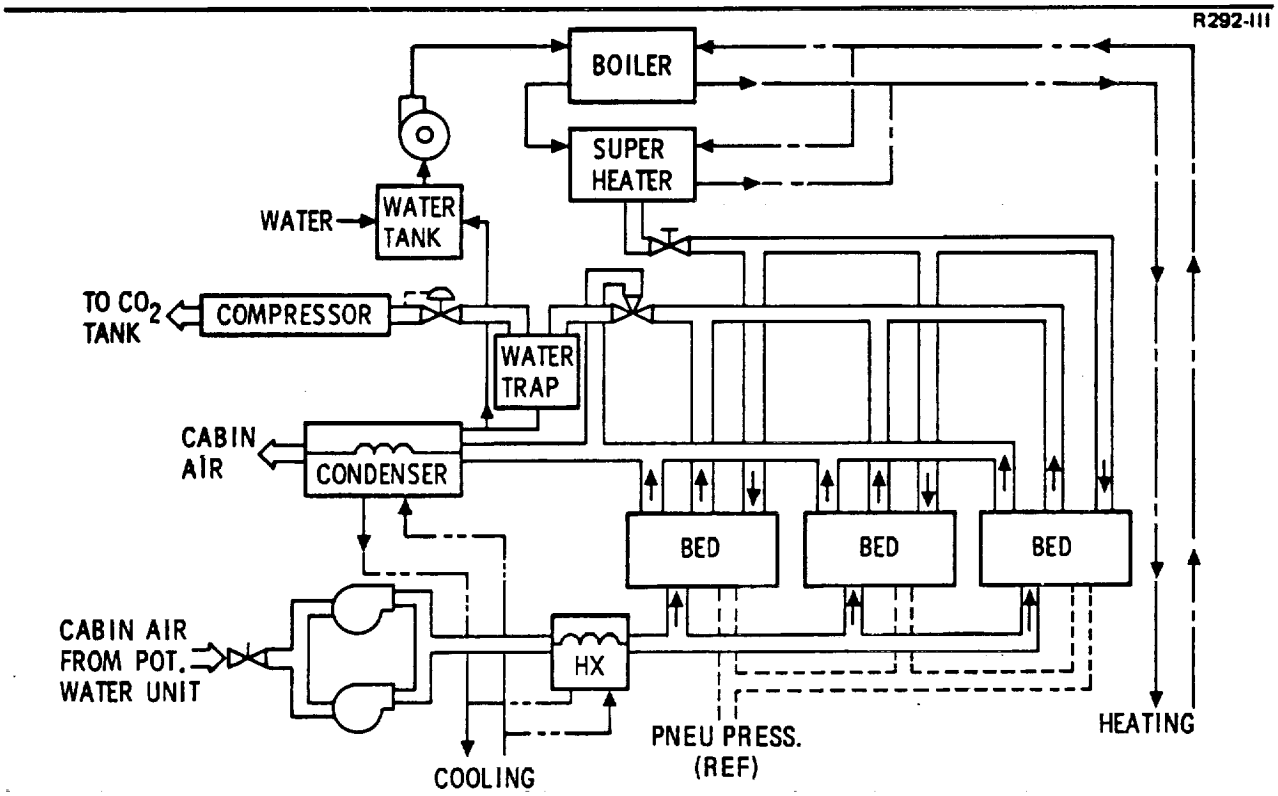


Figure 2-75. CO_2 Concentrator—Solid Amine Unit

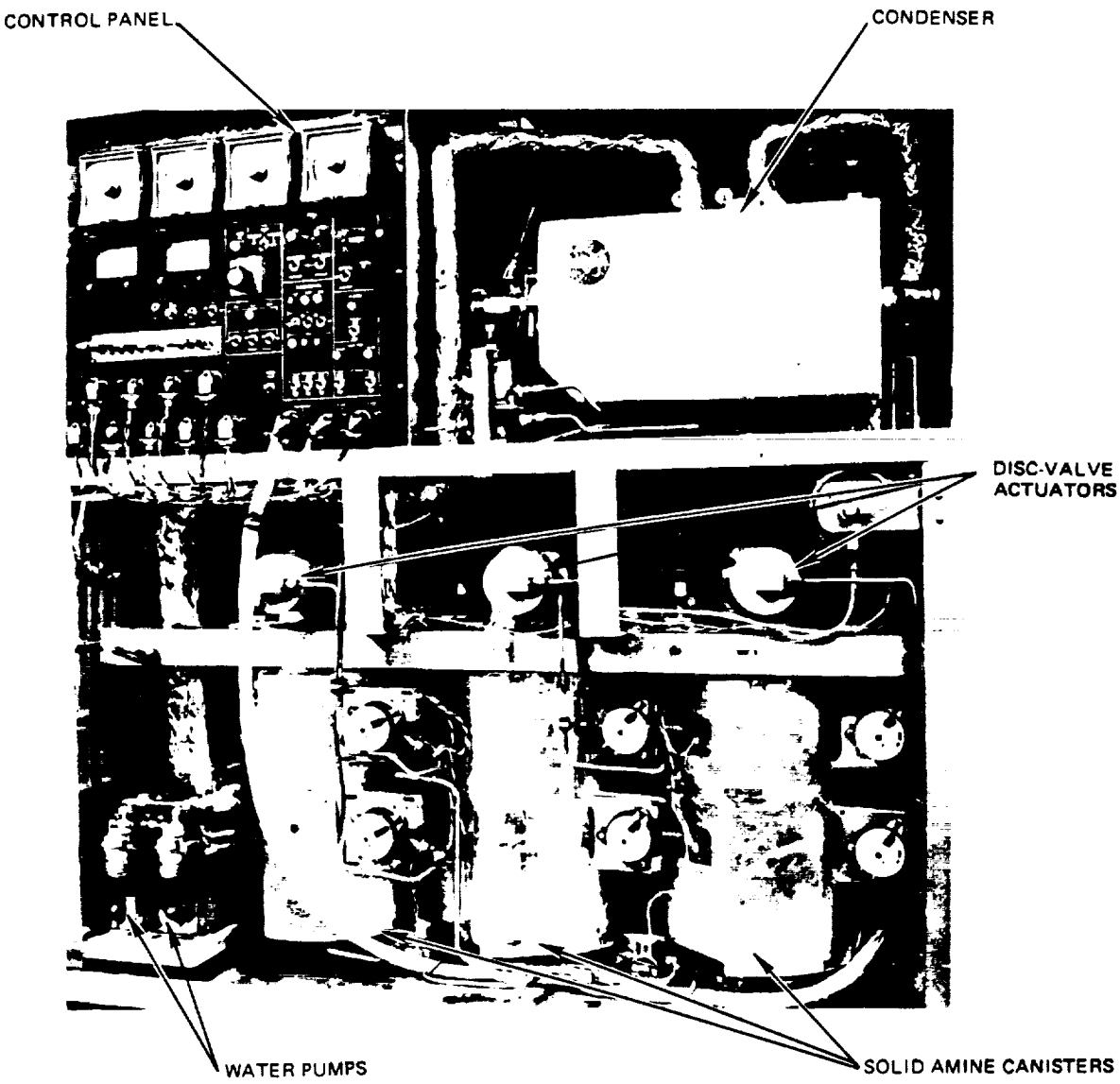


Figure 2-76. Solid Amine CO_2 Concentrator Unit

40

CO_2 is eluted from the canister. The CO_2 is then pumped to the CO_2 storage accumulator. The temperature sensor in the bed discharge line senses when the steam breaks through indicating the end of CO_2 desorption. A diverter valve then diverts the bed effluent (steam and water) to the cabin through the second condenser/heat exchanger. Either two- or three-bed operation is possible. In the three-bed mode, two beds are absorbing with the third on desorb, and the absorption half-cycle is normally twice as long as the desorption half-cycle. In the two-bed mode, the third bed is a redundant standby and the absorption and desorption portions of the cycle are of equal length.

Molecular Sieve

The basic components of the molecular sieve unit are two silica gel beds in parallel, a heat exchanger, a circulation blower (Apollo suit compressor), two molecular sieve beds in parallel, a sequence timer, manifolds, and sequence control valves. A condenser and zero-g water separator are provided to remove water vapor from the silica gel bed desorption airstream. A schematic of the unit is shown in Figure 2-77 and the installed unit is shown in Figure 2-78.

Function of the unit is as follows: cabin air is drawn through the adsorbing silica gel bed where the moisture in the air is removed to a dew point 227.6° to 216.5°K (-50° to -70°F). The flow then enters the circulation blower and

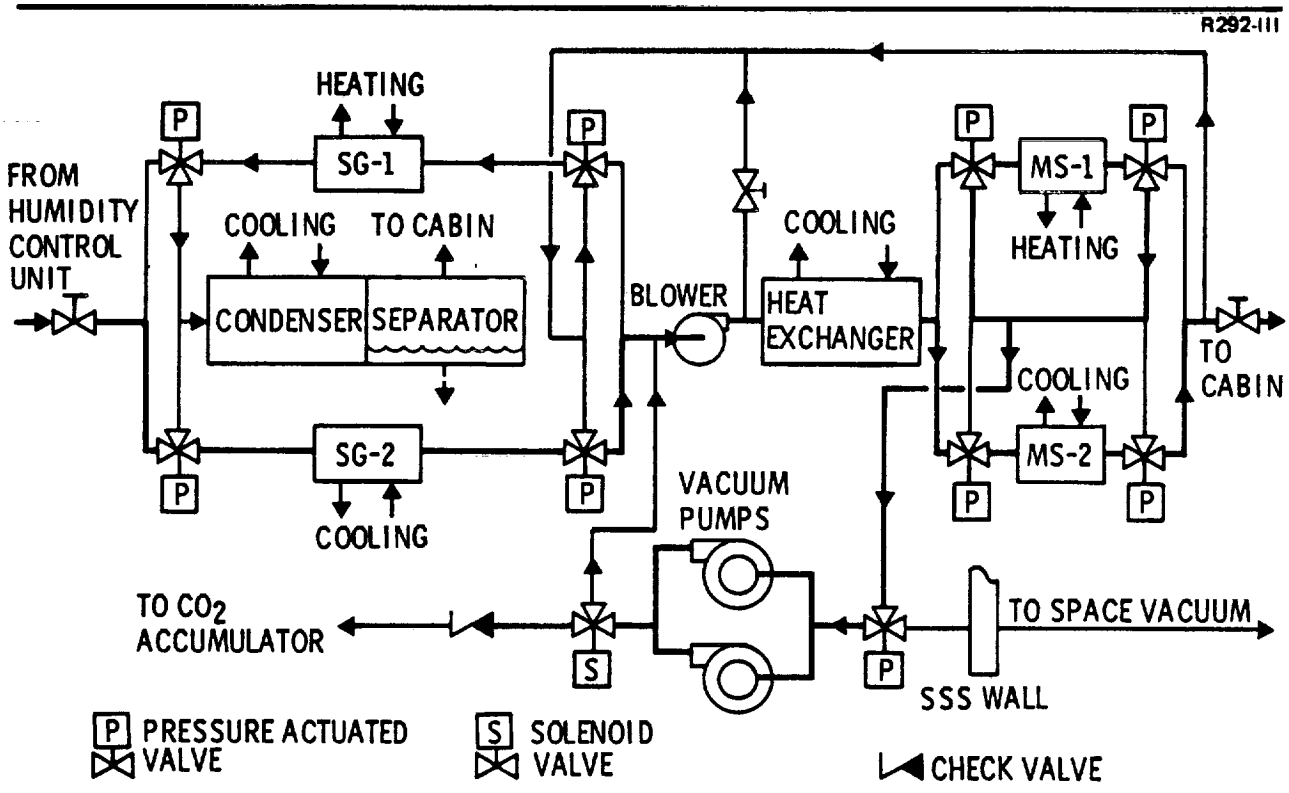


Figure 2-77. CO_2 Concentrator—Molecular Sieve Unit

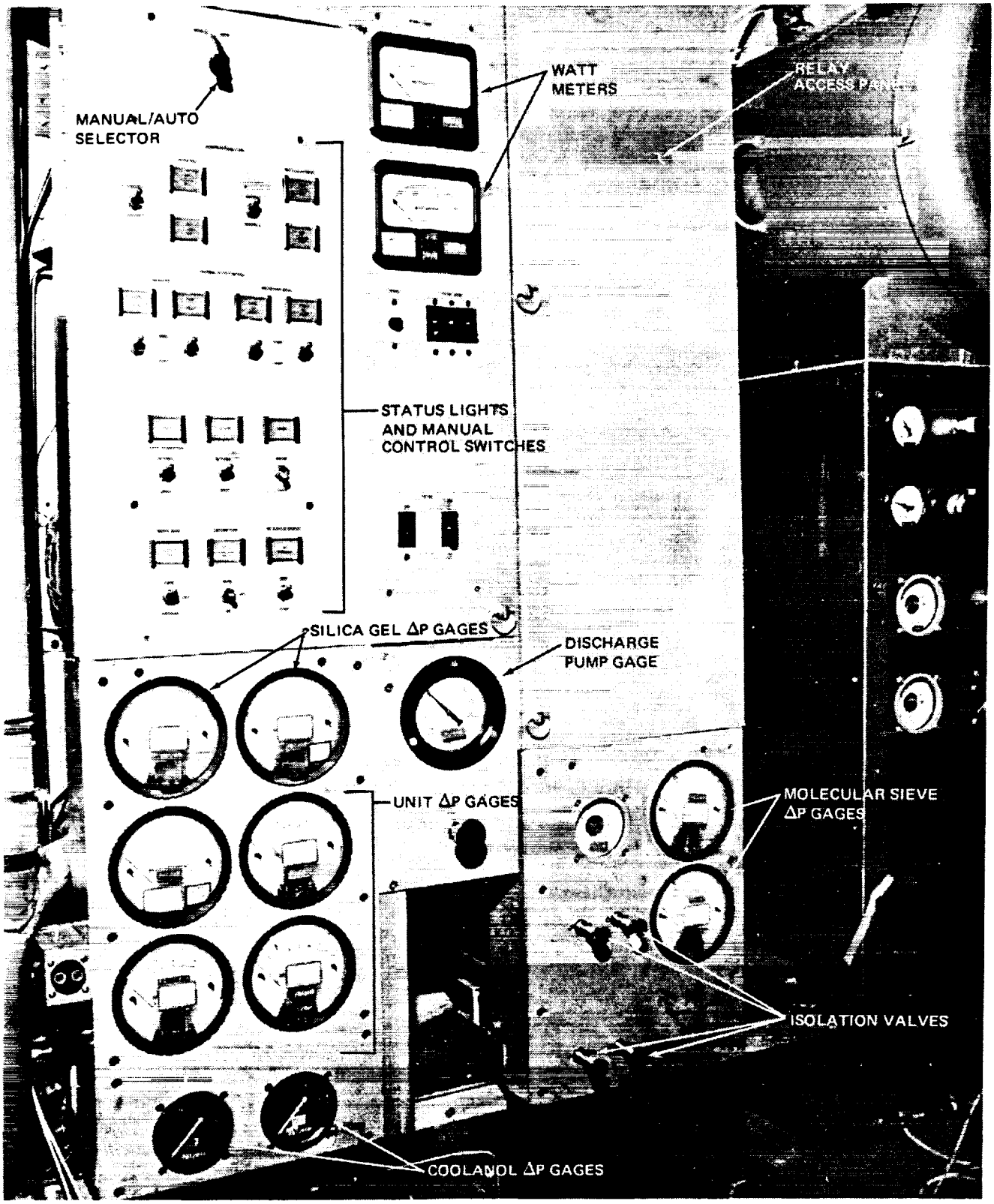


Figure 2-78. Molecular Sieve CO_2 Concentrator Unit

passes through the heat exchanger cooling it to 278° to 283°K (40° to 50°F). The cool, dry air then passes through the adsorbing molecular sieve bed where the CO_2 is removed. Approximately 80 percent of the dry, CO_2-free gas is discharged into the cabin. The remaining gas is passed to the desorbing silica gel canister which has been heated to approximately 422°K (300°F) with hot Coolanol. This dry gas flow picks up the water being driven off the beds by the heat and carries it to the condenser and separator where it is collected and passed to storage. The desorbing molecular sieve bed is meanwhile being regenerated, heated to 422°K (300°F) with the hot Coolanol and evacuated with a vacuum pump (or external vacuum system if not necessary to collect the CO_2). The vacuum pump pumps the desorbed CO_2 to an accumulator for storage. To remove the atmospheric gas from the canister voids at the start of the desorb cycle, the gas is pumped back to the cabin through the adsorbing molecular sieve bed for a few minutes. This insures pure CO_2 when flow is switched to the accumulator. After 30 minutes of desorption, cold Coolanol is pumped to the desorbing beds to cool them for 15 minutes before cycling to the adsorption cycle. The timer then sequences the valves to divert the cabin flow through the regenerated beds and place the beds now requiring regeneration on desorption cycle. Hot Coolanol will then flow through the desorbing beds and the cycle is repeated. The time for a complete adsorption, desorption, and cooling cycle is 90 minutes.

Lithium Hydroxide

For emergency use, in the event both the primary and backup CO_2 concentrator units were inoperative and repairs could not be completed before the CO_2 concentration reached excessive levels, a lithium hydroxide removal unit was installed. It had the capacity of 28 man-days CO_2 removal.

2.3.1.2 Performance

The cabin atmosphere CO_2 concentration during the 90-day run is shown in Figure 2-79. The abnormal operation peaks are numbered for reference. The significant events are as follows:

Test Day

3 Main valve on bed 1 did not automatically cycle. Crew had to rotate valve manually. This occurred approximately 200 times until day 14.

13 Peak (1). CO_2 removal efficiency reduced. It appears bed 2 was excessively wet, due to delays in performing the above-noted manual valve sequencing. Attempts to dry bed 2 failed.

14 Unit shutdown. Molecular sieve started up. Drying of solid amine beds accomplished.

18 Solid amine bed 1 isolated because of valve problem. It was suspected that valve sticking caused bed 2 to overwet. Operation on beds 2 and 3 initiated; molecular sieve shutdown.

19 Peak (2). Solid amine could not maintain the cabin CO_2 concentration within acceptable limits. Molecular sieve placed in operation.

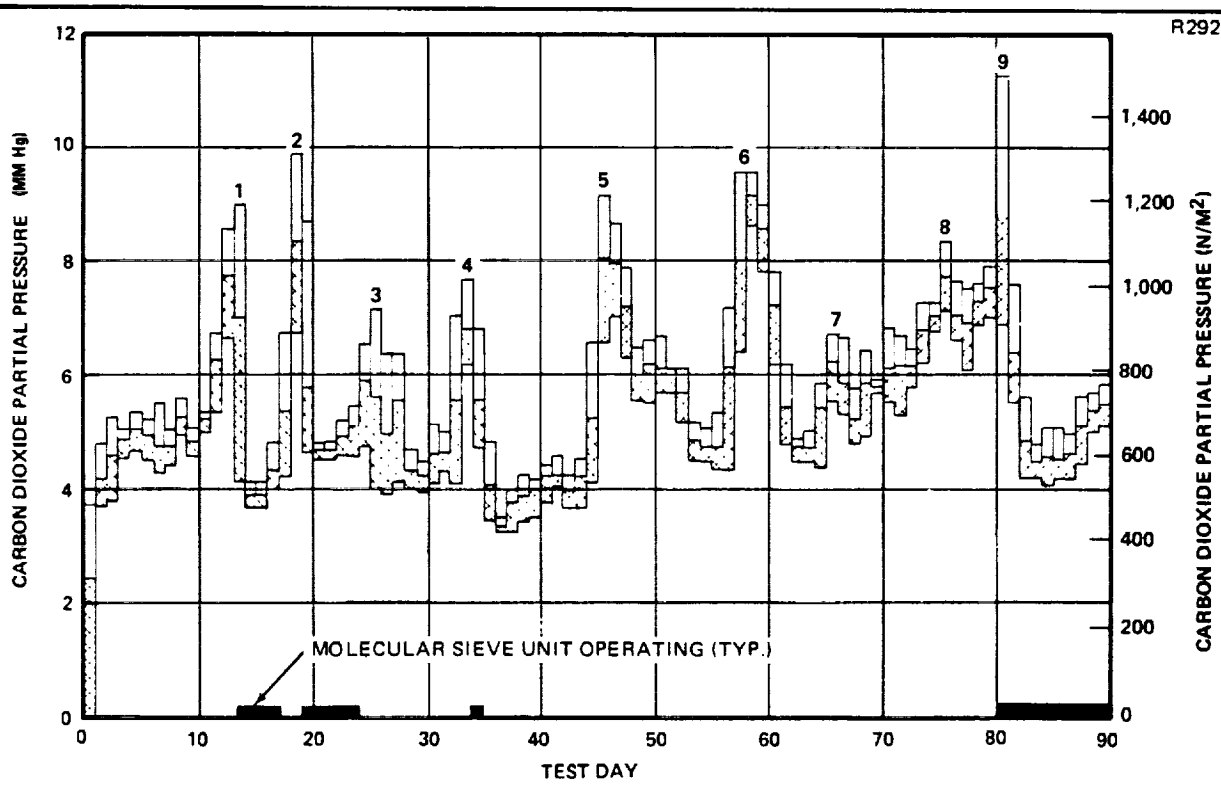


Figure 2-79. Carbon Dioxide Partial Pressure

Test Day

25 Problem in solid amine traced to shifting of inlet air thermocouple reference junction by 8°K (+15°F). Instrumentation recalibrated. Molecular sieve shutdown. Solid amine restarted; operation satisfactory.

26 to 28 Peak (3). Solid amine not maintaining CO_2 level. Evaluation showed steam generation rate too low. Water filter element changed, rate increased. Operation satisfactory.

33 Peak (4). Pneumatic compressor on solid amine valve actuation system failed. Solid amine shutdown. Molecular sieve started up.

34 Molecular sieve performance marginal due to water accumulation. Bakeout performed. Unit performance satisfactory after bakeout. Restarted solid amine unit, with gaseous nitrogen supplied to unit, replacing air compressor function.

45 and 46 Peak (5). Solid amine could not maintain the required CO_2 levels. It was suspected bed 2 was excessively wet. Bed 2 dried by "dry" desorb technique. Operation improved.

Test Day	
48	Condensate was observed to be flowing from the condenser outlet. Investigation revealed the condenser was full of water. The drain line was plugged. This caused excessive wetting of bed 2. The physical layout of the system allowed water trapped in the heat exchanger to drain back from the heat exchanger inlet to the discharge line from bed 2, and into bed 2. Therefore, bed 2 received excessive water. The water line was disconnected and backflushed through the heat exchanger.
58	Peak (6). High cabin CO_2 level. The heat exchanger again was plugged, causing excessive wetting of the beds. The heat exchanger was blown out again, beds "dry" desorbed. Performance improved. (This occurred approximately every 2 to 3 days until end of operation.)
65	Peak (7). Water filter changed allowing greater steam generation rate. Improved performance.
74	Plug fell out of amine bed 3 canister allowing several pounds of amine resin to leak out of the canister. Hole plugged. Performance marginal.
76	Peak (8). Solid amine could not maintain required CO_2 level. Cycle time shortened from 13 to 12 minutes.
80	Cycle time reduced to 11 minutes in attempt to improve performance.
81	Solid amine unit shutdown.
81	Molecular sieve started.
90	Test terminated.

A typical CO_2 breakthrough curve is shown in Figure 2-80 for the solid amine unit. These data were taken during test day 53. Also plotted in Figure 2-80 is the CO_2 accumulator buildup during the solid amine desorption cycles. The curves indicate a slight breakthrough toward the end of the cycle. The CO_2 bed exit pressure should ideally be below 0.267 kN/m^2 (2.0 mm Hg) during the entire cycle. Apparently, the bed wetness was not in the desired range. Figures 2-81, 2-82, and 2-83 present data on the molecular sieve performance for one complete cycle on test day 17. Figure 2-81 presents the bed temperature profile during the cycle. The molecular sieve bed temperatures are within normal design range. The silica gel bed 1 temperature during desorption is lower than desired. Apparently, the bed was excessively wet and complete desorption was not taking place. This is borne out by the dew point curve shown in Figure 2-82. For silica gel bed 2, the discharge dew point is approximately 11°K (20°F) higher than normal. This condition leads to the slightly degraded breakthrough curve of CO_2 shown in Figure 2-82. Bed 1 performance was not quite as good as bed 2 during molecular sieve unit operation. Figure 2-83 also shows that bed 2 performance is better than bed 1. The CO_2 pressure

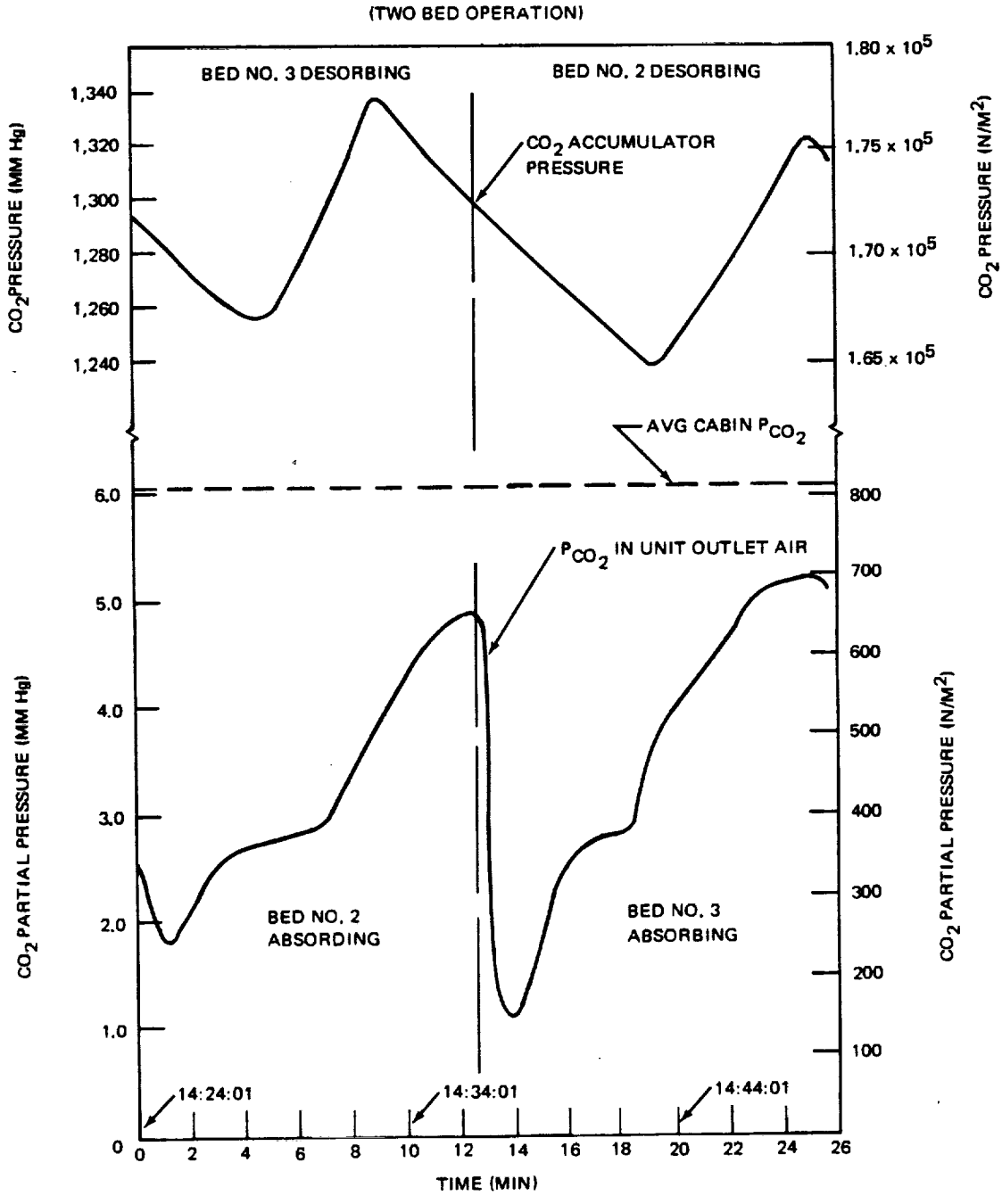


Figure 2-80. Solid Amine CO_2 Concentrator Performance (Day 53, 14:24:01 to 14:49:01)

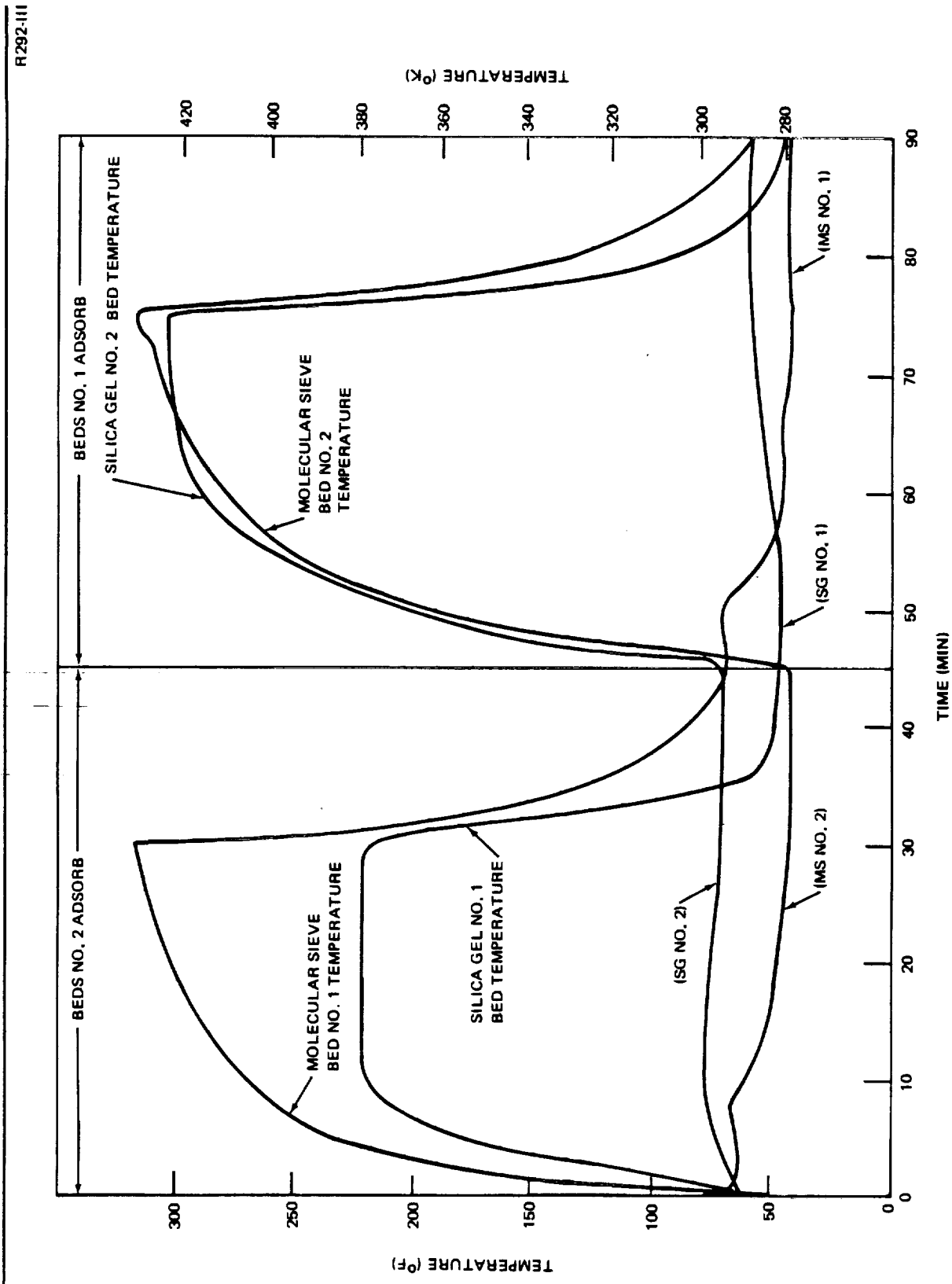


Figure 2-81. Molecular Sieve Temperature Performance (Day 17 – 1,000 Hours)

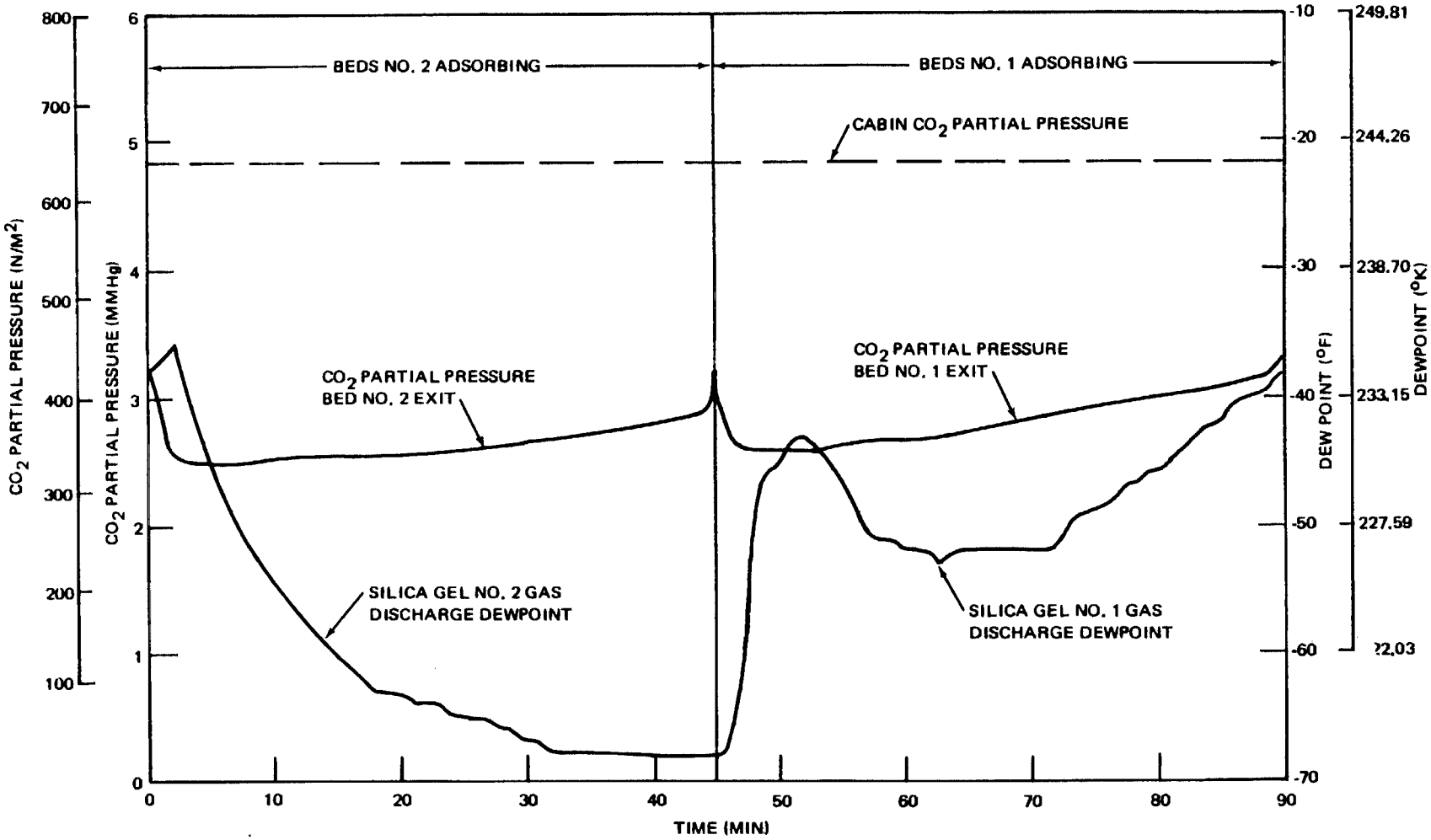


Figure 2-82. Molecular Sieve CO_2 Partial Pressure Performance (Day 17 – 1,000 Hours)

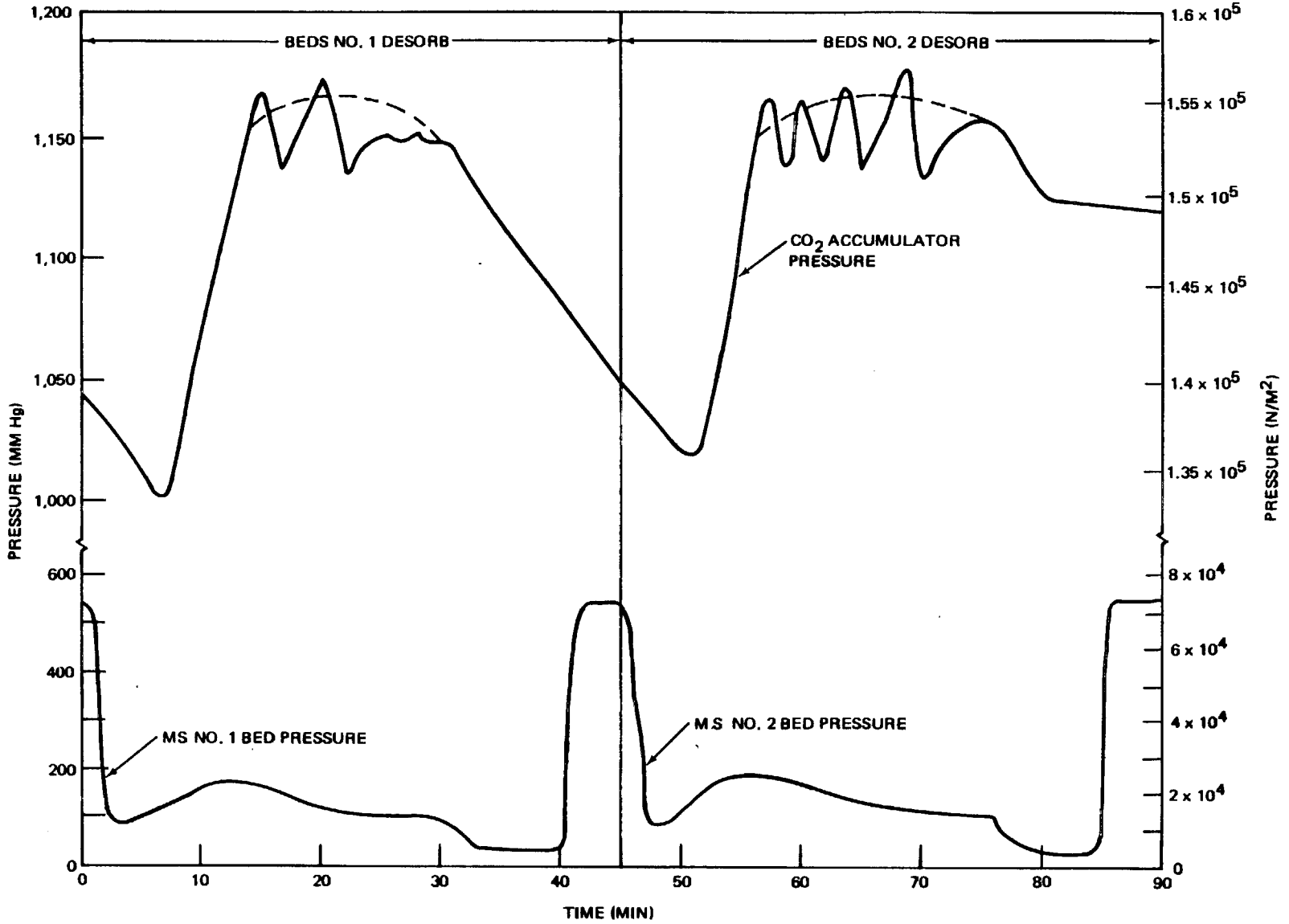


Figure 2-83. Molecular Sieve Pressure Performance (Day 17 – 1,000 Hours)

in the accumulator during bed 2 desorption built up to a greater pressure. The performance was within acceptable limits, however, and had continued operation been required for the molecular sieve, the situation might have corrected itself without a bakeout or maintenance.

A maintenance summary of the two concentrators is shown in Table 2-44. The majority of these maintenance activities has been discussed in the log of significant events. The remaining items were of a minor nature and did not result in unit downtime. These minor events for the solid amine unit consisted of switching to the backup blower, water pump and CO_2 compressor, when the redundant alternates malfunctioned, and the replacement of a sticking water solenoid valve. Minor problems with the molecular sieve unit included repairing a leak in the silica gel condensate tank and attempts to correct a malfunction of the molecular sieve purge diverter solenoid valve. This valve, which is activated by the sequence timer, normally cycles, at the start of the desorb cycle, to divert atmospheric gas from the canister voids back to the adsorbing molecular sieve bed. However, on day 34, it was noted that this valve was not seating properly and permitting CO_2 to flow back from the accumulator into the adsorbing molecular sieve bed. During the fault isolation procedures, the purge line was disconnected from the molecular sieve inlet, a check valve was installed between the accumulator and diverter valve, and the purge cycle time reduced from 6 to 4.5 minutes. Since this effort corrected the problem, the diverter valve was not replaced.

A significant performance factor is the thermal balance of each unit. The requirement for heating and cooling can constrain vehicle design. The typical thermal balance of each unit is shown in Figures 2-84 and 2-85.

2.3.2 Thermal Control

The thermal conditioning unit was designed to maintain temperature levels suitable for human comfort within the SSS. The thermal conditioning unit accomplished temperature control by removing sensible heat dissipated into the atmosphere from occupants, high temperature heat transfer lines, electric energy and the onboard Pu-238 radioisotope capsules.

2.3.2.1 Thermal Conditioning Unit Description

The thermal conditioning unit configuration (Figure 2-86) utilized during the 90-day test consisted of two supply blowers in parallel which drew cabin atmosphere through aluminum mesh filters for removing 5 to 10 μm particles [filter face area 0.372 m^2 (4 ft^2)], an acoustical sound trap, and a flow tube for measuring flow rate. The discharge from the two blowers passed through a noncondensing, extended-fin heat exchanger and an eliminator plate before entering the discharge acoustical sound trap. Conditioned atmosphere was furnished to the SSS living and bunk areas from a pressurized plenum with 19 low-induction-type perforated diffusers attached to its underside. Conditioned atmosphere was supplied to the equipment area by two rectangular diffusers mounted against the acoustical partition between the living and equipment areas. An atmospheric bleed of approximately 0.71 liters/sec (90 ft^3/hr) was also provided to the toxin control and sampling for the mass

Table 2-44

CO_2 CONCENTRATOR MAINTENANCE SUMMARY (Page 1 of 2)

Unit	Activity	Spares Usage	No. of Times	Hour
Solid Amine	Attempted to free sticking bed cycle Valve	-	1**	10.0
	Lubricated bed cycle valve	Krytox grease	1	1.0
	Dry-down of beds*	-	3	1.5
	Changed water filter*	Filter element and Krytox	11	1.8
	Cleaned pneumatic compressor	-	1	2.0
	Installed alternate pneumatic source	Miscellaneous fittings and tubing	1	2.5
	Switched to backup blower	-	1	0.2
	Switched to backup water pump	-	1	0.2
	Backflushed condenser drain with N_2	Miscellaneous fluid fittings and tubing	8	4.0
	Switched to backup CO_2 compressor	-	1	0.2
	Corrected sticking water solenoid valve	-	14	5.5
	Replaced water solenoid valve	Valve and miscellaneous fluid fittings	1	2.0
	Installed drip pan at condenser outlet	Miscellaneous fluid fittings and tubing	1	2.0
	Plugged hole in bed No. 3	Aluminum tape	2	0.5
		Subtotal	47	33.4

**This problem occurred over 200 times between days 4 and 14.

Table 2-44

CO_2 CONCENTRATOR MAINTENANCE SUMMARY (Page 2 of 2)

Unit	Activity	Spares Usage	No. of Times	Hour
Molecular Sieve	Repair leak in silica gel condensate tank	Miscellaneous fluid fittings and RTV sealant	1	2.0
	Baked-out molecular sieve and silica gel beds*	-	1	0.7
	Installed check valve between accumulator and valve	Check valve	1	0.5
	Corrected sticking diverter valve	-	2	0.5
	Disconnected line between accumulator and molecular sieve bed	-	2	0.5
	Adjusted cam timer	-	1	0.2
		Subtotal	8	4.4
		Total	55	37.8
		*Maintenance	-15	-4.0
		Repairs	40	33.8

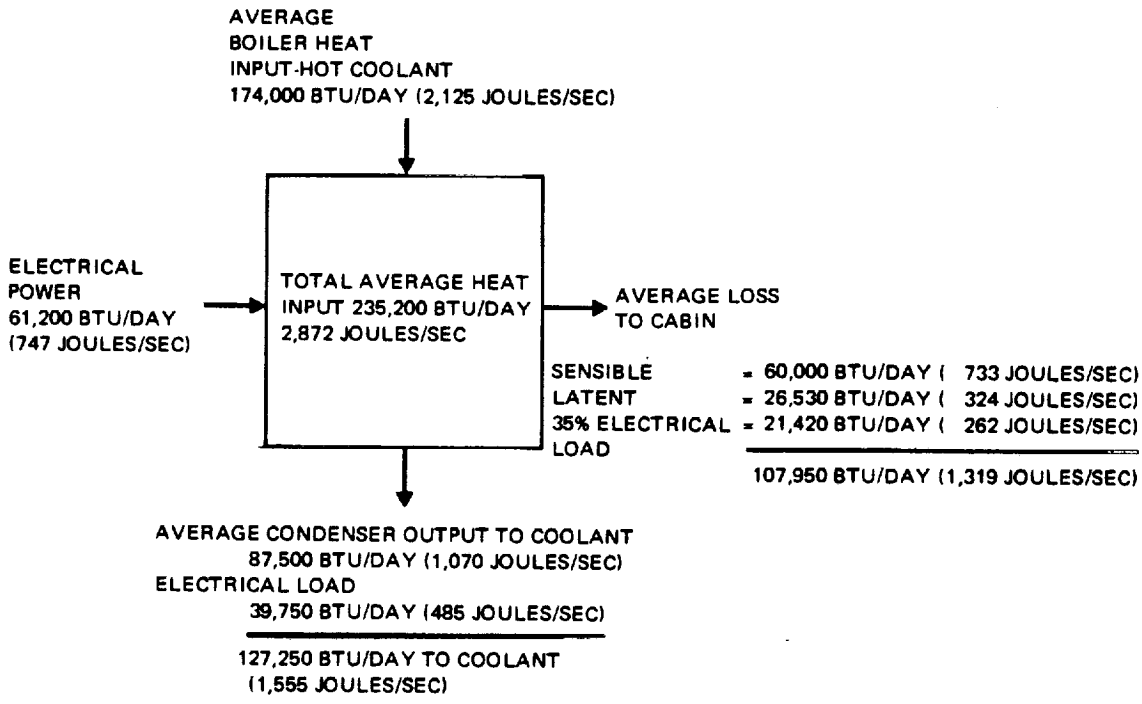


Figure 2-84. Thermal Balance of Solid Amine Unit

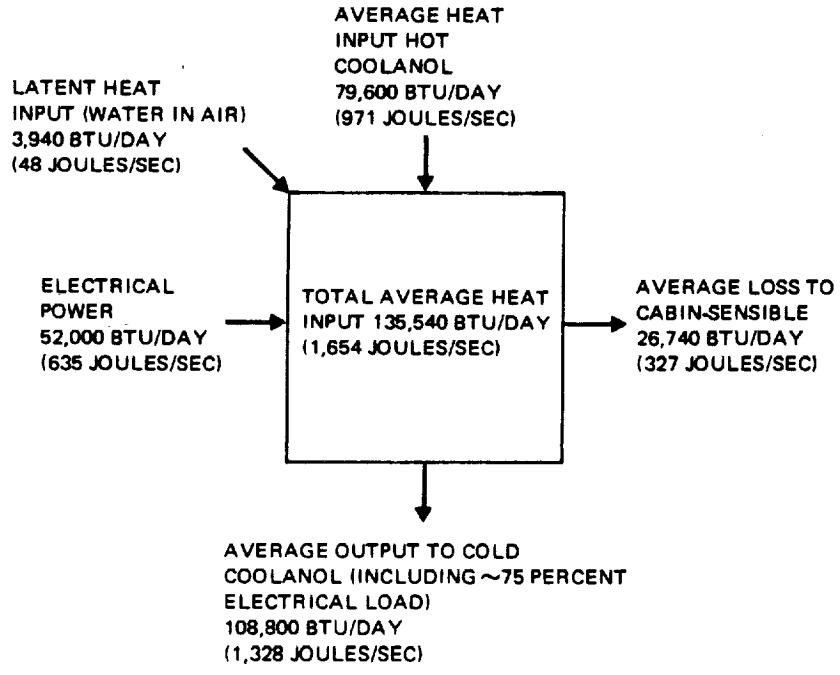


Figure 2-85. Thermal Balance of Molecular Sieve Unit

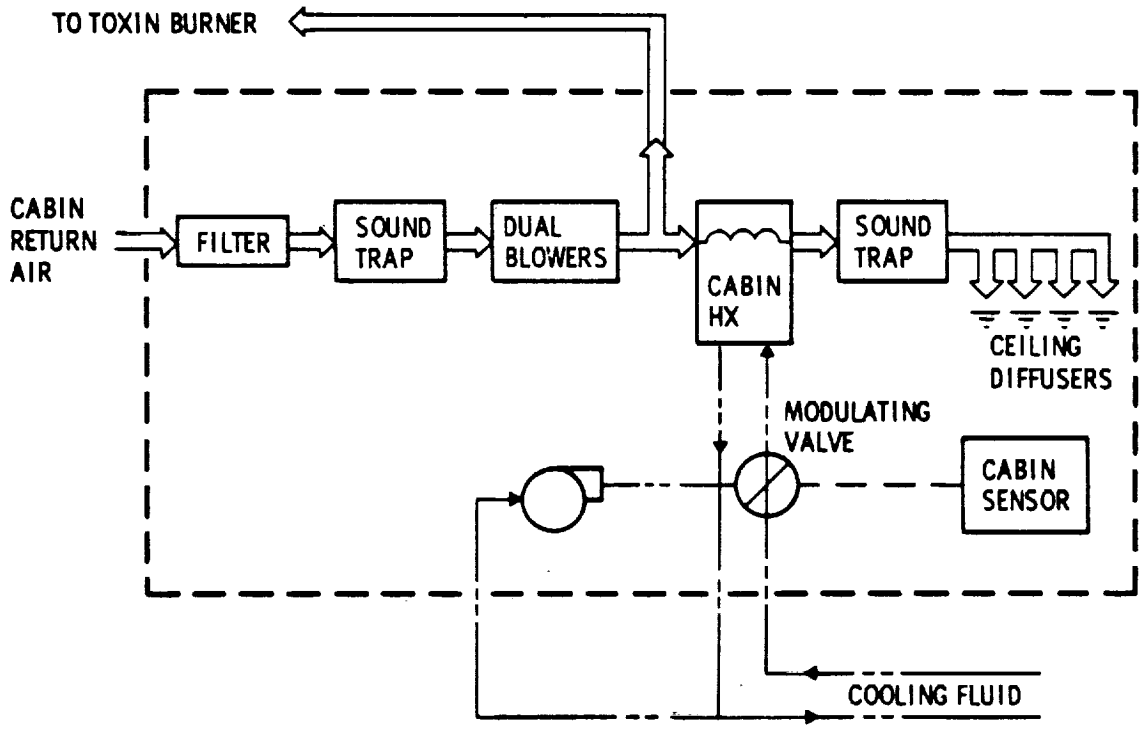


Figure 2-86. Thermal Conditioning Unit Schematic

spectrometer. Return atmosphere from the living and bunk areas passed either the acoustical trap mounted in the door or through the acoustical trap located in the partition. The compact thermal conditioning unit also incorporated two specially designed dynamic transitions which served to reduce the noise and pressure loss due to high-velocity and turbulent atmosphere. One transition was installed between the flow tube and the parallel blowers while the other transition was installed between the blowers and the noncondensing heat exchanger.

Coolanol 35 was used in the liquid side of the heat exchanger as the coolant fluid. The SSS temperature was controlled by utilizing electronic sensors with a thermostat located in the living area approximately 1.52 m (5 ft) from the floor. The electronic controls consisted of a modified Wheatstone bridge with a motor-balancing potentiometer, a low-limit heat exchanger fluid inlet temperature controller, and an amplifier-discriminator circuit. The primary signal to balance or unbalance the bridge network was provided by the thermostat located in the living area.

A drain pan beneath the heat exchanger and an eliminator plate on the discharge side of the heat exchanger were provided to collect any condensate which might result from dew points higher than design levels.

2.3.2.2 Thermal Conditioning Unit Performance

Performance of the thermal conditioning unit was monitored by thermocouples installed to measure temperatures within the three areas of the SSS, return atmosphere, heat exchanger discharge atmosphere, and inlet-outlet coolant

fluid. In addition, atmospheric mass flow through the unit and coolant mass flow through the heat exchanger were measured. This was accomplished by using a calibrated flow tube with a differential pressure transducer for the atmosphere and turbine flow meter in the supply coolant to the heat exchanger. Signals from this instrumentation were fed into preselected channels of the LSDS where values were recorded on a half-hour basis throughout the test.

The results of the thermal conditioning unit performance were reflected in the SSS atmospheric temperature levels maintained during the 90-day test. Daily average temperatures for the bunk area, living area, and equipment area are shown in Figure 2-87. Examination of these data indicates fluctuations of 0.5°K (1°F), 1.1°K (2°F), and 4.1°K (7.5°F) respectively. Heat removal rate by the thermal conditioning unit heat exchanger varied between 4,180 joules/sec (14,272 Btu/hr) and 5,850 joules/sec (19,980 Btu/hr). Total heat rejection rates for the SSS were between 6,690 joules/sec (22,800 Btu/hr) and 8,650 joules/sec (29,500 Btu/hr) during the test. The difference between the total rejection rate and the thermal conditioning removal rate consisted of energy rejected directly into the thermal control fluid loop through cold plates or compact extended surface heat exchangers. Units incorporating these include the solid amine, wick evaporator, CO_2 concentrator, VD-VF potable water unit, and wash water unit. Peak thermal conditioning heat rates correspond well with high-temperature periods. The atmospheric mass flow rate remained essentially constant throughout the test. A flow rate decrease of approximately 0.0257 kg/sec (204 lb/hr) was noted from the initial level of 0.825 kg/sec (6,546 lb/hr) by test day 70. This decrease was due to slight clogging of the coarse particle (i.e., 5-10 μm) filters which restricted the atmosphere mass flow.

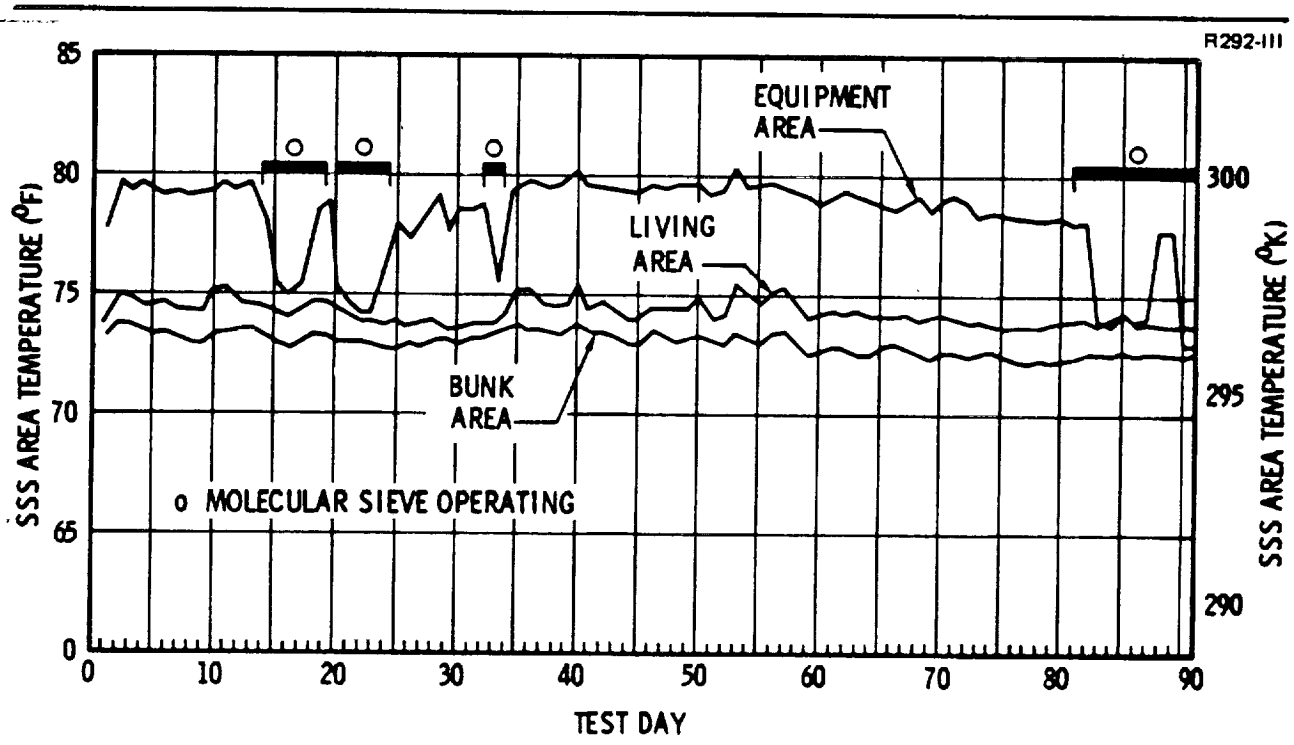


Figure 2-87. Average Test Day Simulator Temperatures

Design and operational performance parameters are tabulated in Table 2-45 for comparison. Closer temperature control of the bunk and crew area was realized during the test than thought possible during the design formulation. However, the upper limit on equipment area temperature was exceeded during much of the test. This was due primarily to higher heat dissipation within the equipment area than allowed for in the design. Atmospheric diffusion rates in the equipment area were designed to remove 13.45 joules/sec-m^3 (1.3 Btu/hr-ft^3). Heat dissipation densities in this area exceeded 17.1 joules/sec-m^3 (1.65 Btu/hr-ft^3) during all but three periods of the 90-day test. These three periods occurred on test day 14 through 17, 20 through 24, and 81 through 91. Figure 2-87 shows the equipment area temperature dropping from the previous highs during these periods. All three periods occurred at a time when the advanced (solid amine) CO_2 removal unit was off line and the baseline (molecular sieve) CO_2 removal unit was on line.

Examination of the sensible heat loss to the SSS atmosphere by each unit indicates the advanced CO_2 removal unit increased the thermal conditioning load by 2,210 joules/sec (6,482 Btu/hr).

The heat exchanger effectiveness achieved during the test was considerably below that indicated by the manufacturer for this service. Calculations show the realized operation effectiveness to be approximately 0.2 (i.e., $\epsilon_T = 0.2$) rather than 0.5 as indicated by the supplier. This was determined before the test and the supply fluid (Coolanol 35) temperature to the heat exchanger was reduced approximately 4.5°K (8°F) to meet the design temperature level in the crew area. Standard commercial heat exchangers are commonly designed and rated for use with water rather than with Coolanol 35. Improper techniques were apparently employed in rating this unit for Coolanol 35 use. Heat transfer coefficient (H_c) for Coolanol 35 is 1/10 of that for water (flow and inlet temperature being equal).

Some humidity condensation occurred in the thermal control heat exchangers, particularly during periods of high atmospheric dew point. This condensation occurred on the end of the heat exchanger because of an atmospheric leak between the end plate and cold tube return bends. No condensation was observed within the extended fin portion even though the fluid temperature was below the simulator atmosphere dew point. A drain pan was installed to catch the water as the leak was discovered after the heat exchanger was installed. Condensation from this source averaged 0.544 kg/day (1.2 lb/day). During the test the crew installed a line between the pan drain and overflow sump which was located beneath the wick evaporator condenser/separator to automatically drain this condensate.

The atmospheric filters installed in the return duct of the thermal conditioning unit did not require changing during the test. Their condition at test completion is shown in Figure 2-88.

2.3.3 Humidity Control

The humidity control unit (Figure 2-89) was integral with the wick evaporator and shares the blower, ducting, and zero-g condenser/separator. A two-position automatic control system was installed to shutdown the blower when the relative humidity dropped below 40 percent. The control system used a lithium chloride electronic humidistat located in the crew area, which

Table 2-45

THERMAL CONDITIONING DESIGN AND OPERATIONAL DATA

Data	Design Performance	90-Day Test Performance
Temperatures		
Living area	294 ± 2.8°K (70 ± 5°F)	296.5 ± 0.8°K (74 ± 1.5°F)
Bunk area	294 ± 2.8°K (70 ± 5°F)	296.0 ± 0.7°K (73 ± 1.3°F)
Equipment area	294 ± 2.8°K (70 ± 5°F)	298 ± 2°K (77 ± 3.6°F)
Inlet heat exchange fluid	282 ± 2.2°K (48 ± 4°F)	276.5 ± 2.2°K (38 ± 4°F)
Flows		
Atmospheric	0.945 m^3/sec [2,000 cfm (actual)]	1.01 m^3/sec [2,130 cfm (actual)]
Heat exchanger (Coolanol 35)	1.0 liters/sec (16 gpm)	1.2 liters/sec (19 gpm)
Normal Maintenance		
During test	None	None
Filter changes	One	None
Total heat rejection	7040 joules/sec (24,000 Btu/hr)	5850 joules/sec (19,980 Btu/hr)

R292-III

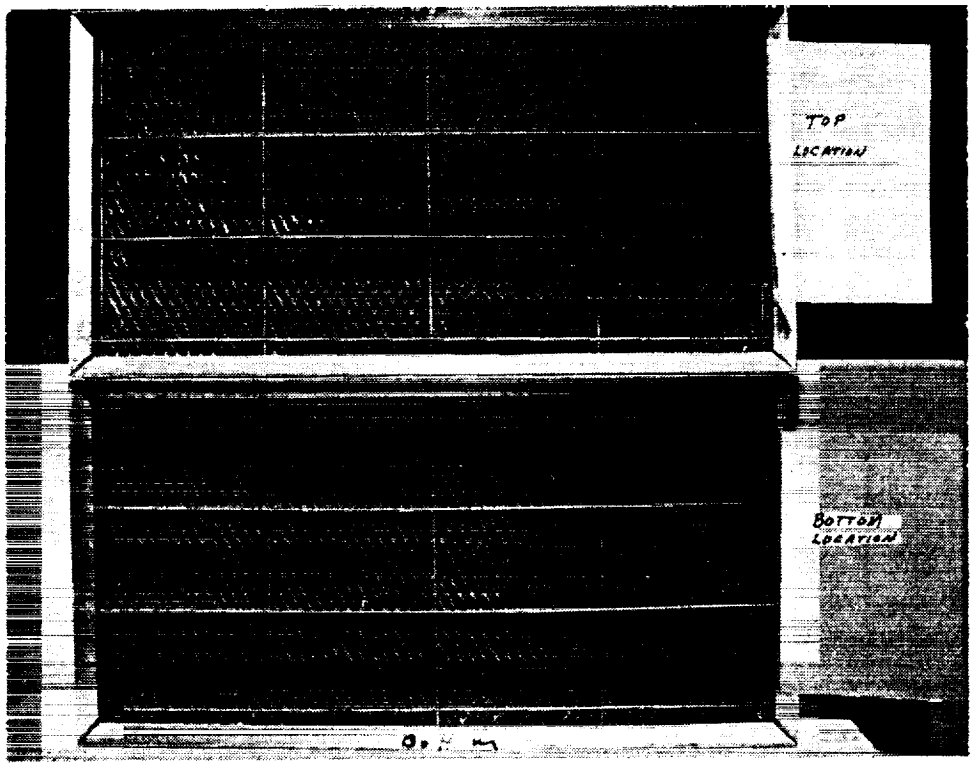


Figure 2-88. Thermal Conditioning Unit Coarse Particle Filters at Test Completion

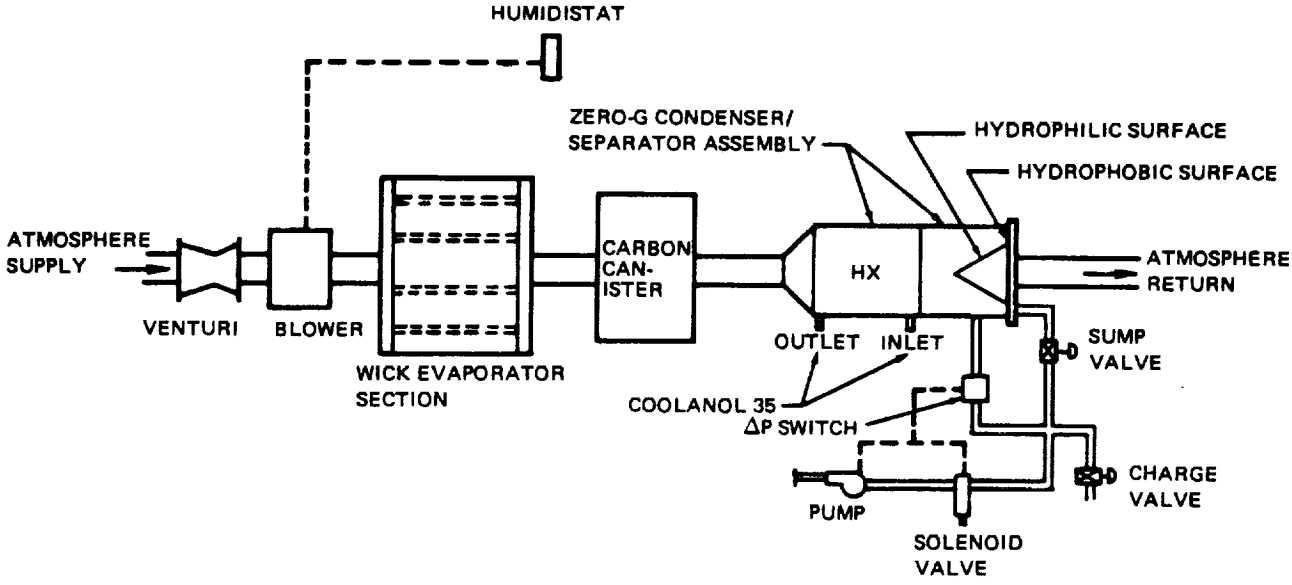


Figure 2-89. Humidity Control Schematic

furnished a signal to balance or unbalance the Wheatstone bridge. When operating, the blower delivered a constant atmospheric mass flow of 0.034 kg/sec (270 lb/hr) through the zero-g condenser/separator. A description of the zero-g condenser/separator, its method of operation, and the maintenance performed is covered in Section 2.2.

Relative humidity was in the upper design range throughout most of the test and exceeded the design range during seven periods. The humidity level never reached the lower limit which would initiate shutdown of the blower by the control system. SSS atmospheric water vapor levels are reflected in Figure 2-90, which indicates the minimum, maximum, and average dew point levels on a daily basis. The high atmospheric water vapor content is not indicative of poor humidity control unit performance as test data show that the humidity condensate processed was 1, 130 kg (2, 492 lb) during the 90 days. This production is more than 200 percent of the design capacity of the unit. The high humidity processing rate and the high atmosphere water content can be attributed to excessive water dissipation in the SSS atmosphere by one advanced subsystem (solid amine), except for the final days of the test where frequent clothes washing cycles contributed to the appreciable water vapor.

2.4 ATMOSPHERE SUPPLY AND PRESSURIZATION

Atmosphere supply and pressurization during the 90-day test was accomplished by the integrated Sabatier/toxin control unit, the water electrolysis units, and the two-gas control units. The Sabatier reactor converted the CO_2 concentrated by the atmosphere purification equipment into water and methane. The methane was discharged overboard and the water was electrolyzed to hydrogen and oxygen. The hydrogen was returned to the Sabatier reactor and the oxygen

R292-III

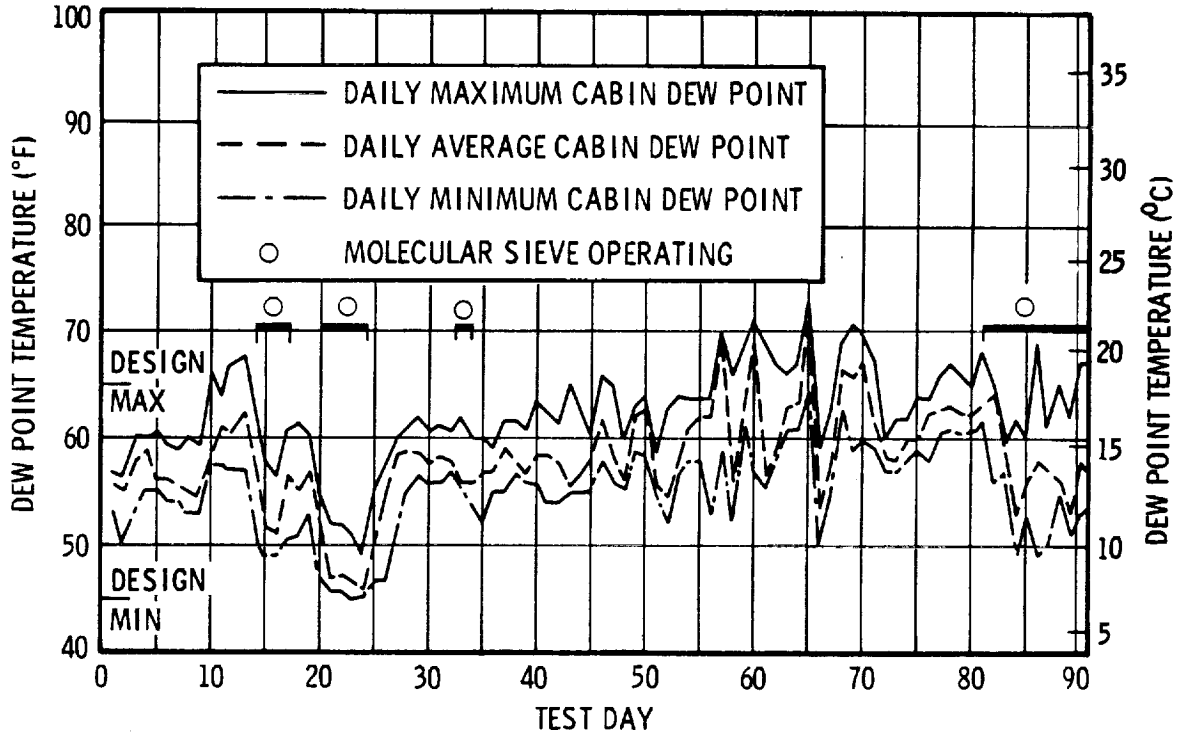


Figure 2-90. Dew Point Levels

was supplied to the SSS atmosphere as required to make up for crew consumption and leakage. The control of oxygen and nitrogen to the chamber was done by the two-gas controls from signals of the mass spectrometer sensor.

Operation of the Sabatier reactor during the initial 30 days of the 90-day manned test was somewhat erratic due to catalyst poisoning which was found to be caused by trace quantities of Freon 113 appearing in the carbon dioxide. Operation returned to normal after replacing the catalyst and adding a carbon filter to remove the contaminant from the carbon dioxide. The unit produced about 162 kg (357 lb) of water during the test. The average water production rate for the last 60 days was 1.99 kg/day (4.38 lb/day). When the reactor was operational, the conversion efficiency of hydrogen to water and methane was over 95 percent. The toxin burner operated throughout the test except for a period of 14 days in which it was turned off to evaluate the rate of trace contaminant increase.

Three different water electrolysis units were used during this test. A commercial unit was used for backup to the two experimental units. One experimental unit uses a vapor feed and intermittent circulation of electrolyte and was installed inside the SSS. The other unit uses a liquid feed with continuous electrolyte circulation and was installed outside the SSS. All three units were operated during the test period. The experimental units provided 71.6 percent of the total hydrogen required and 68.3 percent of the total oxygen required. All units experienced failures. Some of these failures caused early shutdown because inaccessibility and lack of proper parts, other failures were repairable. This program indicated that additional development and testing of water electrolysis systems is needed. Greater care in hardware selection should be made and electrolytic cells should be designed to perform reliably under adverse startup, operating, and shutdown conditions. Improvements in the performance of two-phase separators is also required.

The unit for controlling and metering the supply of atmospheric gases to the SSS functioned successfully. A four-gas mass spectrometer was utilized to provide the control signals to the atmospheric controller. The controller added 392 kg (862 lb) oxygen and 127 kg (279 lb) of nitrogen to the SSS during the test. During most of the test, the oxygen partial pressure was controlled within ± 67 N/m^2 (± 0.5 mm Hg) of the control setpoint of 20.7 kN/m^2 (155 mm Hg) and the nitrogen partial pressure within ± 1.0 kN/m^2 (± 8 mm Hg) of the control setpoint. The greater variation of the nitrogen channel was apparently due to the higher than predicted cabin leakage associated with a low control loop gain, and can be improved by simple design modifications.

2.4.1 Integrated Sabatier Reactor/Toxin Control

The Sabatier reactor functioned to recover oxygen from the carbon dioxide exhaled by the crew. The carbon dioxide was reacted with hydrogen from the electrolysis unit at a temperature of about 644°K (700°F) in the presence of a nickel catalyst to produce water for the electrolysis unit, methane (exhausted), and heat.

The toxin burner oxidized low-molecular-weight hydrocarbons, methane, and carbon monoxide to carbon dioxide and water vapor. This reaction occurred

at 590° to 644°K (600° to 700°F) in the presence of a catalyst. Because of the low concentraction of oxidizable material, heat must be added to maintain reaction temperature.

The integration was planned to use the heat produced by the Sabatier reactor to support the toxin burner operation, thereby reducing spacecraft power requirements.

2.4.1.1 Equipment Description

The primary components of the Sabatier reactor were the CO_2 pressure regulator, H_2 and CO_2 mixture control valves, a catalytic reactor bed, a reactor pressure control valve, and a zero-g condenser/water separator. An electric heater was provided in the Sabatier cooling air inlet line for reactor startup operations only. The toxin burner consisted of a regenerative heat exchanger, an electric heating element, a temperature controller, and a reactor with a Hopcalite catalyst. A schematic of the integrated unit is presented in Figure 2-91. The unit as installed is shown in Figure 2-92.

The Sabatier reactor obtains CO_2 at an accumulator pressure of 140 to 210 kN/m^2 (20 to 30 psia). The CO_2 flows through the pressure regulator, which obtains a pressure reference from the H_2 supply. The regulated CO_2 then flows through a control valve under critical flow conditions. The H_2 flows directly to a separate critical flow-control valve. The two gas streams mix downstream of the control valves and then flow into the reactor. The reactor is a jacketed cylinder; the inner cavity contains the nickel-on-Kieselguhr catalyst. Air from the toxin burner regenerative heat exchanger flows through the jacket to remove

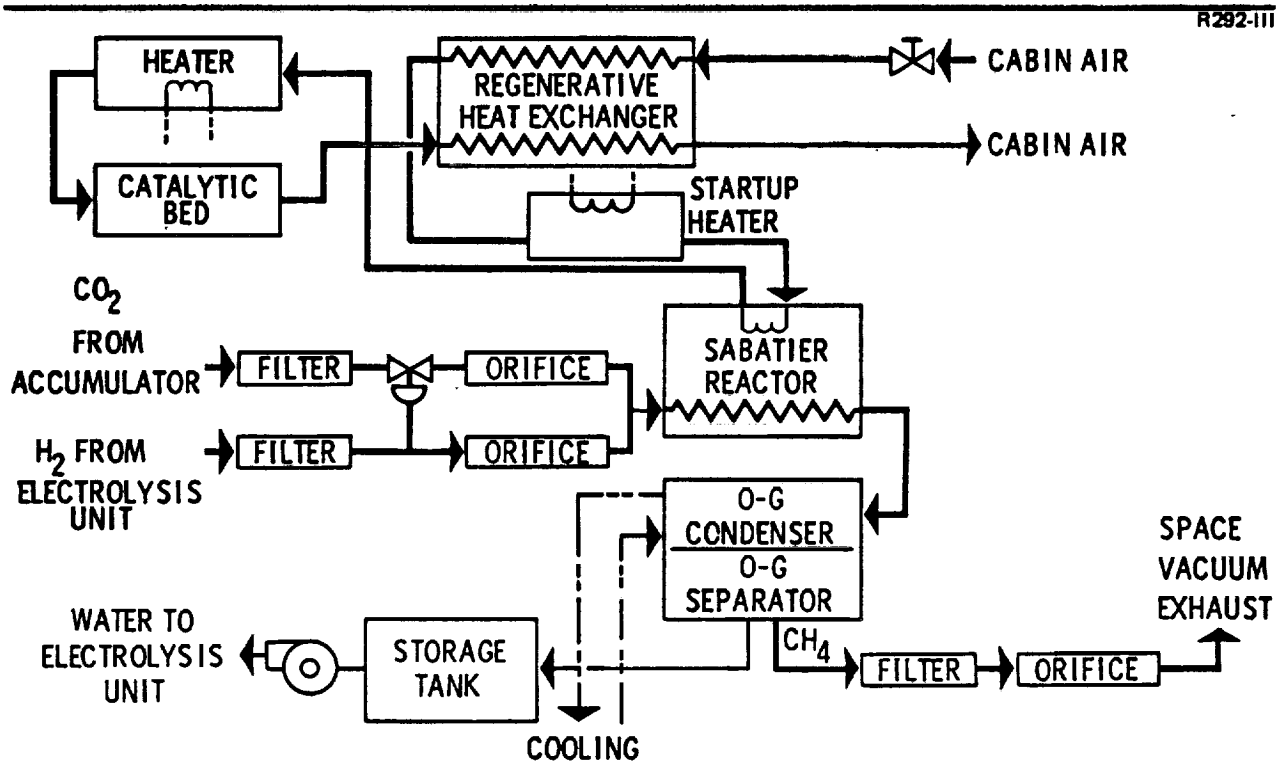


Figure 2-91. Integrated Sabatier and Toxin Control

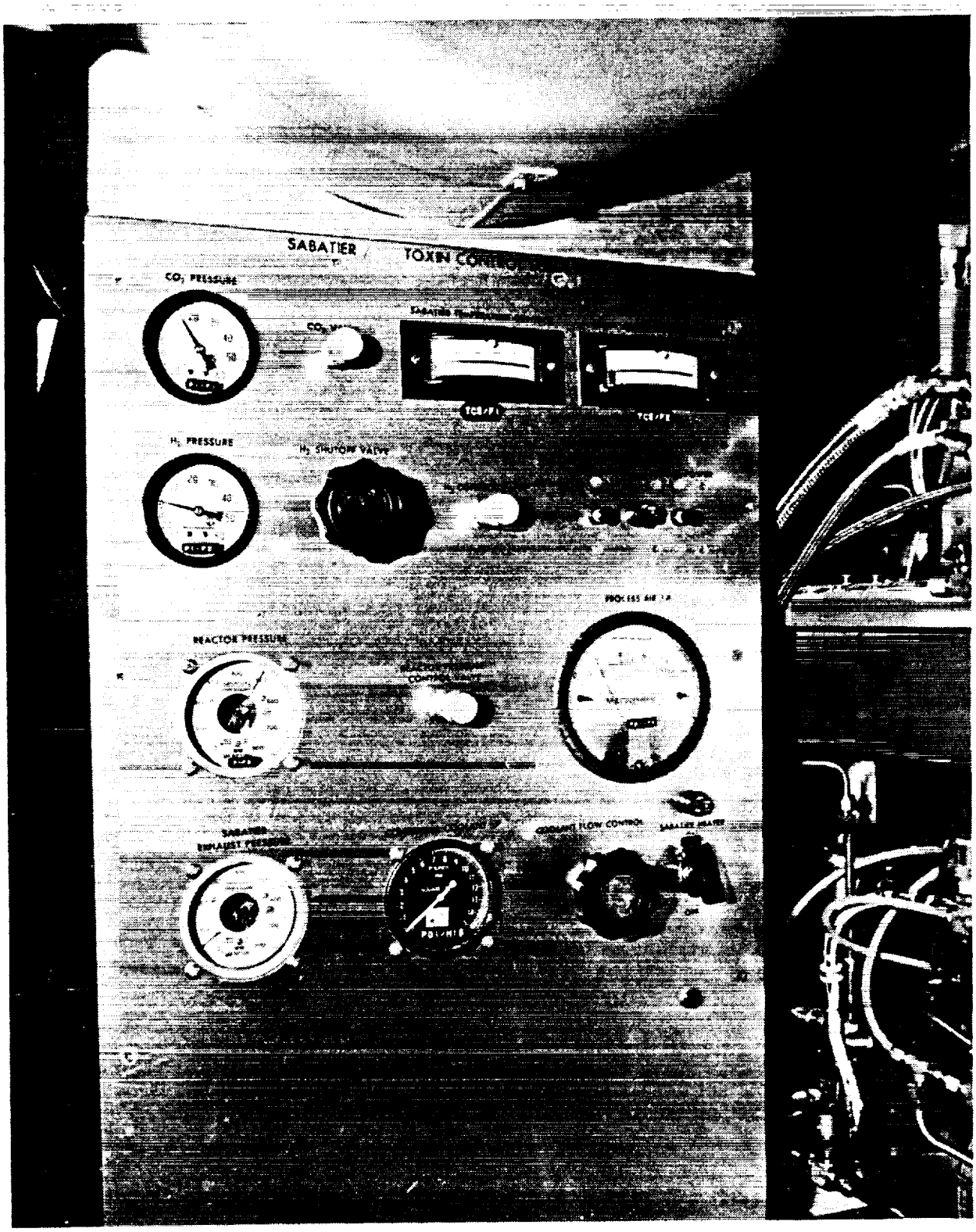


Figure 2-92. Integrated Sabatier Reactor/Toxin Control

reactor heat. The catalyst bed is normally operated at a pressure ranging from 61 to 67 kN/m^2 (460 to 505 mm Hg) and a temperature of 533° to 672°K (500° to 750°F). The CO_2/H_2 mixture reacts to form methane (CH_4) and steam. The average mixture ratio was 2.5:1.0 by volume.

The product gases containing some excess CO_2 and a small amount of unreacted H_2 leave the reactor and flow through the zero-g condenser/separator and then a conventional backup condenser where the steam is condensed and separated as water. The CH_4 and unreacted gases then flow through the critical-flow reactor pressure-control valve to the SSS vacuum subsystem. The zero-g condenser/separator is approximately 0.20 m (8 in.) long by 0.10 m (4 in.) wide by 0.04 m (1-1/2 in.) high and is divided into two compartments by a partition of porous metal. Water, cooled by an integral circuit, wets one surface of the porous plate. The reaction gases flowing along the opposite surface are cooled and the stream condenses and wets the porous surface. The condensed water will then transfer through the porous plate into the cooling water by capillary action and a controlled pressure difference. Product water flowing through the plate increases the displacement of a negative-pressure device. When fully displaced, a reed switch is magnetically tripped, which introduces compressed CO_2 to displace the water into the electrolysis water storage tank. The backup condenser collects any water it recovers in a small accumulator. A float switch in the accumulator activates a positive displacement pump which also discharges the condensate into the water storage tank. The toxin burner obtains SSS air from the discharge side of the thermal control blowers at a rate of about 0.71 liters/sec (90 ft^3/hr). The air passes through the regenerative heat exchanger where it is preheated by the exit gas stream, then through the cooling jacket of the Sabatier reactor where it absorbs a portion of the reaction heat (and likewise cools the reactor). The gas then passes through the electric heater, where the gas temperature is increased to the proper oxidation temperature (predetermined by the temperature controller), traverses the catalytic reactor bed to the hot side of the regenerative heat exchanger, and exits to the cabin.

2.4.1.2 Operation of Sabatier Reactor

During the initial part of the test, many valve adjustments and operations of the starter heater were required. The maintenance activity during the test is summarized on Table 2-46. The unexpected attention requirements were partially caused by the frequent changes in hydrogen sources and pressures affecting H_2/CO_2 mixture ratios. At the middle of the third week, it became apparent that the reactor was not operating in a normal manner. Observed temperatures indicated that the reaction had shifted toward the aft end of the reactor, and a tendency for the reaction to be "blown out" the end of the reactor was experienced. Poisoning of the catalyst was suspected. Since electrolysis produces almost pure hydrogen, it seemed likely that the poison was entering with the CO_2. On the 16th day, the reactor was switched to commercial grade bottled CO_2 to observe if the catalyst would "clean up" and, if not, to ascertain the degree of catalyst deterioration. Samples of CO_2 from the onboard accumulator were analyzed to determine what trace contaminants might be present. Contaminants found, in addition to the expected O_2 and N_2, were ethanol, acetone, and Freon 113. A brief review of the literature indicated (Reference 2-7) that nickel-hydrogenation catalyst could be poisoned by compounds containing sulfur or halogen groups, by a mechanism of tying up the "active" sites on the catalyst. Freon 113 contains both chlorine

Table 2-46

SABATIER REACTOR/TOXIN CONTROL
MAINTENANCE ACTIVITY

Unit	Maintenance Activity	Spares Usage	No. Times	Hours
Toxin control	None	None	–	None
Sabatier	Replaced fuse and primed water pump	Fuse	1	1.5
	Replaced CO_2 flow transducer*	Transducer	1	0.3
	Cleared water from methane pump*		1	0.2
	Installed carbon filter in CO_2 line*	Carbon column	1	3.0
	Changed catalyst	Catalyst	1	7.0
	Changed carbon*	Activated carbon	5	2.5
	Changed zero-g condenser	Condenser	1	1.5
	Attempted to unstick negative pressure device		8	0.6
	Replaced leaking tube at reactor outlet	12-in. tubing	1	2.0
			20	18.6

*Outside activity

and florine atoms of the halogen group. The next question was to determine if significant amounts of Freon 113 would be thermally decomposed under the reactor conditions. Arrangements were made to operate a Sabatier reactor at NASA-LRC with similar Freon concentrations and conditions. LRC quickly reported that they found Freon decomposition to be in excess of 80 percent, with no halogens being found in the exhaust gas stream, but with significant concentrations of halogens being present in the product water.

The source of the Freon 113 is attributed to the cleanup following a failure of a Coolanol line during the unmanned SSS baseline test (Reference 2-2). Freon was used as a final wash to remove all traces of the Coolanol. Although the SSS was ventilated for several days before the repeat of the unmanned baseline test, it is believed that trace quantities remained absorbed on surfaces within the simulator or in the activated carbon bed in the wick evaporator unit. The trace quantities that desorbed during the test were found to be present in the SSS atmosphere (Section 2.1.5) and were removed by the CO_2 concentrator units.

Reactor operation on bottled CO_2 did not significantly improve. Reaction during this period remained in the aft end of the bed with occasional "flame-outs". The reactor operated from the 16th to the 22nd day on 12.85 kg (28.3 lb) of bottled CO_2, when an activated carbon filter was placed in the cabin CO_2 delivery line. Gas samples taken downstream of the carbon filter indicated that the carbon was effectively removing the Freon and the organic trace contaminants. Operation continued without improvement utilizing CO_2 from the molecular sieve until the 28th day when it was decided to replace the catalyst. It is interesting to note here the past history of the catalyst. This catalyst was operated for 15 days before the 60-day manned test, 52 days during the 60-day manned test, about 25 days of bench testing prior to the 90-day manned test, and 8 days of operation during the unmanned and manned tests, giving a total operational history of about 128 days. No sign of deterioration was measured during operation before the unmanned baseline test.

The reactor was down the 28th and part of the 29th day while the crew replaced the catalyst and leak tested the reactor and subsystem. The used catalyst was placed in a No. 2 tin can and sealed while awaiting the next scheduled pass-out. The new catalyst (Ni-0104T-1/8", Harshaw Chemical Company) was placed in an open aluminum pan until the exothermal reaction with the oxygen-rich atmosphere was complete to avoid any crew handling accidents while loading the reactor. After completion of loading and sealing the reactor, it was leak checked by pressurizing it to 207 kN/m^2 (30 psia) with nitrogen and immersing in water. After assembly into the subsystem, the entire unit was evacuated to 34.5 kN/m^2 (5 psia) and preheated to 422°K (300°F) to demonstrate gas-tight integrity at elevated temperatures. The reactor was then heated to 450°K (350°F) and slowly purged with hydrogen to activate and reduce the catalyst. The unit was then started using routine procedures.

Operation with the new catalyst was smooth and required little attention by the crew. Water production increased from an average of 1.2 kg/day (2.7 lb/day) for the initial 30 days to 1.99 kg/day (4.38 lb/day) for the remaining 60 days. These values as well as the daily water production quantities are shown in Figure 2-93. This figure also includes the total of 11.44 kg (25.2 lb) of measured water loss through the exhaust with the methane. This water loss was measured by collection in a trap and correction of exhaust gases for satuation with water vapor. Hydrogen utilization is shown on Figure 2-94 and carbon dioxide utilization is shown on Figure 2-95.

Some crew attention was required to remove the reactor insulation during the period when the toxin burner was intentionally turned off, to compensate for the decrease in reactor cooling normally accomplished with the toxin burner air stream.

The reactor was shut down for partial periods during four of the last 60 days of the test because of interruption of supply gases. The carbon filter had a capacity of about 1.97 liters (120 $in.^3$) of activated carbon and a useful life of about 11 days. The effluent gas downstream of the filter was tested biweekly and Freon 113 was not detected at any time. However, whenever a shifting aft of the Sabatier reaction was detected, it was assumed that the carbon filter required replacement. During the short period of time (approximately 20 minutes) required to change the carbon, CO_2 bypassed the filter to maintain reaction. For a period of 6 to 24 hours after changing the filter, the reaction remained stable in the aft end of the reactor before returning to the normal position.

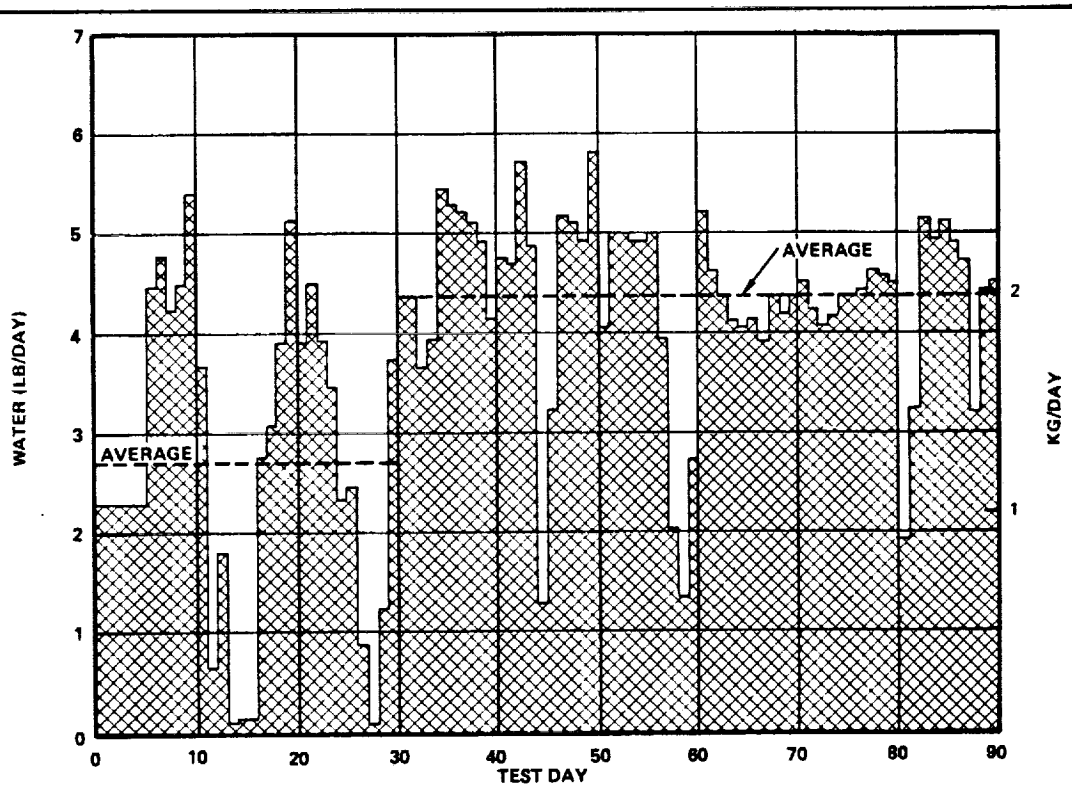


Figure 2-93. Sabatier Water Production

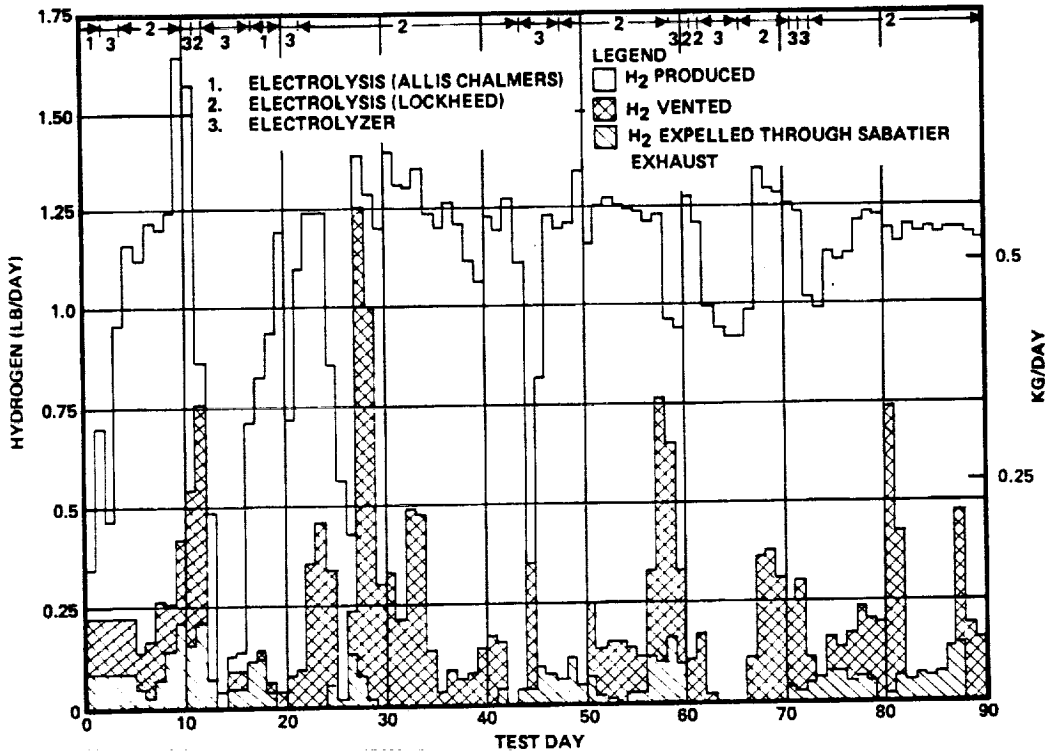


Figure 2-94. Hydrogen Utilization

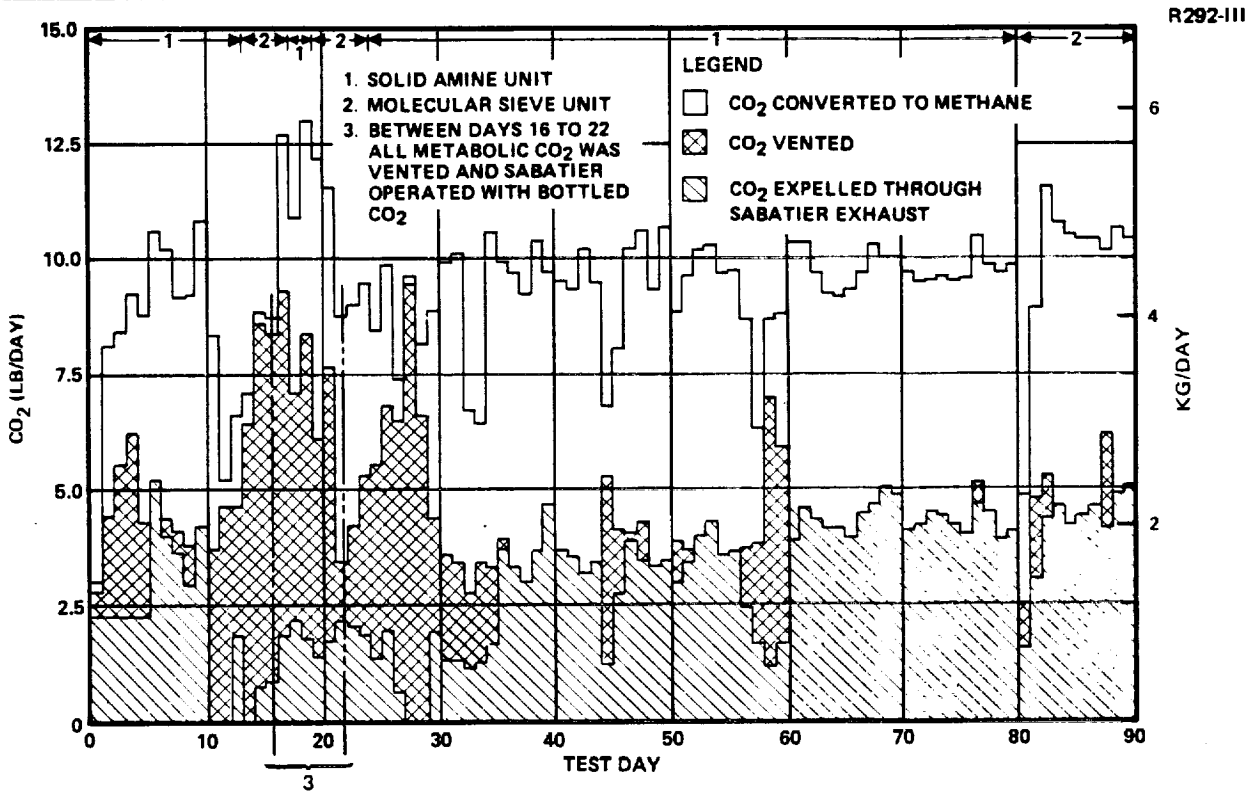


Figure 2-95. Carbon Dioxide Utilization

On test day 87, methane concentration in the SSS increased significantly, as shown in Figure 2-30. The Sabatier, a producer of methane, was then reduced in operating pressure from about 70.7 to 64.0 kN/m^2 (530 to 480 mm Hg), well below cabin pressure. The SSS methane concentration then leveled off and began to decrease. However, the reactor pressure control valve was in the fully open position to maintain the pressure at a lower than cabin level. On the 88th day, the reactor was shut down and leak tested. A gross stress corrosion failure along the minimum stress axis of a $\pi/2$ rad (90-degree) bend in the stainless steel exhaust line between the reactor and the condenser was found. The corrosion was attributed to hydrogen chloride and hydrogen fluoride in the exhaust. The line was replaced by the crew, and the reactor operated normally for the remainder of the test.

Daily analysis of the Sabatier exhaust gases was made by gas chromatograph and quantities recorded by wet test meter. Figure 2-96 shows the results of these measurements and provides information relative to the use of this exhaust gas as propellant in a resistojet thruster system. Although not shown, the exhaust includes some nitrogen as measured in the input CO_2 discussed earlier. All nitrogen entering the system is unreacted as it passes through the reactor and exhausts with any unreacted CO_2.

Operation of the zero-g condenser/separator was initiated on the 14th day of the test. Cold Coolanol flow was maintained through the condenser throughout the test, the product condensate being allowed to drain into the backup condenser. When the negative pressure device was energized, it pumped gas through the porous plate of the condenser. Repeated attempts to stop the gas breakthrough were tried on test days 16, 29, 30, and 50.

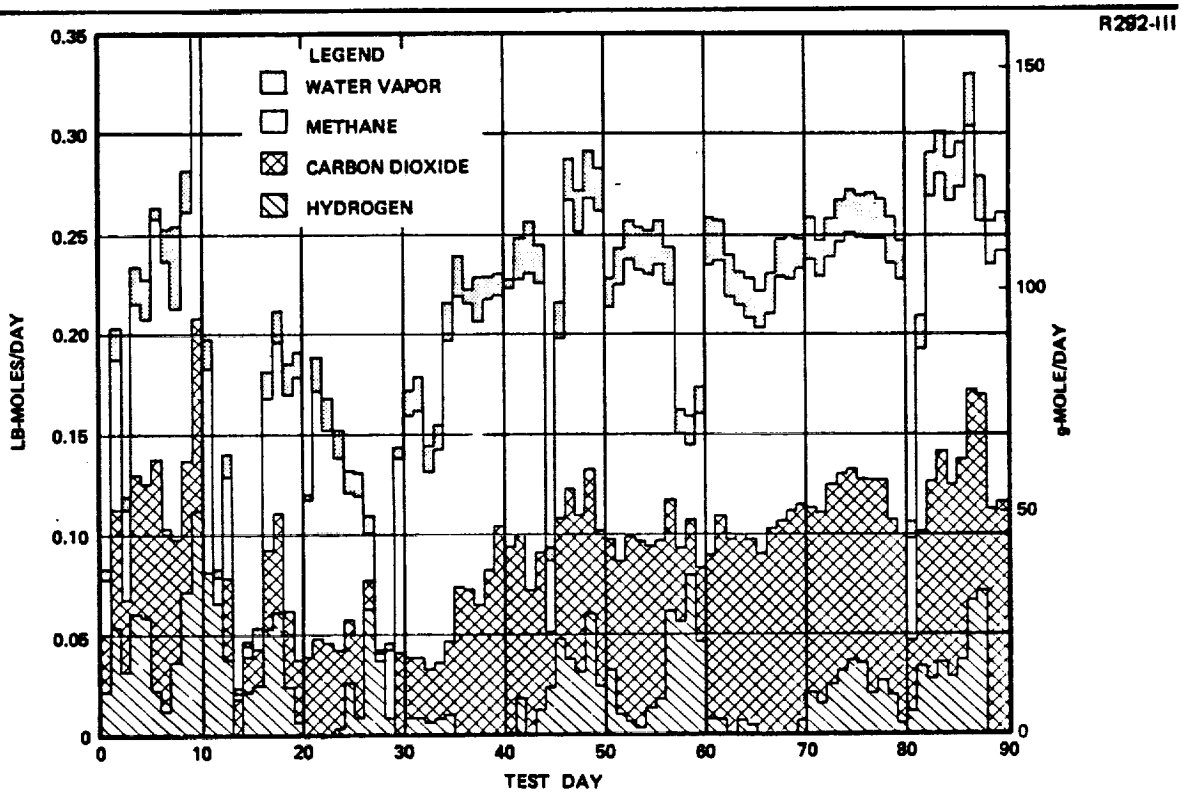


Figure 2-96. Sabatier Exhaust Products

Efforts included various adjustments in cooling flow. The negative-pressure device was actuated 42 times during these four test days. Replacement of the condenser was delayed to avoid possible spillage of the Coolanol. The condenser was replaced on test day 81. Inspection of the original condenser indicated discoloration and corrosive pitting of the porous plate, probably caused by hydrogen chloride and hydrogen fluoride resulting from the thermal decomposition of Freon and absorbed in the product water.

The new unit worked in a normal manner until day 83 when the negative-pressure device became stuck about a quarter of the way down on the down stroke. The negative-pressure device had automatically pumped 31 strokes of water at this time. The unit was freed by actuating a momentary switch in parallel with the piston proximity switch. This method of actuating the negative-pressure device was used for the remainder of the test.

Typical operating conditions of the zero-g condenser during the run on the Coolanol side were 276.5°K (38°F) inlet and 286°K (54°F) outlet. The vapor side temperatures were 345°K (163°F) inlet and 306°K (90°F) outlet. The dew points of the exhaust gas from the reactor were calculated from the vent gas composition. The maximum dew point found was 315°K (171°F) and the minimum found was 344°K (160°F). The water loss through the vent is apparently caused by inadequate heat transfer surface within the condenser.

The hydrogen-carbon dioxide mixture ratio varied during the test but was always CO_2 rich to insure maximum conversion of hydrogen except during initial reduction of the catalyst on day 27. The optimum mixture ratio is a

function of crew respiratory quotient (RQ) and cabin leakage. Assuming a RQ of 0.8 and zero cabin leakage, the optimum mixture ratio would be 2.5 H_2/ CO_2 by volume. Cabin leakage will increase the mixture ratio because more hydrogen is available from electrolysis to make up the oxygen leakage. The daily average mixture ratio is presented in Figure 2-97. The relatively high mixture ratios obtained on test days 11 and 27 resulted from reducing the catalyst with hydrogen in an attempt to overcome poisoning.

A summary material balance for the Sabatier reactor is presented in Table 2-47. The table shows that the overall conversion of H_2 to water and methane was 95 percent. The baseline requirement was 91 percent conversion. The CO_2 conversion during periods of reactor operation was 66 percent as compared to the baseline goal of 56 percent.

2.4.1.3 Operation of Toxin Burner

Operation of the toxin burner throughout the test was routine and without operational problems, as previously noted on Table 2-46. Burner temperatures were adjusted between 567° and 661°K (560° and 730°F) throughout the last 60 days of the run to investigate variations in cooling effect to the Sabatier reactor. The toxin burner was turned off from days 68 through 81 to observe changes in carbon monoxide, methane trace contaminants, and microbiological activity.

On day 68, while turning the toxin burner off, the crew observed a powder deposit in the area of the discharge-to-cabin vent. A sample of this material was collected and passed out for chemical analysis. Preliminary results indicated the material to be mainly chlorides of aluminum, copper, iron, nickel with minor amounts of silicon, magnesium, chromium, titanium, manganese, and boron. It would appear that the material resulted from the thermal decomposition of Freon in the toxin burner to form chlorides and probably fluorides with the Hopcalite catalyst and the stainless steel and aluminum components of the unit. Since this material has an insignificant vapor pressure, it is not known how the material could transport through the regenerative heat exchanger to the vent. Dust carried along with the process gas stream seems the only obvious method.

In light of the catalyst poisoning experience in the Sabatier reactor and the chloride deposits, it can be suspected that the Hopcalite was adversely affected by the Freon.

Correlation of carbon monoxide and methane concentrations in the SSS with toxin burner operation is not conclusive. Carbon monoxide is completely oxidized at room temperature by Hopcalite; therefore, correlation with it should be more pronounced. During the period the toxin burner was off, carbon monoxide concentration increased from about 16 to 26 ppm. When the unit was returned to operation, the concentration decreased over a period of 9 days to a level of 18 ppm. This seems to indicate the burner did function to affect the CO level; however, this type of correlation could possibly be expected with an unheated catalyst. The strongest evidence of the ability of the toxin burner to oxidize methane is exhibited during the last 3 days of the test after the repair of the Sabatier reactor exhaust leak. Hydrocarbon concentration at this point reached a level of 60 ppm heptane equivalent, and decreased to a level of 50 ppm at the end of test. Cabin leakage was minimal during this period, so that little washout effect of contaminants occurred.

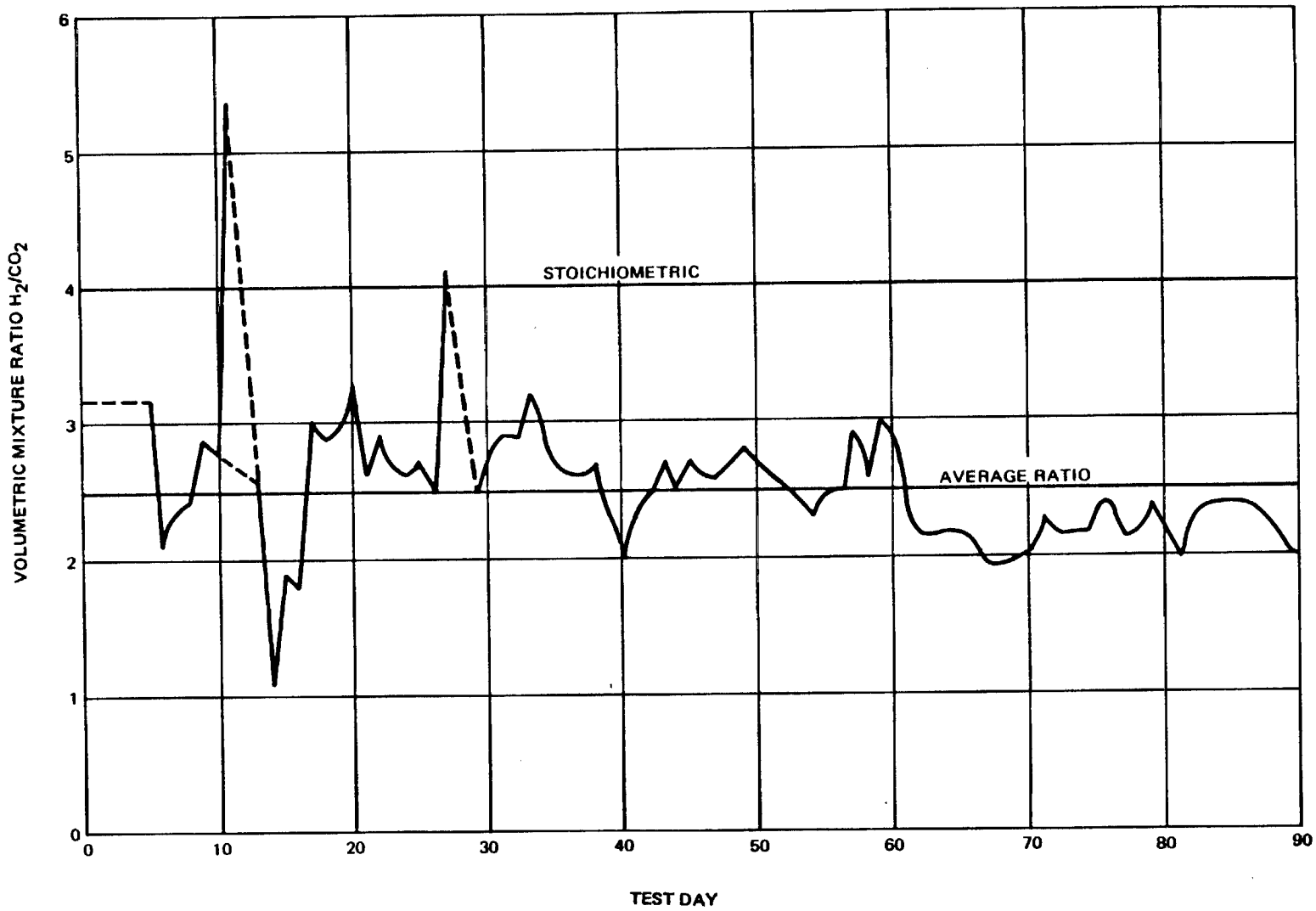


Figure 2-97. Sabatier Mixture Ratio

Table 2-47

SABATIER REACTOR MATERIAL BALANCE

Material In			Material Out		
	kg	(lb)		kg	(lb)
Carbon dioxide	288.9	636.9	Water to electrolysis cell	150.6	332.0
Hydrogen	36.7	81.0	Methane	69.2	152.5
Nitrogen	7.5	16.6	Carbon dioxide	98.7	217.6
Oxygen	3.7	8.1	Nitrogen	7.5	16.6
Water vapor	2.5	5.5	Oxygen	0.2	0.5
Total	339.3	748.1	Hydrogen	1.7	3.8
			Water exhausted	11.4	25.2
			Total	339.3	748.2

This significant lowering in hydrocarbon level also tends to indicate the toxin burner maintained some effectiveness throughout the test. However, the general gradual rise in hydrocarbon levels in the atmosphere during the test, which was mainly due to an increase in methane concentration, may indicate that a gradual reduction in capacity was occurring. Daily values of cabin hydrocarbon concentrations are shown in Figure 2-98.

2.4.2 Water Electrolysis

The gas supply subsystem for the 90-day manned SSS test consisted of three different water electrolysis units and a stored gas supply. These units were required to produce high-purity oxygen for meeting metabolic and leakage requirements and high-purity hydrogen for carbon dioxide reduction in the Sabatier reactor. High-pressure nitrogen from bottle storage was provided for leakage makeup. The stored gas supply of oxygen and hydrogen were used only in emergencies where excessive demand exceeded the output capability of the operating electrolysis units.

The electrolysis units used in this test were a commercial unit and two experimental units developed specifically for this test program. The commercial unit was used for backup when neither experimental unit was capable of meeting either hydrogen or oxygen demands of the LSS. This unit was the Stuart unit, manufactured by the Electrolyzer Corporation, Ltd., of Toronto, Canada. The other two units were manufactured by Allis-Chalmers Manufacturing Company (A-C) and the Lockheed Missiles and Space Company (LMSC). The A-C unit uses a vapor feed and intermittent circulation of electrolyte and was installed inside the chamber during the test. The LMSC unit uses a liquid feed with continuous electrolyte circulation and was installed outside the simulation chamber during the test. All of these units were used during

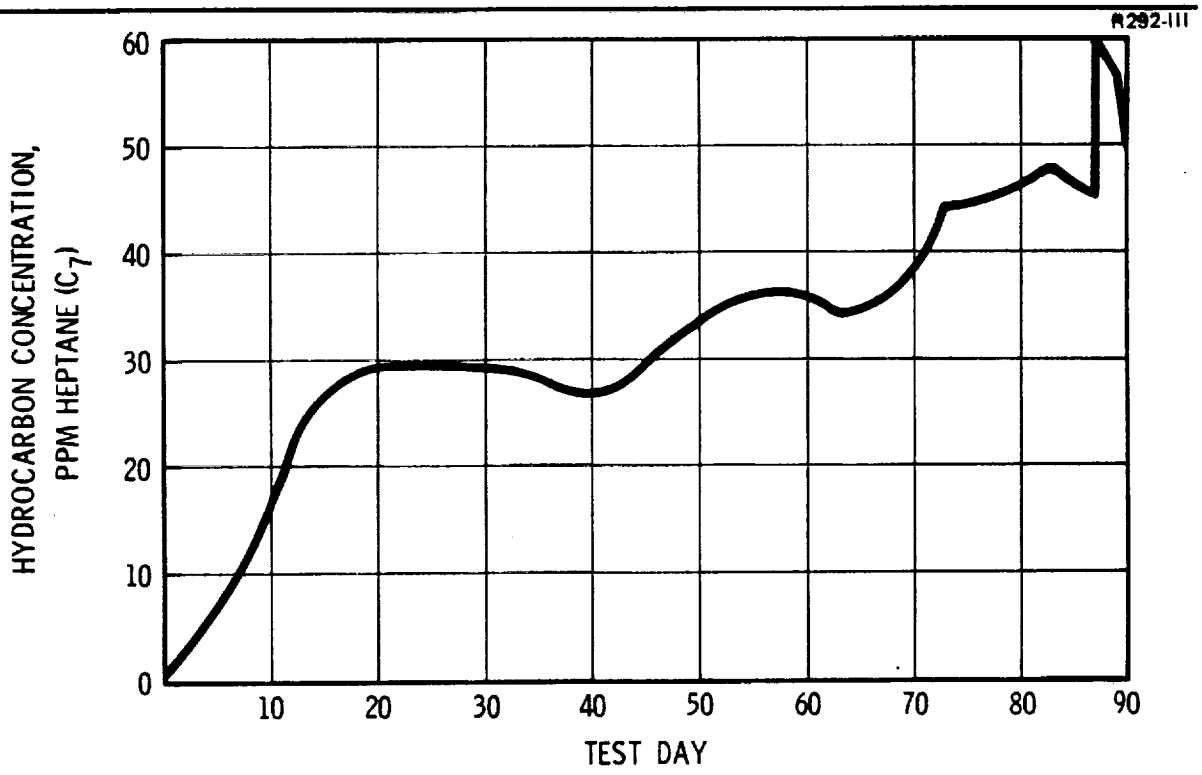


Figure 2-98. On-Line Hydrocarbon Analysis

the 90-day test. Water for the experimental units was provided from a closed water supply onboard the SSS and from the water generated by the Sabatier reactor. All three units were designed to provide the normal oxygen requirements of the four-man crew and all three units experienced some problems.

2.4.2.1 Unit Descriptions

The following paragraphs briefly describe the salient features of the two experimental units and the integration of the three units into the chamber design. Also described are the performances of the two experimental units. as well as the major problems encountered.

Allis-Chalmers Water Electrolysis Unit

The A-C water electrolysis unit was designed to be an integral part of the SSS. At its present stage of development, it is a nonflight unit which incorporates the basic principles and fundamentals of a zero-g flight-type unit but not necessarily the weight, bulk, and detail design. Oxygen output capacity of the unit is as much as 4.54 kg/day (10 lb/day). To meet the specified average requirements of 3.63 kg/day (8 lb/day) of oxygen, the unit must produce 0.151 kg/hr (0.33 lb/hour) or 0.0503 kg/hour/module (0.111 lb/hour/module). This in turn, required 0.1701 kg (0.375 lb) of water be fed to the unit each hour, and 33.9 amp total (an average of 11.3 amps applied to each module). The unit is contained in an enclosure approximately 0.61 m (24 in.) wide, 0.61 m (24 in.) high, and 0.457 m (18 in.) deep, weighing approximately 99.8 kg (220 lb) fully charged with coolant and electrolyte.

A schematic of the unit is shown in Figure 2-99. During normal operation, feed water is pumped to the accumulator from a supply source every 2 hours. The water is then fed on a pressure-demand principle through the separator to the electrolyte cavities in the three electrolysis modules. The water is electrolyzed into hydrogen and oxygen. The O_2 and H_2 are supplied to the SSS accumulators through a condenser and their respective back-pressure regulators. Water vapor, condensed from the O_2 and H_2 gas, is fed back to the electrolysis modules. Every 2 hours the electrolyte solution (35 percent KOH, 65 percent H_2O by weight) in the modules and feed lines is circulated by a pump through the two-phase gas separator to remove noncondensible gases accumulated in the unit. This purge process lasts approximately 3 minutes. Current to the electrolysis modules is regulated by sensing the oxygen accumulator pressure downstream of the unit to adjust the production rate to meet system demands. The operation is completely automatic after startup is achieved.

Instrumentation on the front panel includes switched readout of individual cell voltages, module voltages, module current, unit voltage, unit current, module temperatures, and unit temperatures. Pressure gages are used to indicate the gas and water pressures in the unit manifolds before the condensers and at their respective accumulators. Annunciator lights indicate when the main power to individual modules and individual heaters is on. Alarm lights are provided for high and low hydrogen pressure, high and low water pressure, high oxygen pressure, and high cold plate temperature.

The unit has several safety devices and control circuits intended to provide the operator with sufficient information to take corrective action. Each module is protected by fast-acting circuit breakers that limit the current to 20 amps. Fuses are provided to protect individual circuits. The method of safety for the remainder of the fault conditions is a complete shutdown and isolation from the external line. The instant power is cut off, gas generation stops; hence, no change in internal pressure should occur after the unit is shutdown. Isolation solenoids for retaining internal pressure for short periods of time after power cuttoff should prevent unbalancing of the hydrogen and oxygen pressure loops. The isolation valves in the inlet water lines to the modules serve two purposes. At shutdown, they isolate the water cavities to prevent flooding into the hydrogen cavities. They also provide a means of allowing all the flow from the circulation pump to be directed through any one module during a purging operation by manually closing two of the three solenoids. All safety devices except the temperature switch operate latching-type relays which in turn operate the indicator lamps on the front panel. The lights remain on even though the fault may correct itself before the operator reaches the unit. A reset switch on the front panel energizes the reset coils in the latching relays.

Lockheed Water Electrolysis Unit

The LMSC electrolytic oxygen generator is a water electrolysis unit which was suitable for integration into and operation with the environmental control life support system of the SSS. Oxygen output capacity of the unit is 3.63 to 4.54 kg/day (8 to 10 lb/day) at a discharge pressure of 145 to 186 kN/m^2 gage (21 to 27 psig). The normal hydrogen discharge pressure is 62.1 kN/m^2 gage

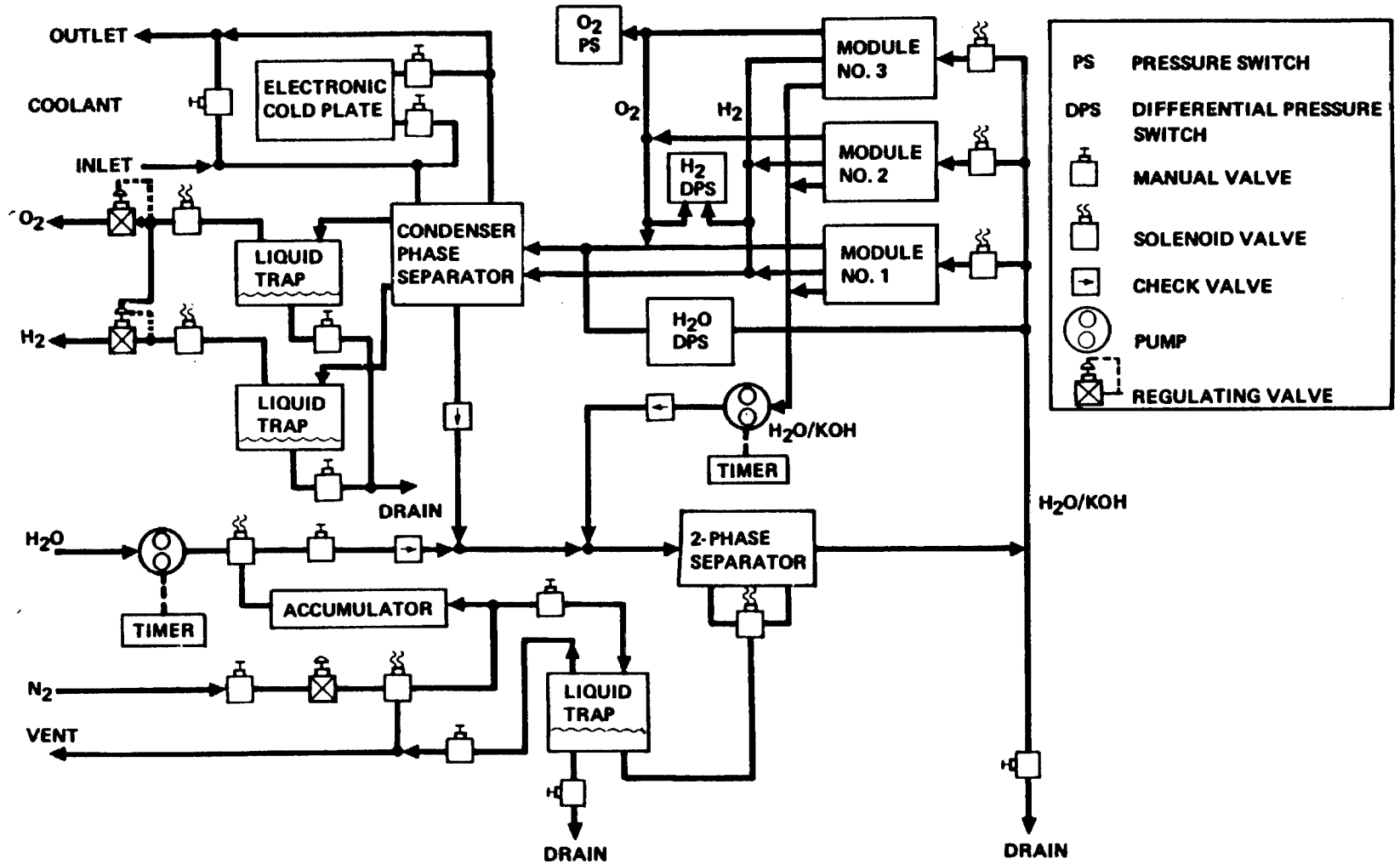


Figure 2-99. Water Electrolysis Unit—Allis-Chalmers

(9 psig). The outside dimensions of the unit enclosure are 0.61 m (24 in.) wide, 0.56 m (22 in.) high, and 0.79 m (31 in.) deep. It weights 129.3 kg (285 lb) fully charged with coolant and electrolyte.

A schematic of the unit is shown in Figure 2-100. The concepts employed in the unit design include the use of dual-matrix, liquid-center electrolysis cells with a circulating 30 percent potassium hydroxide electrolyte. The generating unit consists of four electrolysis modules, each containing 16 cells connected hydraulically in parallel, and divided electrically into two 8-cell banks. The cells in each 8-cell electrical bank are connected in series. Peripheral manifolding within the module provides separate paths for electrolyte circulation, oxygen and hydrogen discharge, and nitrogen purge. Differential pressure control is used to maintain gas-liquid phase separation across absorbent matrices contiguous to the electrodes.

Electrolyte is pumped through a closed circulation loop using one of the two in-line magnetic-coupled centrifugal pumps; the second pump is an installed spare. The electrolyte leaving the pump passes through the tube side of a shell-and-tube heat exchanger. Coolant supplied to the shell side removes waste heat generated in the electrolysis modules. Flow control valves in these lines are used to balance the flow meters. Valves in the discharge electrolyte lines from the modules are provided so that a disabled module can be isolated from the circulation loop. During normal operation, these discharge valves are fully open.

Downstream of the discharge valves, the electrolyte is manifolded together and enters the electrolyte reservoir for return to the pump. Unit pressure is applied with a nitrogen pressurization system on the top of the reservoir.

Water feed for the electrolysis process is supplied by direct injection of liquid water into the reservoir. A gear pump used in conjunction with a flow control and solenoid valve provides the proper water pressure and flow rate.

Hydrogen is delivered from the electrolysis modules at approximately 62.1 kN/m^2 gage (9 psig). Oxygen is discharged from the electrolysis modules at approximately 62.1 kN/m^2 gage (9 psig) and is pumped to 145 to 186 kN/m^2 gage (21 to 27 psig) using a diaphragm pump. A pressure regulator across the pump maintains the pump suction pressure at 34.5 kN/m^2 gage (5 psig).

Nitrogen purge is provided to maintain gas-liquid differential pressure during startup and interim shutdown. When this function is activated, either manually or automatically during safety shutdown, inlet and outlet solenoid valves in the hydrogen and oxygen discharge lines open, allowing nitrogen to flow through the oxygen and hydrogen chambers of the electrolysis modules. A micrometer valve is used to adjust the nitrogen flow rate.

The electrolysis unit is designed to operate in an automatic mode during normal operation except during manual startup and shutdown. Automatic controls include electrolyte temperature which is accomplished by using a thermostat in the electrolyte discharge line from the modules. Coolant flow to the electronics coldplate is continuous and is regulated with a flow control valve. Water balance in the circulating electrolyte is maintained relatively constant by controlling electrolyte volume in the reservoir. Two differential pressure controllers mounted on each module are set to control the hydrogen

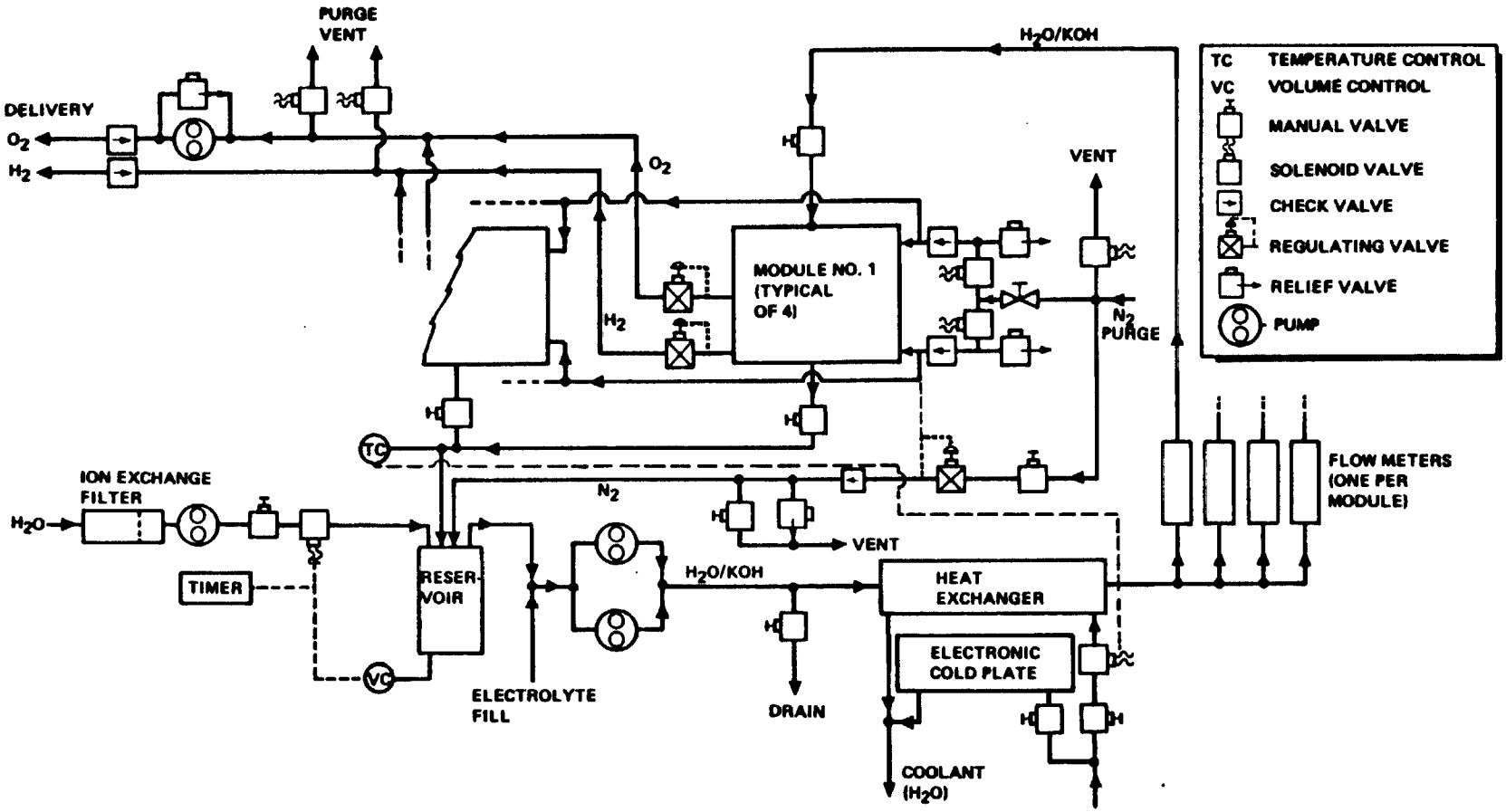


Figure 2-100. Water Electrolysis Unit—Lockheed

and oxygen pressures at 6.23 kN/m^2 (25 in. water) above the electrolyte pressure to maintain gas-liquid phase separation. Each electrolysis module is provided with a current-controlled switching regulator to control the dc current input.

Safety circuits are provided to automatically shutdown the unit under abnormal operating conditions. In an automatic shutdown, electrolysis module power is turned off; the electrolyte pump, the water feed, and the unit reset are turned off; nitrogen purge to the modules comes on; and the cause of shutdown is indicated on the front panel. The shutdown signal is derived from nongate circuitry which continuously monitors the following safety circuits: (1) module temperatures, (2) O_2 and H_2 safety pressure, (3) H_2 detector, (4) electrolyte volume, and (5) interruption of 60-Hz power. Each safety circuit, except item (5), has its own memory latch which allows the system to remember what type of malfunction caused the shutdown. The input to these memory latches is driven by the safety sensors. When an out-of-tolerance condition exists, the respective latch will be set. A reset condition can be obtained by depressing the unit reset button.

2.4.2.2 System Integration

The Stuart Electrolyzer unit used in this test was an upgraded version of the configuration used in the 60-day test conducted in 1968. Detailed schematics and equipment descriptions are provided in Reference 2-8. Briefly, the unit consists of an air-cooled transformer and rectifier, three Stuart electrolytic cells connected electrically in series, a water seal, a low-pressure gas holder for each gas, an air-cooled electrically driven compressor for each gas, a catalytic purifier for each gas, storage and reserve tanks for each gas, cell interconnecting piping, various protective devices, and automatic controls.

Figure 2-101 indicates how the three electrolysis units were integrated to supply hydrogen and oxygen to the other SSS subsystems. The Stuart unit had its own gas accumulators. Oxygen from the Stuart unit went directly to the two-gas control unit. Hydrogen from the Stuart unit went through a Deoxo-purifier, common to all electrolysis units, before reaching the Sabatier reactor. The A-C and LMSC units were connected in parallel and used common accumulators. Preceding the accumulators were Deoxo-purifiers. The piping arrangement provided the capability, on the oxygen side, to fill the interal accumulator from either the A-C unit or the LMSC unit while the Stuart unit was meeting demands of the two-gas control. The Stuart unit was designed and operated to maintain constant pressure in its own gas accumulators; any excess gas was vented overboard. On the hydrogen side, less versatility existed. The LMSC unit could operate when either of the other two units were providing hydrogen to the Sabatier reactor. If the A-C unit was providing hydrogen, the Stuart and LMSC units were set to vent excess gas. If the Stuart of LMSC units were operating and providing hydrogen gas to the SSS, the A-C unit had to be inoperative. No major problems were encountered with this lack of versatility; however, any future designs should include the ability to operate any of the units without interference with any other.

2.4.2.3 Test Results

Analysis of collected data has indicated that the average oxygen requirement during the 90-day test period was 4.35 kg/day (9.58 lb/day). Figure 2-102

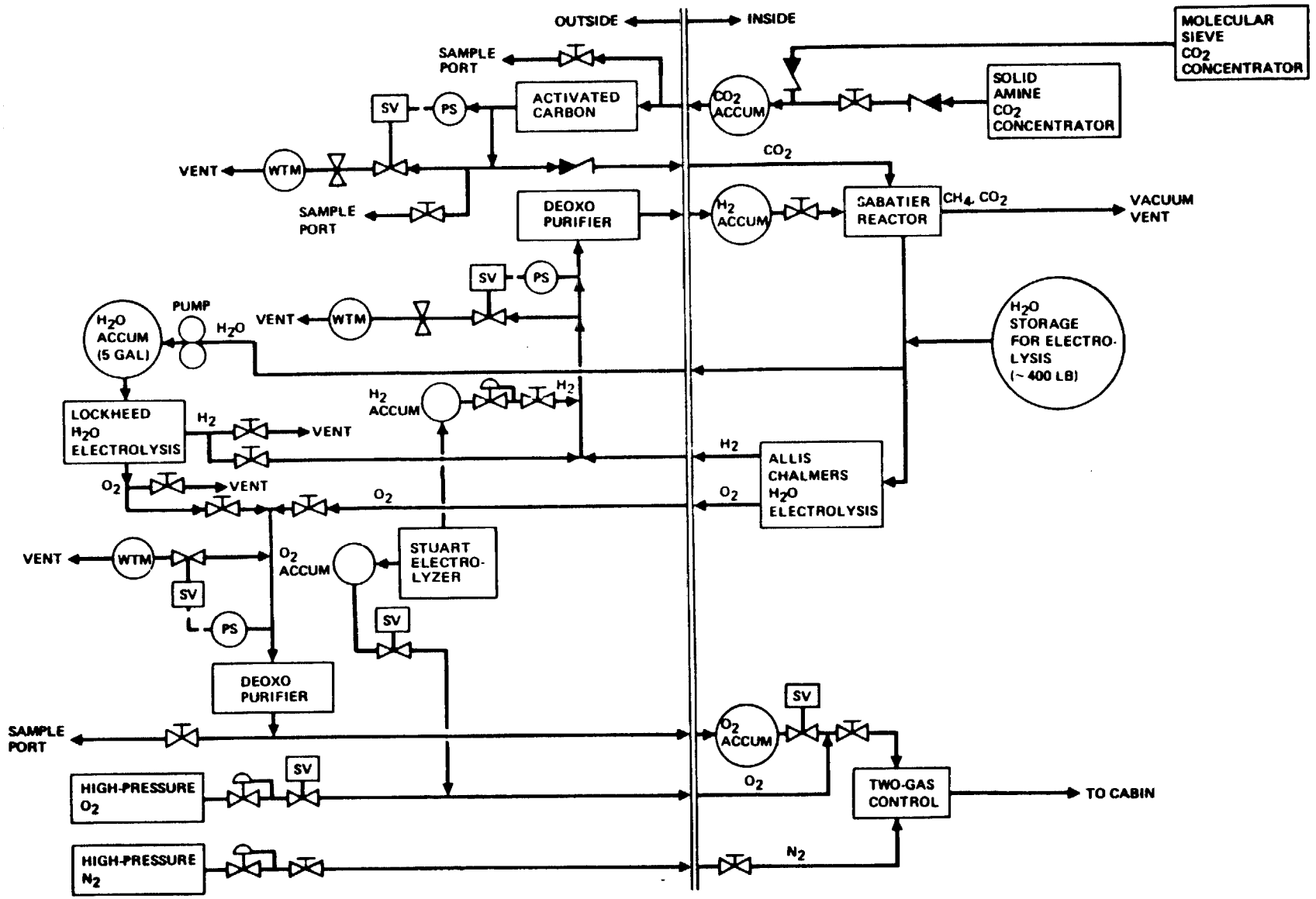


Figure 2-101. Simplified Gas Flow Schematic

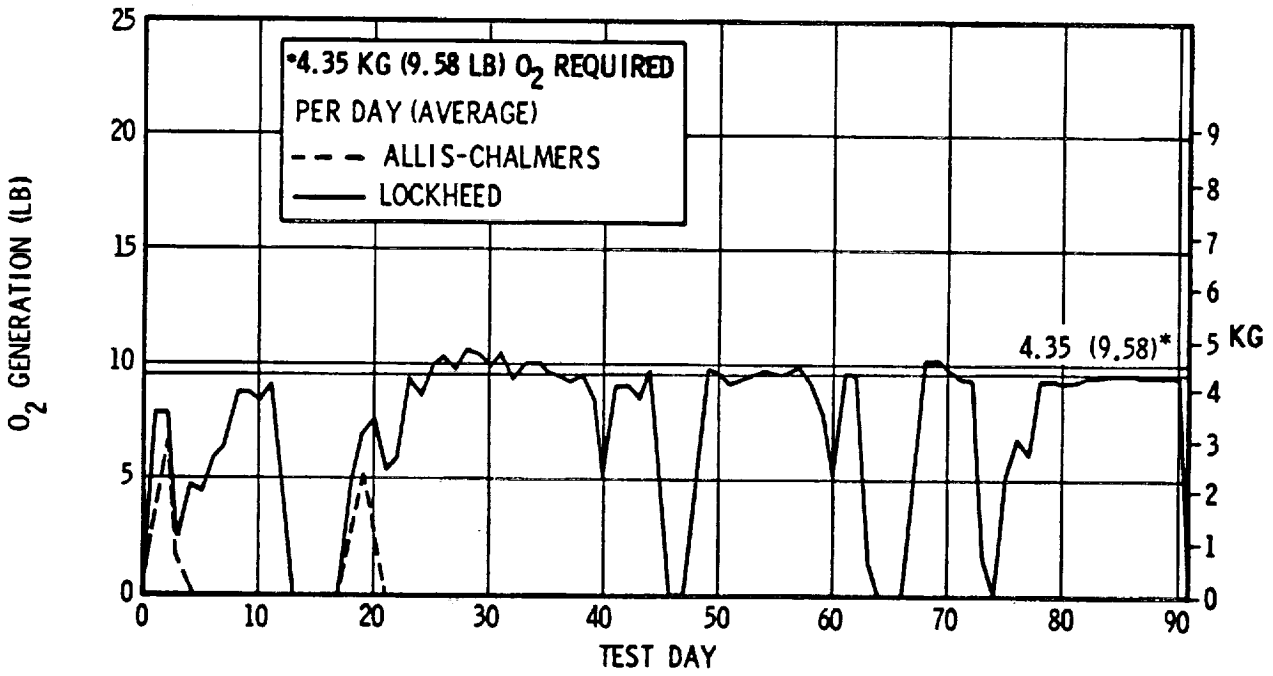


Figure 2-102. Oxygen Generation

shows that value as well as the quantity of gas generated by each of the experimental electrolysis units during the test period.

The test results obtained by operating the two experimental water electrolysis units are described in detail in the following paragraphs.

Allis-Chalmers Water Electrolysis Unit

The A-C unit operated satisfactorily during the first few hours without any difficulties. The detailed performance of this unit is shown on Figures 2-103 through 2-108. High module temperatures and cell voltages appeared as the first problems as shown in Figures 2-105 and 2-108. Normally, temperatures should have been in the 347.1° to 355.4°K (165° to 180°F) range and cell voltages between 1.6 and 1.7. The cause of these problems is not known.

The only operating value out of tolerance at the time was the water pressure, which was 20.7 to 34.5 kN/m^2 (3 to 5 psi) below oxygen instead of the recommended 13.8 kN/m^2 (2 psi). This higher-than-normal pressure differential may have caused unacceptable drying of the electrolyte matrix. Attempts to reduce this high differential and bring the water pressure up to within 13.8 kN/m^2 (2 psi) of the oxygen pressure were not entirely successful, and early on day 3 it was apparent that something was wrong with the N_2 regulator as the pressure in the water accumulator dropped off to less than 68.95 kN/m^2 gage (10 psig) and control was impossible. The water pressure also dropped off as the water was consumed in the electrolysis modules. The low water-to-oxygen differential pressure switch did not appear to be functioning either, as the differential exceeded 75.8 kN/m^2 (11 psi) and the operating manual indicated automatic unit shutdown should occur if the water

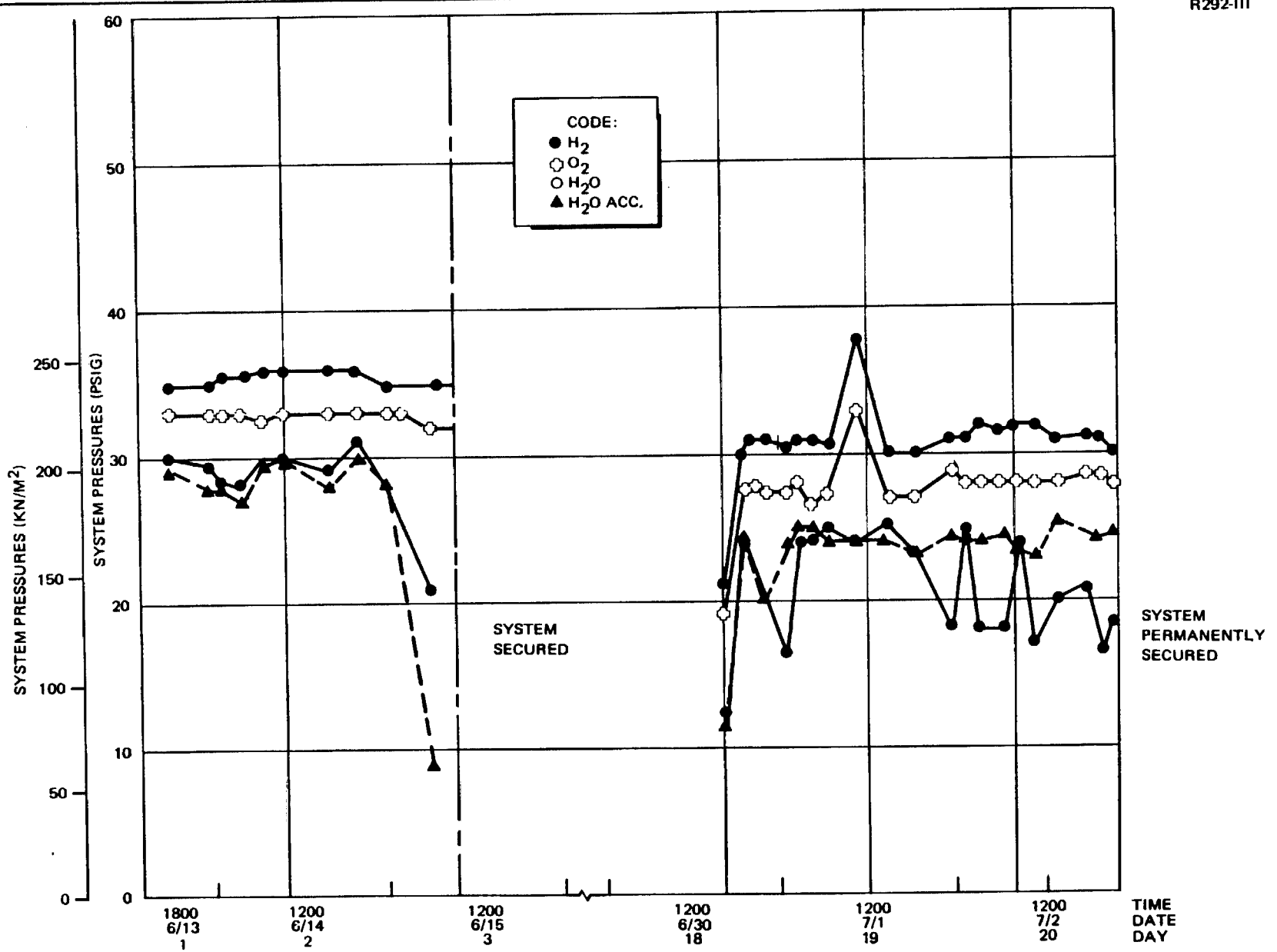


Figure 2-103. Time History of System Pressures

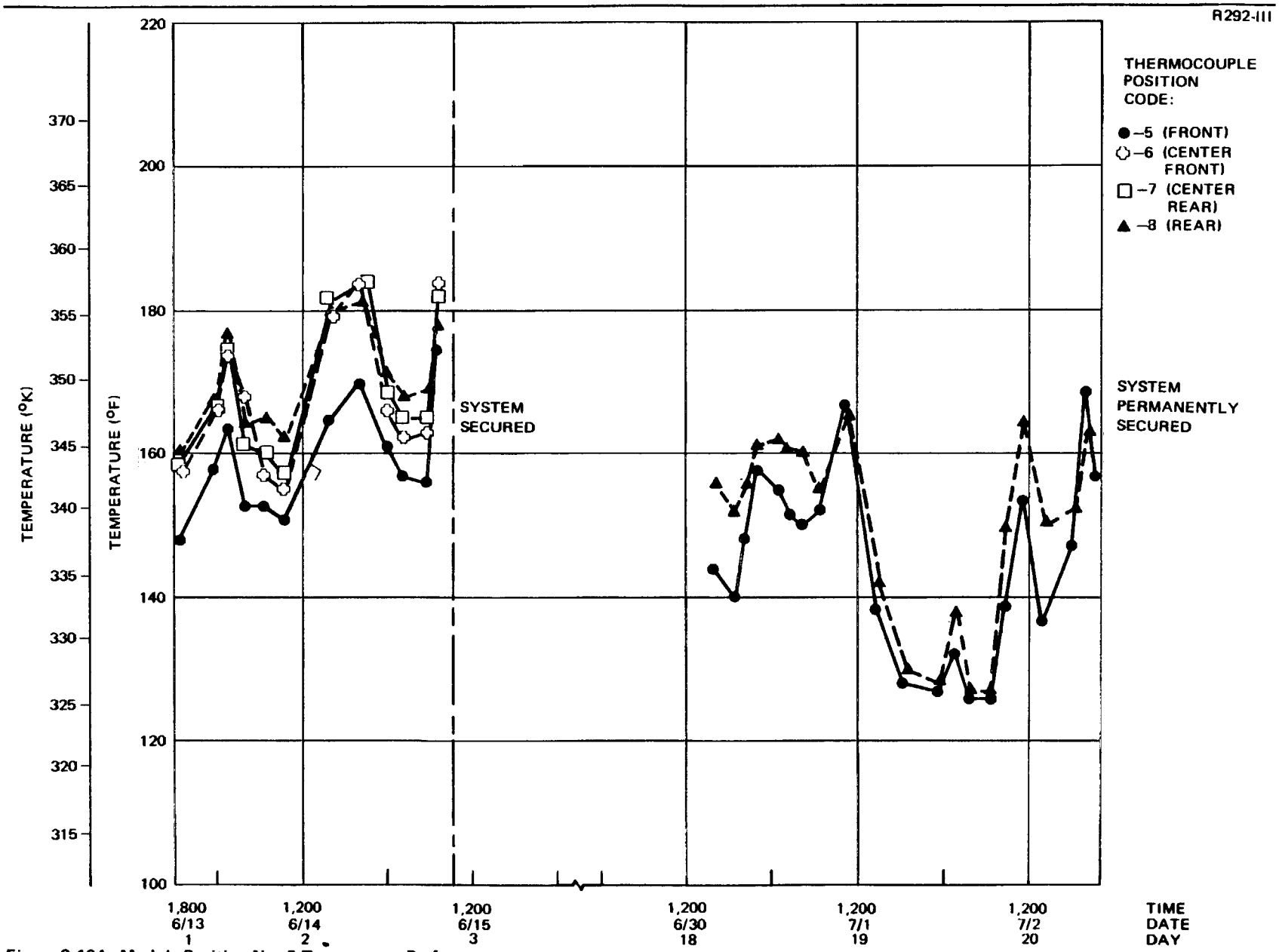


Figure 2-104. Module Position No. 2 Temperature Performance

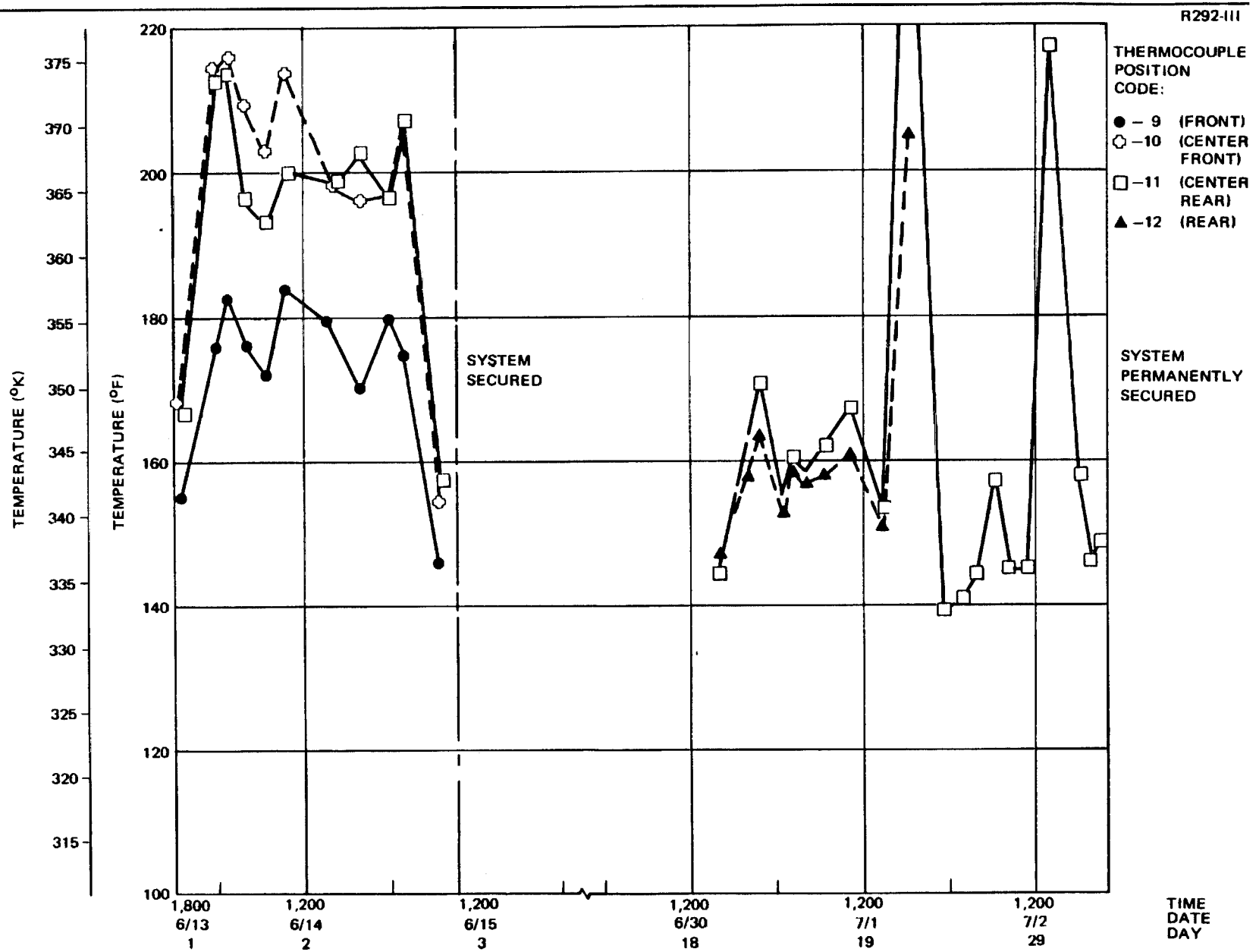


Figure 2-105. Module Position No. 3 Temperature Performance

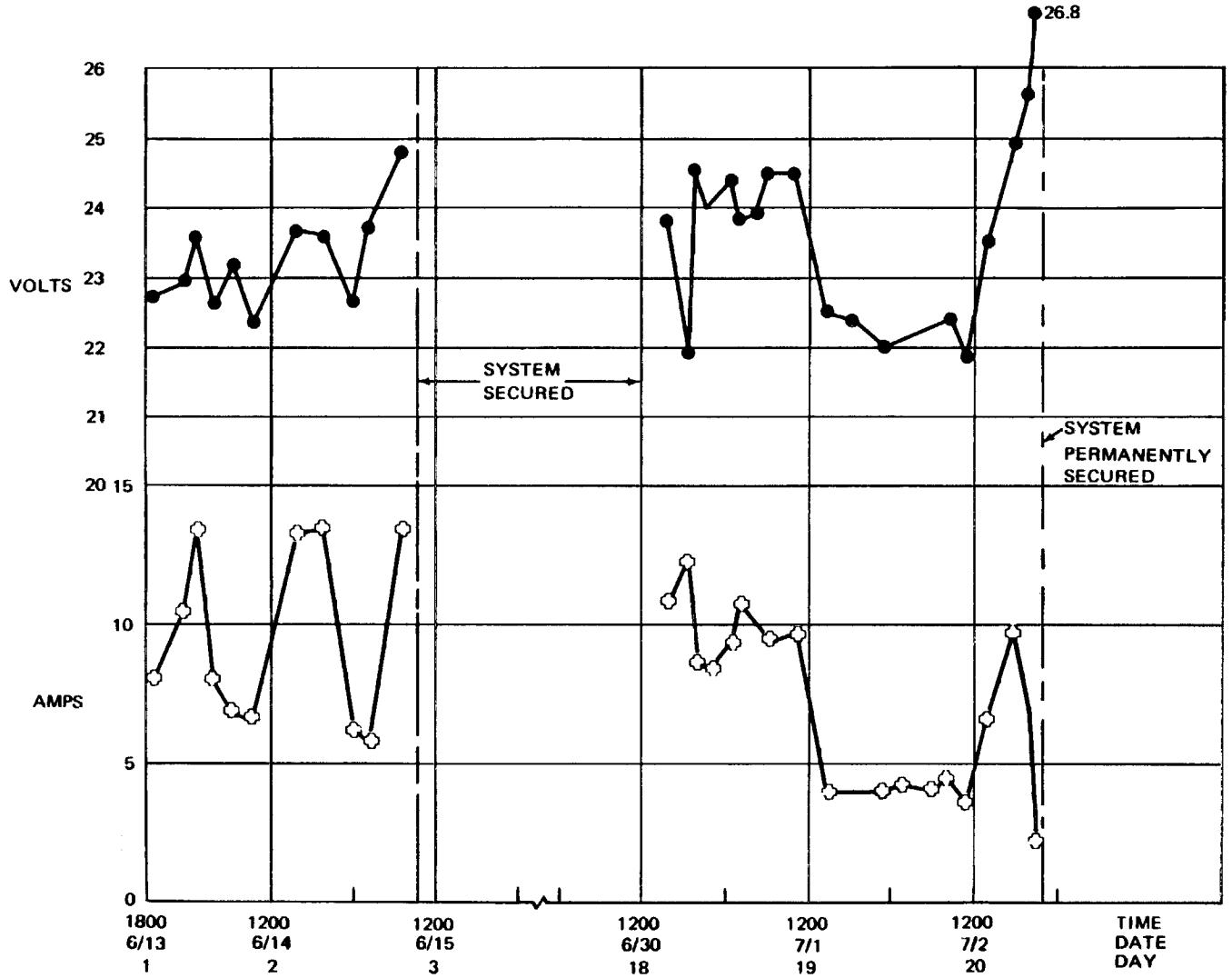


Figure 2-106. Module Position No. 2 Electrical Performance

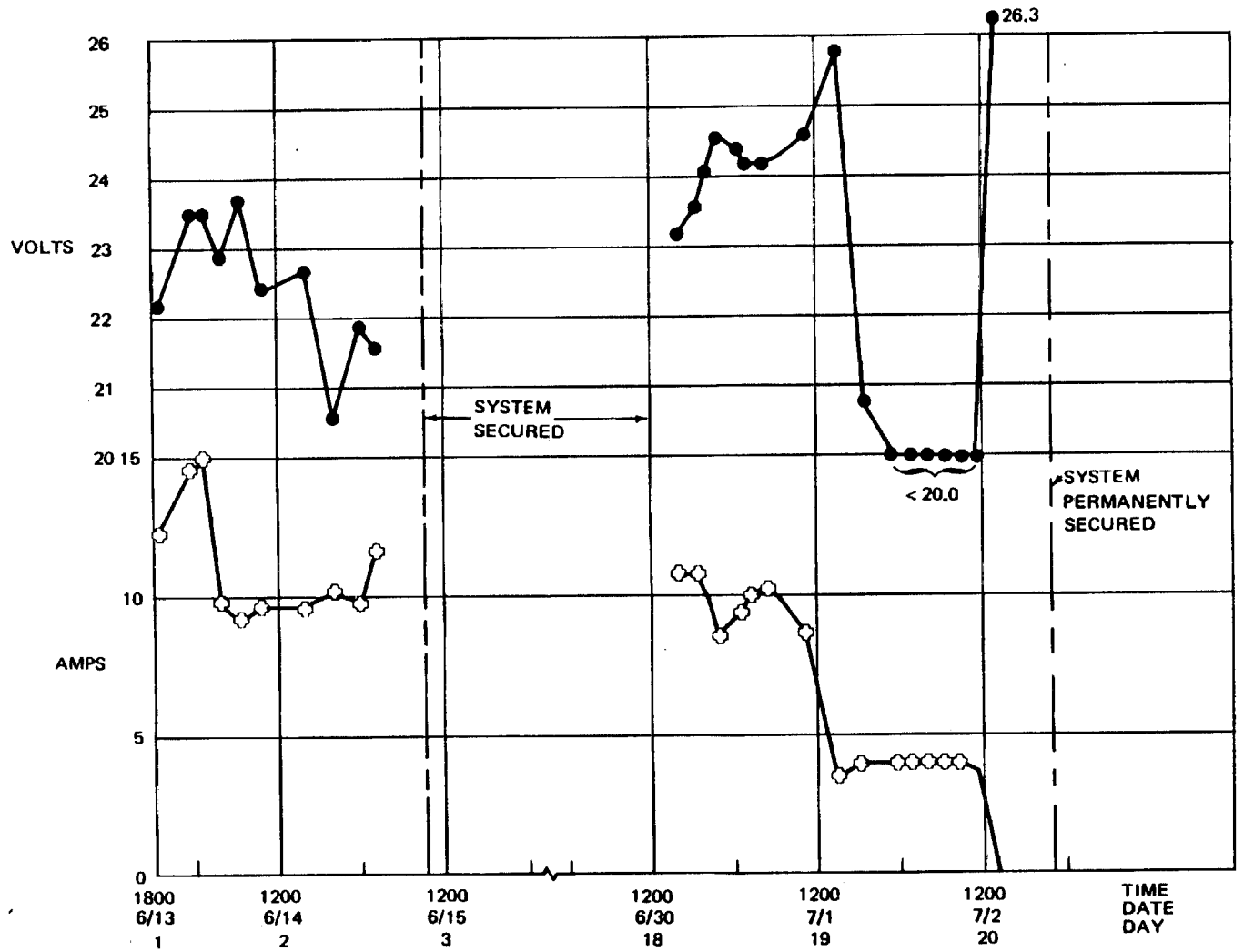


Figure 2-107. Module Position No. 3 Electrical Performance

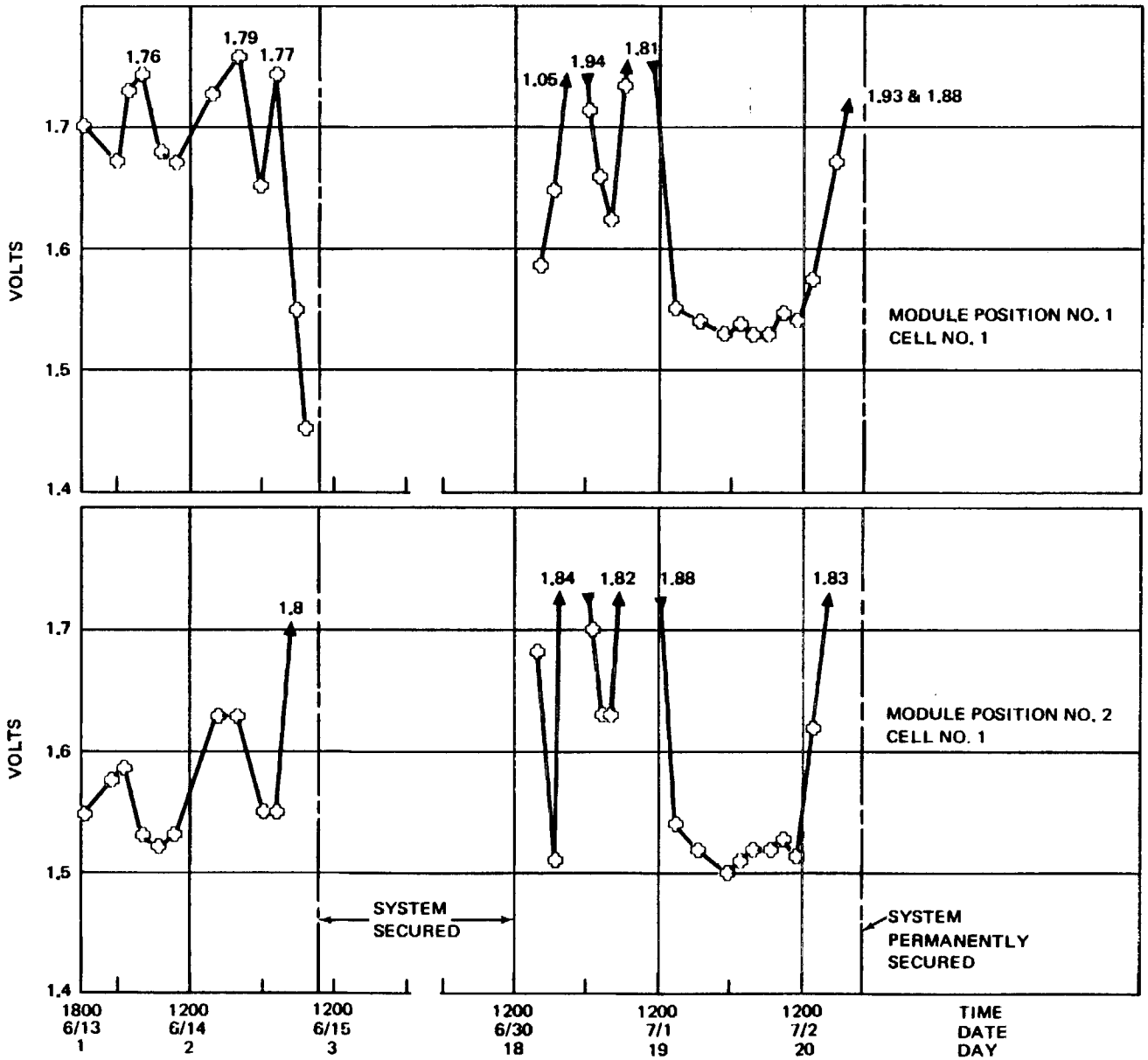


Figure 2-108. Cell Voltage Variations

pressure was more than 27.6 kN/m^2 (4 psi) below the oxygen (Reference 2-9). Numerous attempts to regain normal operation without stopping the unit were unsuccessful and it was decided to secure the unit and make necessary repairs. Also during this period of operation, difficulty was experienced in maintaining current control of module 2. The current reading on module 2 fluctuated at random. Attempts to stabilize these fluctuations were unsuccessful. At 0900 on day 3 the unit was secured for repairs. Basic reasons for shutdown were: no positive current control, N_2 pressure low and regulator not functioning, purging was ineffective, temperature of modules was high, and 5 of the 45 cells had voltages exceeding 1.7 volts.

After shutdown, all modules were flushed by the crewmen for long periods of time on the separate flushing unit to ensure the proper wetness and electrolyte concentration in the matrices. A number of attempts were made to restart the unit between days 3 and 18. During that period, problems were encountered with the MDAC-installed nitrogen regulator, with electrical shorts in the Zener diode and with the bias-power relay. After correcting these problems, the unit was restarted on day 18. Again problems of high cell voltage (Figure 2-108) and high temperature (Figure 2-105) were experienced. Only when the current to the modules was reduced to less than 5 amps was it possible to maintain some degree of stability of cell voltages and module temperatures. The high-pressure peak on Figure 2-103 at approximately 1200 on test day 19 was caused by the Deoxo-purifier in the oxygen discharge line clogging with crystals of potassium hydroxide. The hydrogen pressure rose with the oxygen pressure because the oxygen line is biased to the bonnet of the hydrogen back pressure regulator.

After approximately 1800 on test day 19, the unit water pressure did not continue to follow the accumulator water pressure. Accumulator water pressure remained relatively constant, but unit water pressure would drop off for a while and then slowly rise up to normal then gradually fall off again. The data on Figure 2-103 reflect some of these cyclical fluctuations. Increasing the accumulator pressure in an attempt to return the unit water pressure to acceptable levels only caused the unit to kick off the line due to high water pressure. As soon as the N_2 regulator, which controlled water accumulator pressure, was adjusted to increase water pressure, the unit water pressure would rapidly rise to too high a value. Initially, pulsing the water feed pump and its interconnected solenoid valves had the effect of raising the unit water pressure which would drop off again. Finally, even the pulsing had no effect. It appeared that some type of blockage existed in the plumbing, fittings, valves, separator or other equipment between the accumulator water pressure gage and the unit water pressure gage. Cross leaks were also indicated in a number of modules by the large quantity of gas that had to be bled frequently from the two-phase liquid/gas separator.

After trying all possible corrective measures without any improvement in performance, the unit was permanently shut down on the evening of the 20th test day. Basic reasons for this permanent shutdown were high cell voltages experienced in modules 3 and 5 which had already been shut down, cross leaks in module 4, no positive current control, no positive water pressure control, inability to operate above 5 amps per module for any significant period of time, and overvoltages in some cells in each of the two operating modules. Detailed analysis of test data collected from tests conducted before the 90-day test as well as data collected during the 90-day test indicated that

some damage may have been done to the modules before the test that had caused an increase in the internal resistance of the modules thus causing increased voltages within some cells. This problem was amplified by the high differential pressure between the module water and the unit hydrogen pressure hoop. The high differential pressure allowed hydrogen cross leaks that limited water vapor diffusion to the electrolyte matrix. This caused further concentrating of the electrolyte and still higher voltages due to matrix drying.

Careful and detailed analysis of all available information has indicated that certain changes should be made to the unit before further testing is conducted. Improvements are needed in electronic design (current control and operating logic), pressure and flow regulation, temperature control, liquid/gas separation, operating procedures and man/system interfaces. Cell over-voltages and cross-leaks resulted from consistent and constant lower water pressures than desired; thus, matrices should be designed to withstand greater pressure differentials without cross leaks. Peripheral equipment inadequacies induced failures in the electrolysis modules; thus, peripheral equipment should be designed with greater compatibility for KOH, higher reliability, and in accordance with aerospace standards.

During the 96 hours of operation of the A-C unit, it produced 10.2 kg (22.4 lb) of oxygen and 1.3 kg (2.8 lb) of hydrogen. This is an average of 57.4 percent of the required oxygen for the 4-day period. This unit provided, during its limited operating life, approximately 2.6 percent of the total oxygen and 2.7 percent of the total hydrogen required by the SSS during the 90-day test. A maintenance summary is shown in Table 2-48.

Lockheed Water Electrolysis Unit

The LMSC unit was installed outside of the SSS (in accordance with Reference 2-10 and NASA CR111882) and operated on vent mode during the first 3 days; that is, all oxygen and hydrogen was vented to ambient. On day 3, a nylon fitting in module 1 was found to be leaking hydrogen. The unit was secured, representatives from LMSC made the necessary repairs, and the unit reinstated to normal operations. The reduced performance on Figure 2-102 between day 3 and 11 was caused by frequent unexplained shutdown of the 28-vdc power supply to the unit and a loose hydrogen tube fitting. Figures 2-109 through 2-114 show voltage and current for modules 2A, 2B, 4A and 4B for the 90-day test period.

The next failure was detection of significant quantities of nitrogen in the hydrogen and oxygen supplies. Two solenoid valves were found to have lost their seals and were allowing purge nitrogen to leak into the oxygen and hydrogen gas passages. A 6-day shutdown was required because replacement parts had to be obtained from the solenoid valve manufacturer. After repairs to the solenoid valves, the unit was restarted but capacity was reduced because of intermittent automatic shutdown by the module 2 overtemperature protection switch. This was disconnected and the unit seemed to perform trouble-free until day 40. Early on the morning of test day 40 the facility power failed. During restart of the LMSC unit, smoke was detected from module 1. This was caused by an electrical short from moist potassium carbonate on the outside of one module collecting across electrodes of different cells. The

Table 2-48

ALLIS-CHALMERS MAINTENANCE SUMMARY

Activity	Spares Usage	No. of Times	Hours Required
Purged modules manually to lower voltage		30	7.5
Flushed modules with service unit		3	6.0
Replaced modules	2 Modules	2	2.0
Replaced diode in control	Zener diode	2	3.0
Replaced N_2 regulator	Pressure regulator	2	1.0
Cleaned N_2 regulator		1	1.0
Replaced plugged oxygen purifier*	Deoxo-purifier	1	1.0
Shorted out module cells		2	0.5
Flushed water separator		1	1.0
Jumpered failed relay	Wire and electrical terminals	1	2.0
Modified timer to increase automatic purge frequency		1	0.5
Disconnected automatic current control		1	1.0
		47	26.5

*Outside activity.

carbonate collected from a leaking electrolyte fitting above the module. The problem was overcome by using installed redundancy (module 4). Module 1 was isolated and the leak repaired.

A shutdown on day 45 was caused by hydrogen leaks in the bottom of modules 2 and 3. Module 1 was disassembled and new matrices were installed, also new temperature switches were installed. New fittings were installed in the bottom of modules 2 and 3. Good operation was experienced until days 58 to 60 when the cooling unit, supplying chilled water to the electrolysis unit, developed a clogged filter and cooling capacity was reduced. A nitrogen supply solenoid valve also stuck and required cleaning. Also during this interval the 28-vdc logic power supply failed. After the necessary repairs, the unit was restarted and operated at required gas generation rates for 2 days. At day 63, cross-leaks were discovered in module 2. The unit was stopped and module 2

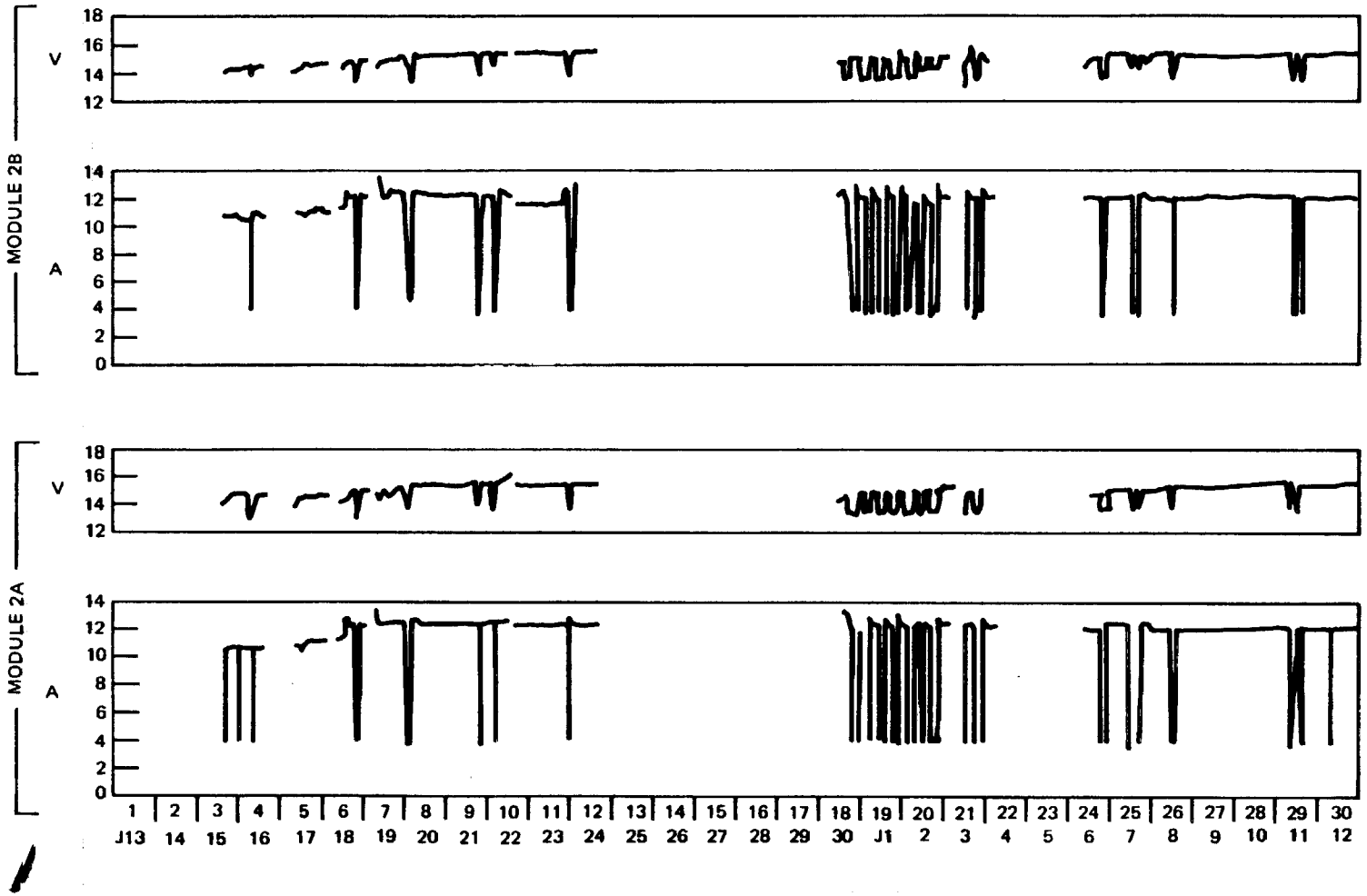


Figure 2-109. Modules 2A and 2B of Electrolysis Unit (Lockheed) Performance—Days 1 through 30

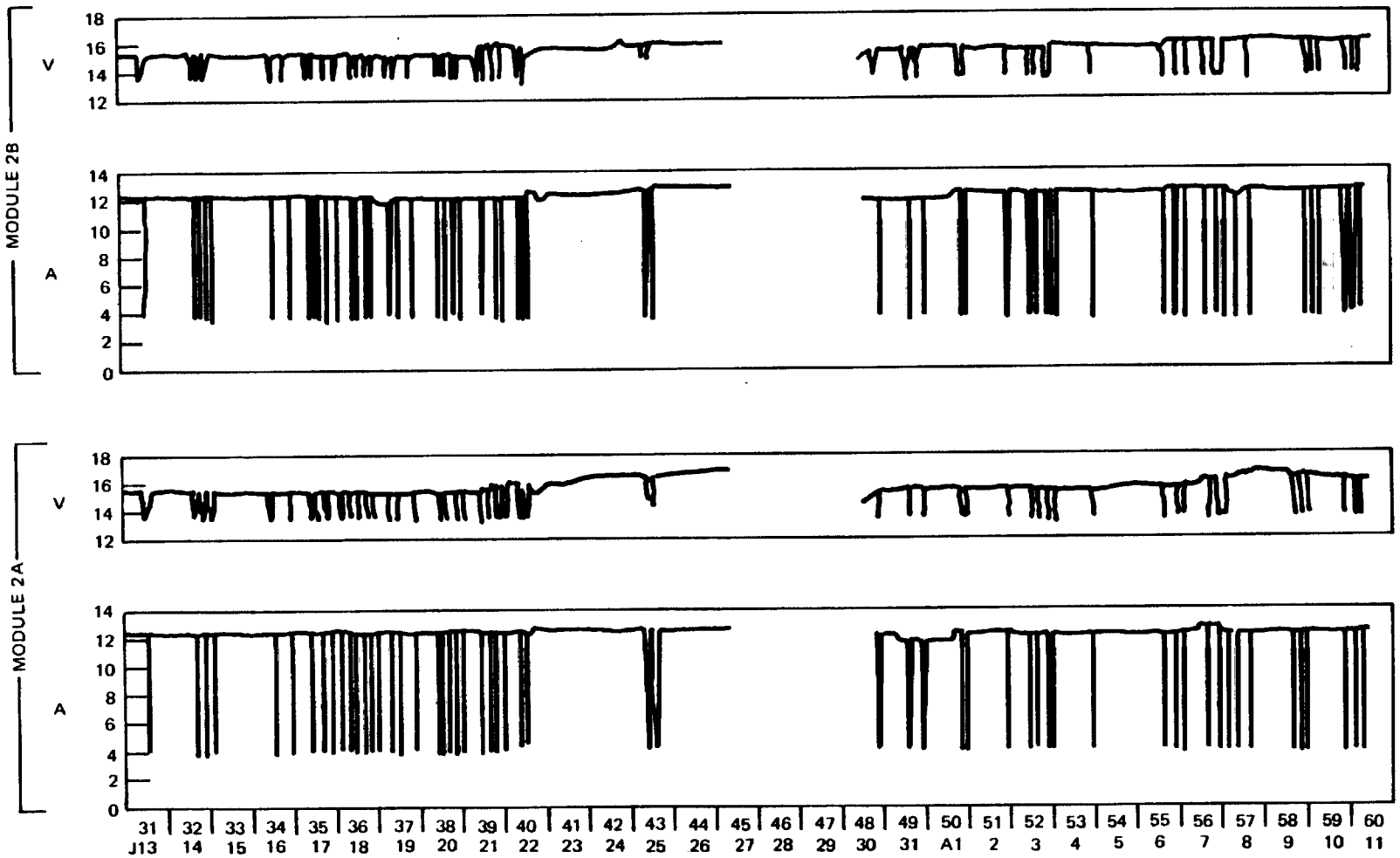


Figure 2-110. Modules 2A and 2B of Electrolysis Unit (Lockheed) Performance—Days 31 Through 60

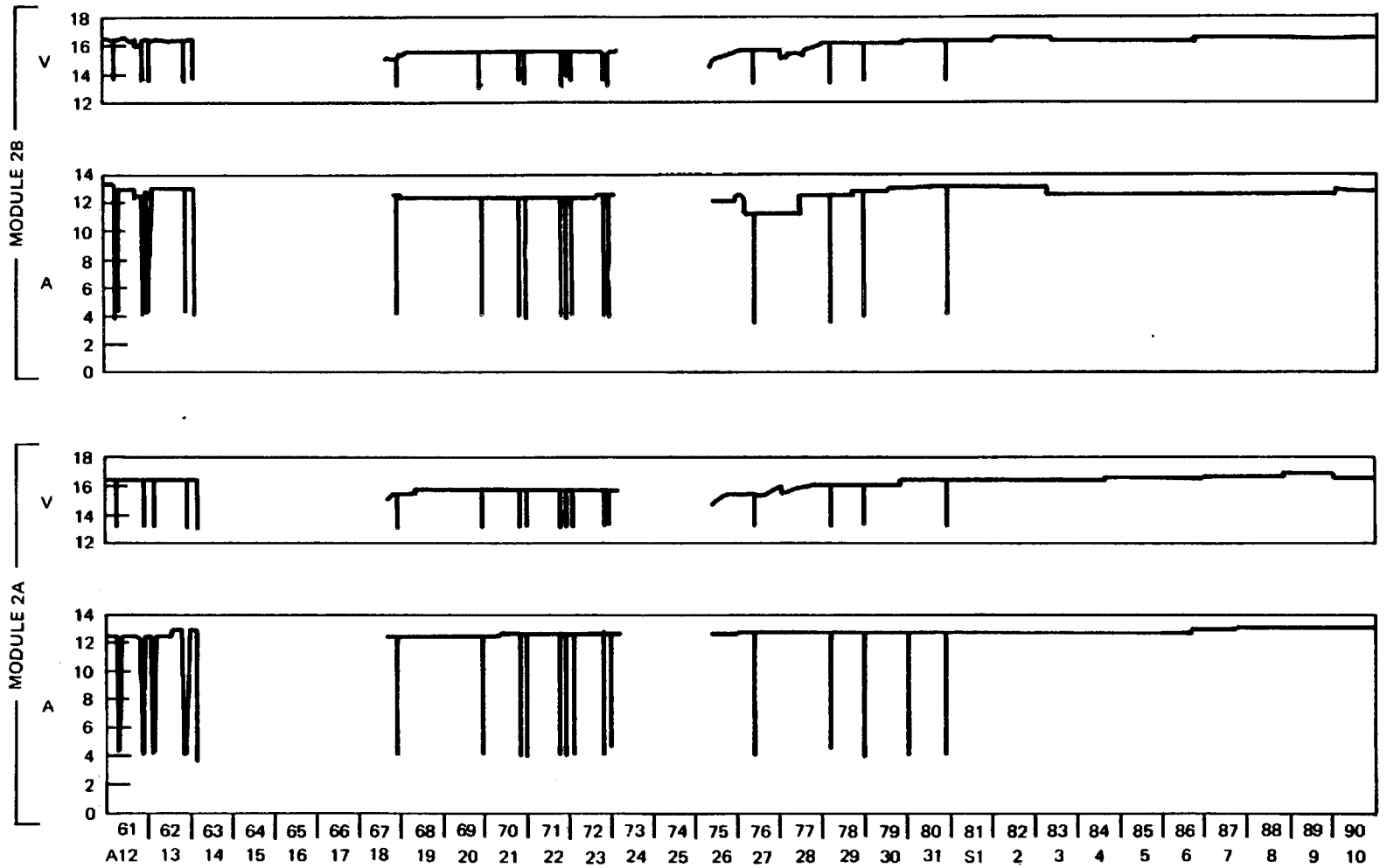


Figure 2-111. Modules 2A and 2B of Electrolysis Unit (Lockheed) Performance—Days 61 Through 90

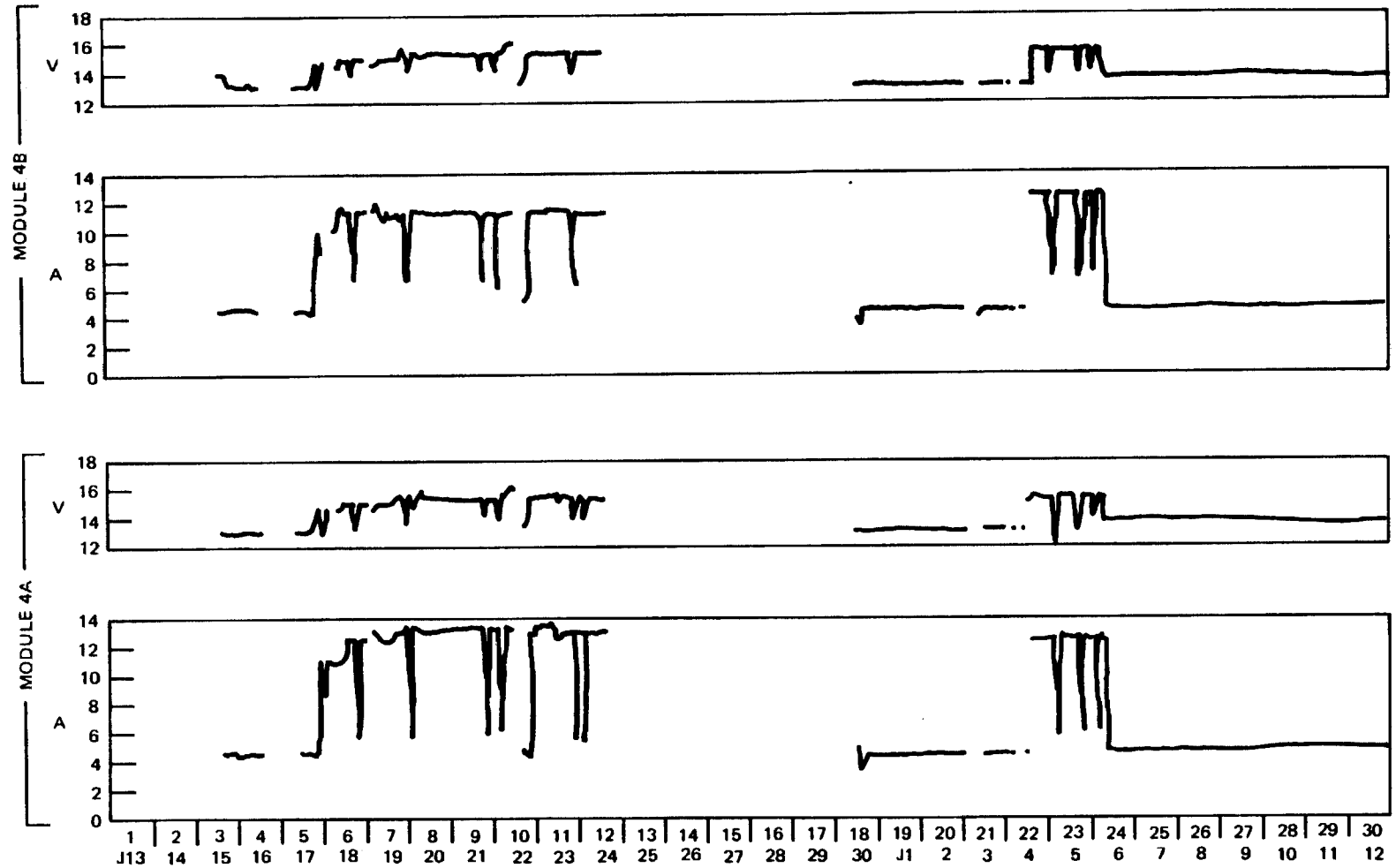


Figure 2-112. Modules 4A and 4B of Electrolysis Unit (Lockheed) Performance—Days 1 Through 30

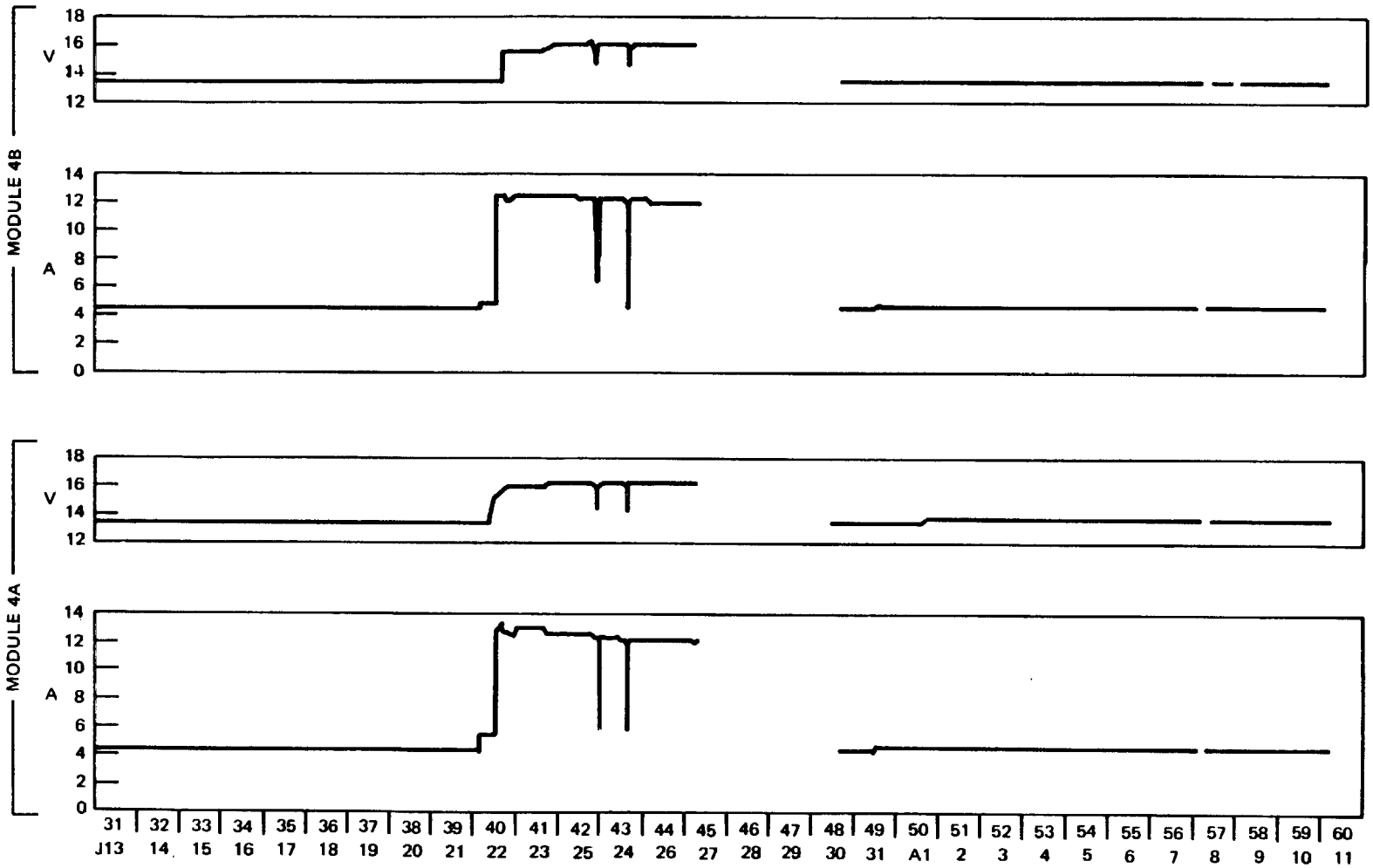


Figure 2-113. Modules 4A and 4B of Electrolysis Unit (Lockheed) Performance—Days 31 Through 60

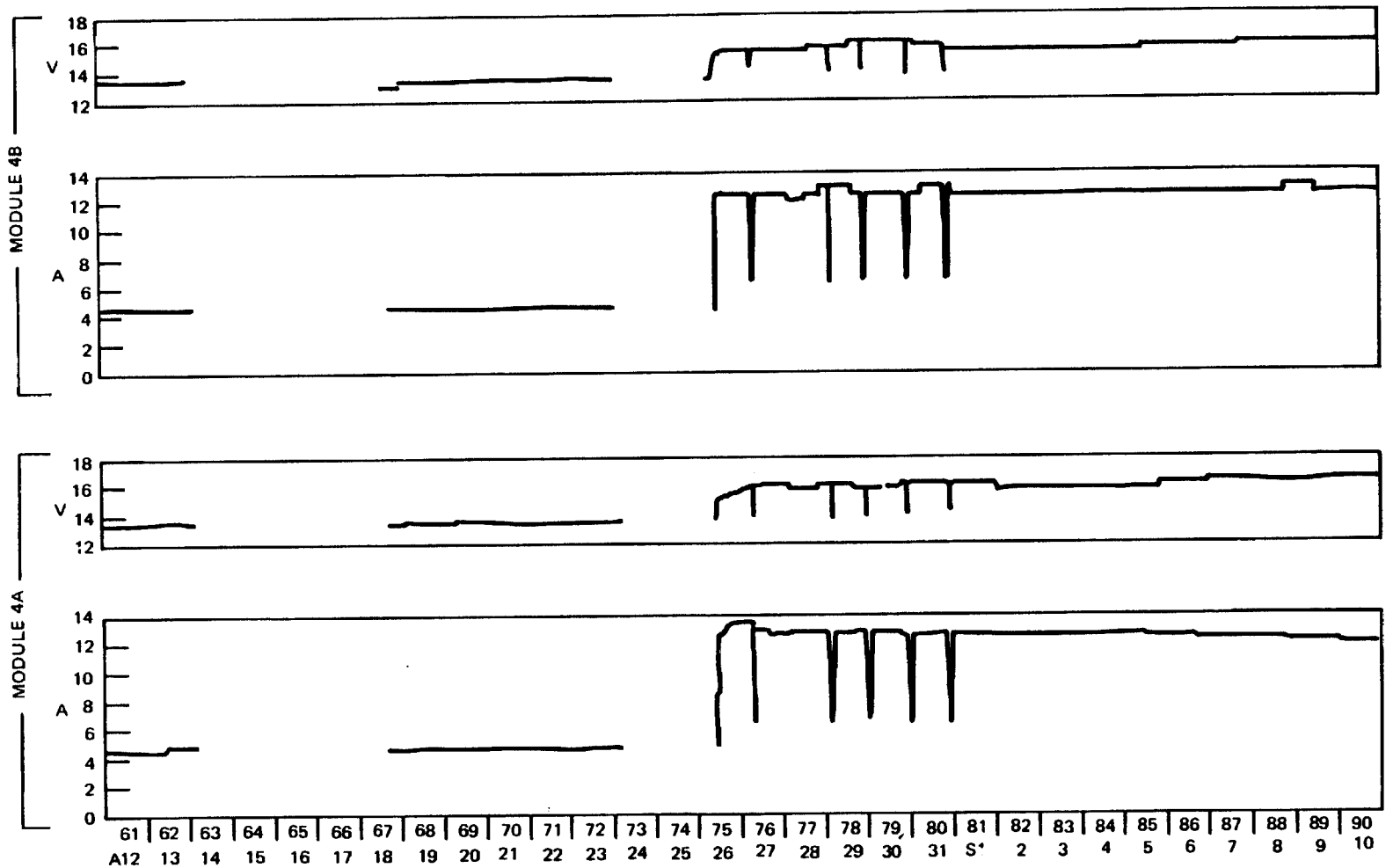


Figure 2-114. Modules 4A and 4B of Electrolysis Unit (Lockheed) Performance—Days 61 Through 90

was rebuilt with new matrices and the unit was restarted. On day 68, more gas bubbles were observed in the circulating electrolyte of all modules and the hydrogen back pressure was found to be up to 77.9 kN/m^2 gage (11.3 psig) instead of the design value of 62.1 kN/m^2 gage (9.0 psig). This high back pressure was caused by the high venting rate of hydrogen through a fixed orifice in the hydrogen wet test meter. Returning the hydrogen pressure to the proper value eliminated most of the bubbles in the circulating electrolyte. The unit was observed for the next few days and on day 73 the unit was shut down to allow LMSC personnel time to rebuild modules 1, 3, and 4. All matrices were replaced in these three modules. The unit was restarted, but module 3 still showed evidence of cross-leaks and it was decided to operate on modules 1, 2, and 4 for the remainder of the test. On day 76, an electrical problem developed in the circuitry of module 1. This was corrected by electrically cross connecting modules 3 and 1. That is, module 3 circuitry provided power to module 1. The unit operated at just under chamber requirements and without additional failures until the end of the test period. A maintenance summary is shown on Table 2-49.

Table 2-49

LOCKHEED MAINTENANCE SUMMARY
OUTSIDE ACTIVITY

Activity	Spares Usage	No. of Times	Hours Required
Repaired H_2 leak in module 1	Miscellaneous nylon fittings	1	3.0
Repaired H_2 leak in fittings		1	1.0
Replaced malfunctioning power supply	Power supply	1	2.0
Replaced leaking N_2 solenoid valves	2 Valves	1	1.5
Disconnected overtemp switch		2	0.1
Repaired short in module 1	4 Epoxy frames and asbestos matrix	1	16.0
Repaired H_2 leak in modules 2 and 3	Miscellaneous nylon fittings	1	5.0
Replaced overtemp switches	2 Switches	1	0.8
Repaired N_2 solenoid valve		2	2.0
Replaced control and logic power supply	Electronic control	1	2.0
Added relay to control circuit	Relay	1	1.0
Rebuilt module 2	Asbestos matrices	1	16.0
Rebuilt modules 1, 3, and 4	Asbestos matrices	1	32.0
Switched electronic control on module 1		1	0.8
		16	83.2

During the 90-day test, this unit operated a total of 1, 681. 2 hours (70. 2 days). The unit supplied the SSS a total of 62. 2 days and for 8. 0 days the gas generated by the unit was vented to ambient. It delivered 257 kg (566 lb) of oxygen and 25 kg (55 lb) of hydrogen to the SSS. This represents 68. 9 percent of the hydrogen used by the Sabatier reactor and 65. 7 percent of the oxygen required for leakage and metabolic consumption. Average oxygen production rate for this unit was 4. 13 kg/day (9. 1 lb/day), which was not adequate to support the average requirement of 4. 35 kg/day (9. 58 lb/day).

The Stuart Electrolyzer unit provided 10. 5 kg (23. 0 lb) (28. 4 percent) of hydrogen to the Sabatier reactor and 117. 3 kg (258. 3 lb) (30. 0 percent) of oxygen to the SSS. Also, 7. 0 kg (15. 3 lb) (1. 7 percent) of oxygen was provided from high-pressure storage.

2. 4. 3 Two-Gas Controller

The two-gas controller functioned by adding fixed pulses of oxygen and nitrogen to the atmosphere. The pulse frequency is controlled by an electronic comparator signal which is proportional to the difference between the sensor output and a level representative of the preselected control point. The quantity of gas added is measured by counting the pulses. The operational characteristics observed during the manned testing are presented.

2. 4. 3. 1 Equipment Description

The two-gas control includes redundant functioning units designated the Mark III flight-weight unit (primary) and the Mark II prototype unit (baseline). Each unit includes an electronics control package and a pneumatics package (see Figure 2-115). The primary SSS gas composition sensor is a four-gas mass spectrometer (Perkin-Elmer). The baseline gas sensors are a polargraphic oxygen analyzer (Beckman) and a total pressure transducer (Statham). The above components are integrated into the SSS by means of an electronic interface box (junction box), which allows redundant operational modes by interconnecting various combinations of gas sensors and electronic control packages (see Figure 2-116).

Both electronics packages use the same principle of operation (Reference 2-11). The baseline unit was fabricated from commercially available components. The input gas sensor signals are balanced by voltage divider networks, and the integrating amplifiers drive meter relays to activate the gas admission solenoid valves. The flight-weight unit employs advanced microcircuits; amplifiers to balance gas sensor signals; and an integrating amplifier, binary counter, and a 10-second timer to activate the gas solenoid valves (see Figure 2-117). The application of advanced technology to the flight-weight unit reduced the weight and volume to 1/6 of the baseline unit.

The flight-weight electronics package operates in the following manner. The amplified gas sensor signals are connected to a sensor-select switch as shown in Figure 2-117. The selected signal is summed at the input to an integrator with a set point voltage which represents desired 0_2 concentration level. The output of the integrator is level-detected and when the output reaches a preset level, the detector provides a reset signal to the integrator and a counting pulse to a binary counter. For each of 16 integration periods, the binary

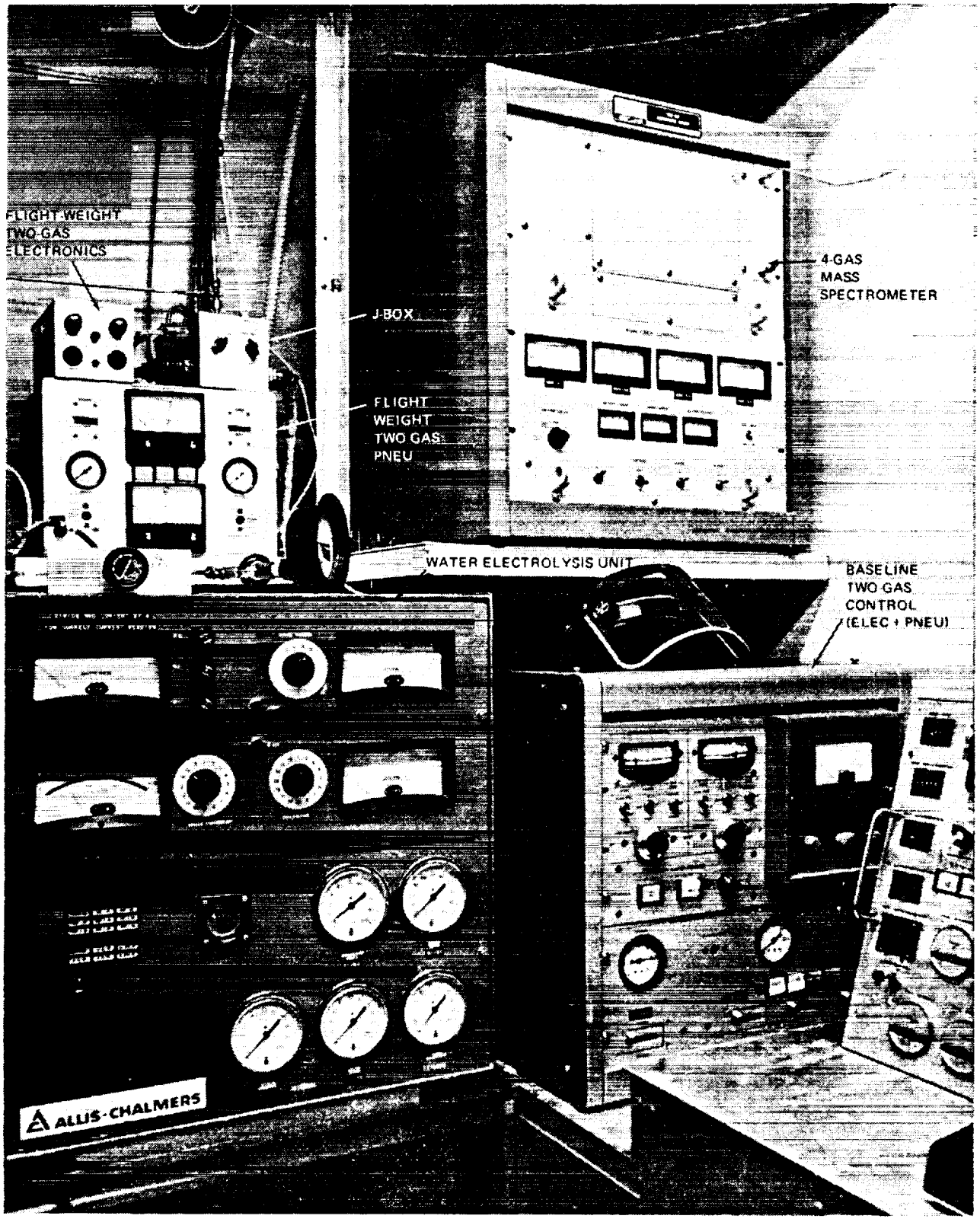


Figure 2-115. Two-Gas Control and Onboard Water Electrolysis Unit

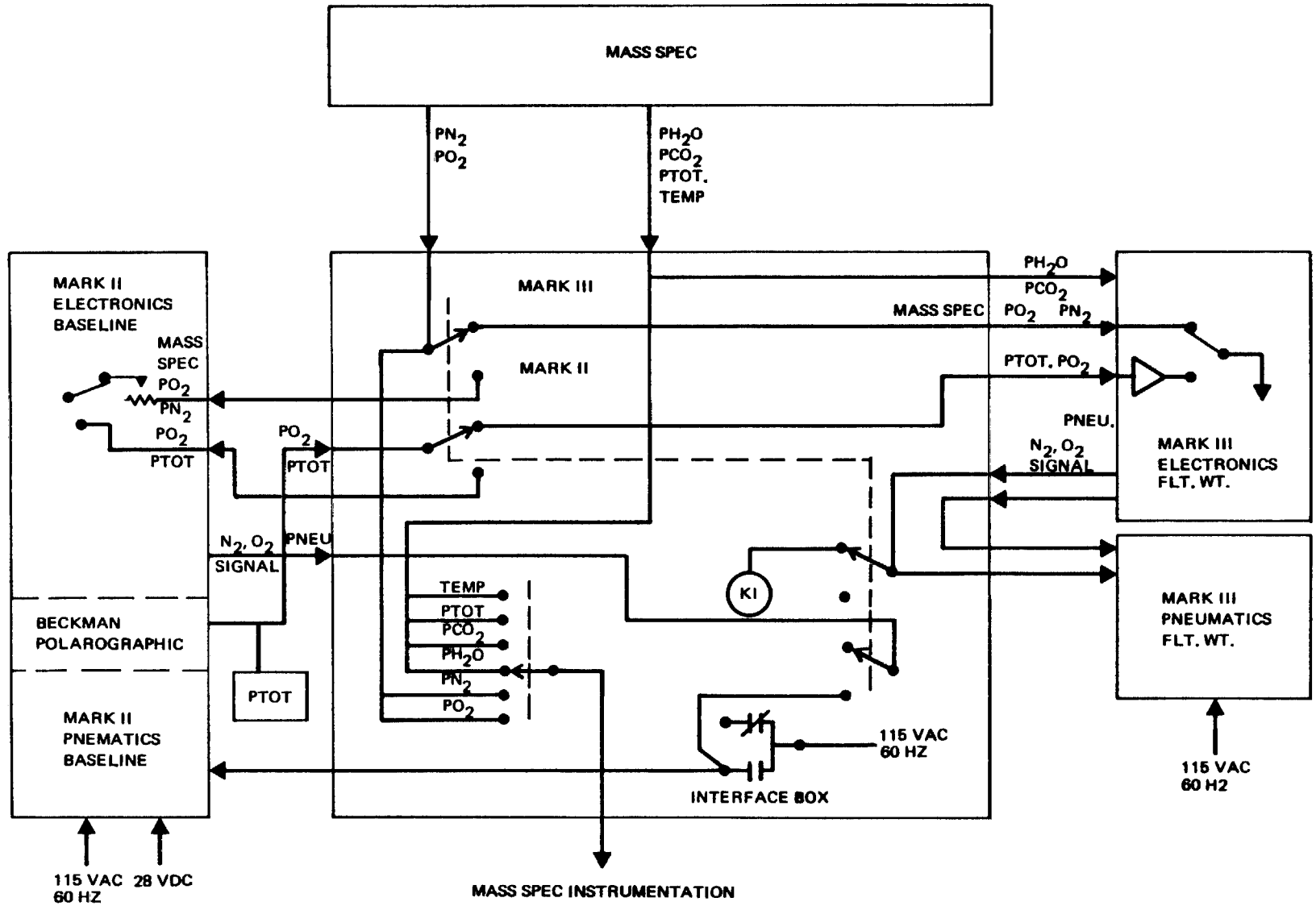


Figure 2-116. Electronic Interface Connections

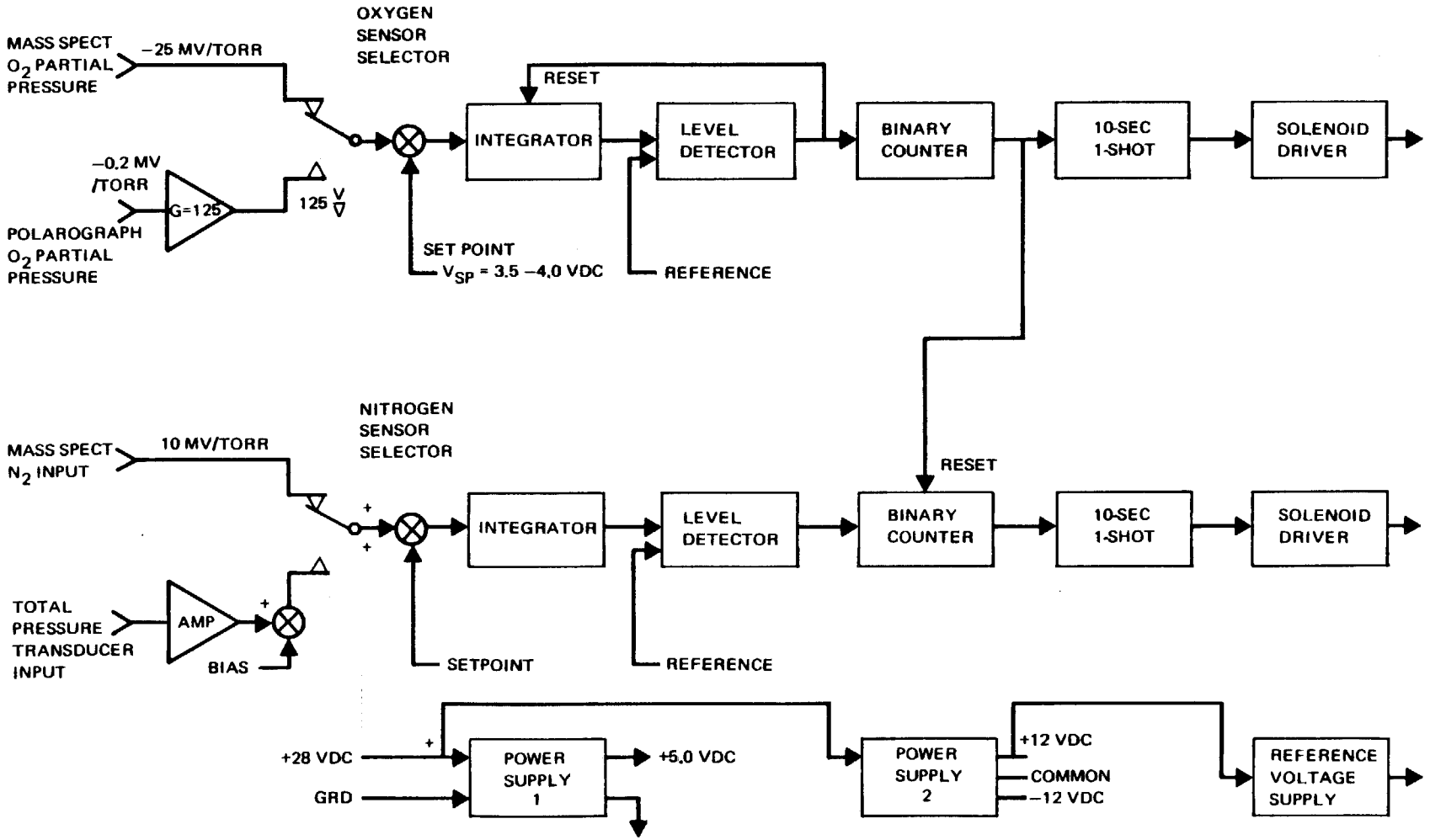


Figure 2-117. Block Diagram of Oxygen and Nitrogen Channels of the Two-Gas Atmosphere Control Unit

counter originates a pulse which activates a 10-second timer. (Only one integrating period occurs for each pulse in baseline unit.) The output of the oxygen binary counter is also used to reset the nitrogen binary counter, thereby preventing the addition of nitrogen to the SSS until the oxygen deficiency is less than one-half the total atmosphere deficiency. The timer output signal activates the appropriate solenoid valve adding a calibrated quantity of gas to the atmosphere and advances an electromechanical totalizer one count. Except for the gas sensor circuits, the oxygen and nitrogen channels are identical.

Total gas usage is determined by multiplying the totalizer count by the quantity of gas per count. The mass flow per count for oxygen was 10.4 g (2.3×10^{-2} lb) at the regulated pressure of 205 kN/m^2 (29.7 psia); the mass for nitrogen was 1.74 g (3.83×10^{-3} lb) per count at a pressure of 240 kN/m^2 (34.8 psia). The pulse quantities were determined by orifice size and adjustment of the gas pressure regulators and were selected on the basis of the predicted use rates of about 3.6 kg (8 lb) per day of oxygen and 0.5 kg (1 lb) per day of nitrogen.

Each of the pneumatic packages contains the solenoid valves, pressure regulators and orifices required for gas admission. During the test, both pneumatic packages were pulsed by the flight-weight electronics; however, only the baseline pneumatics was used for gas supply. The baseline pneumatics package was designed to accept oxygen from one of three sources available for SSS usage: baseline from the flight-type electrolysis units; backup from the commercial Electrolyzer; and storage from bottled oxygen. The design included additional pressure switches and relays to allow oxygen source management. The baseline and backup oxygen supply lines both contain high-limit pressure switches [248 kN/m^2 (36 psia)] and low-limit pressure switches [207 kN/m^2 (30 psia)]. Should baseline oxygen pressure drop to the low-limit pressure level, the switch activates a visual and audio warning signal that the source pressure will not support sonic flow through the metering orifice. The audio warning may be silenced by depressing an acknowledge switch and the backup oxygen supply may be manually selected, or use of the baseline source may be continued even though the pressure is low.

The backup pressure supply switches operate in the same manner to switch to the storage source. The high-level pressure switches provide signals to automatically change back toward the baseline source when the pressure is restored. The source switching circuitry also switches the counting pulse signals to respective counters to provide a record of oxygen supplied from each source. Since the pneumatic components of the flight-weight and baseline units are identical, the test performance of the baseline unit can be directly related to the flight-weight unit.

The primary source of gas composition signals was the four-gas mass spectrometer, which was developed by Perkin-Elmer for NASA-LRC. This instrument analyzes the atmosphere by separating the gas species according to its atomic mass number. It consists of three functional segments: (1) the ion source, (2) the analyzer section, and (3) the collector and electronics. A small continuous sample of the atmosphere is "leaked" into a closed chamber and past an electron beam, causing it to become ionized. The ions are accelerated by an electromagnetic field into the analyzer section. The analyzer section contains

a magnetic field at right angles to the ion-gas flow. This results in the ion-gas flow being deflected from a straight path into arcs following paths of varying curvature. The heavier the ion the less it is deflected by the magnetic field. This causes the ion stream to fan out and intercept the ion collectors. Four specific collectors are positioned to intercept ion masses of 18 (water), 28 (nitrogen), 32 (oxygen), and 44 (carbon dioxide). The ions introduce an electron charge at the collector plates resulting in a current flow which is amplified to the proper magnitude for signal and display uses.

A polarographic oxygen sensor (Beckman) was utilized as a backup sensor. This sensor contains a gold cathode and a silver anode immersed in a gel electrolyte (KCl). A small potential is applied between the electrodes. A section of the sensor is covered with a Teflon membrane which is permeable to oxygen. The oxygen diffuses through the electrolyte and is electrochemically reduced at the cathode allowing a small current to flow. The current flow is directly proportional to the partial pressure of oxygen. This current is then amplified for control and display.

An absolute pressure transducer (Statham) was used to provide a backup signal for nitrogen control. The type used was a strain gage bonded to a diaphragm. The strain gages were connected into a Wheatstone bridge configuration to provide an output signal proportional to absolute pressure.

The electrical interface junction box collects all the sensor signals and distributes them through switches to the selected electronics module. The output signals are also routed through the junction box and are directed to both the pneumatic packages. In addition, the junction box is the interface between the data recording system and the sensor signals originating within the mass spectrometer. These signals are O_2, N_2, CO_2, and H_2O partial pressure, the temperature of the inlet leak, and the total pressure signal from the absolute pressure transducer in the mass spectrometer.

2.4.3.2 Operational Results

During the initial week of the test it became evident that cabin oxygen partial pressure as indicated by the four-gas mass spectrometer was not in agreement with that indicated by the gas analysis console (GAC). The oxygen level control on the atmosphere controller was decreased to bring the oxygen to the specified level as indicated by the GAC. In addition, efforts were started to verify the analysis of the calibration gas used for the GAC and the mass spectrometer. This analysis of calibration gases revealed that the oxygen content of the GAC calibration gas was about 2 percent lower than the vendor's certification stated. This resulted in an actual oxygen partial pressure in the cabin of 19.3 kN/m^2 (145 mm Hg) as compared to the desired level of 20.7 kN/m^2 (155 mm Hg). The set point oxygen level of the atmosphere controller was accordingly increased and oxygen was manually added from high-pressure storage on day 7 of the test in order to bring the oxygen level to the proper 20.7 kN/m^2 (155 mm Hg) level. Figure 2-106 presents the average oxygen partial pressure level throughout the test, and the oxygen level perturbations of the first week are evident. Figure 2-118 also shows that the oxygen stayed within ± 67 N/m^2 (± 0.5 mm Hg) of the control level for the remainder of the test. Nitrogen partial pressure throughout the run stayed within the limits of 44.0 ± 1 kN/m^2 (330 ± 8 mm Hg) after the transients of the first few days settled out. The dips in nitrogen partial pressure indicated in Figure 2-119 for days 8 and 12 resulted from leakage through the waste storage container lid to the annulus. The dip in nitrogen partial pressure indicated on test

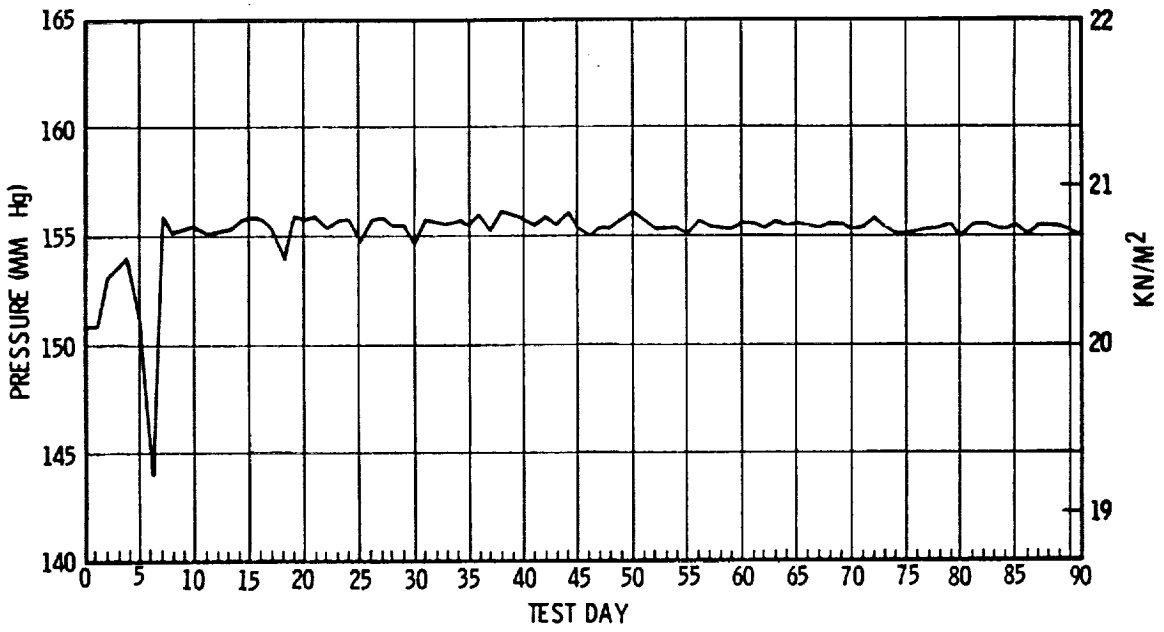


Figure 2-118. Oxygen Partial Pressure

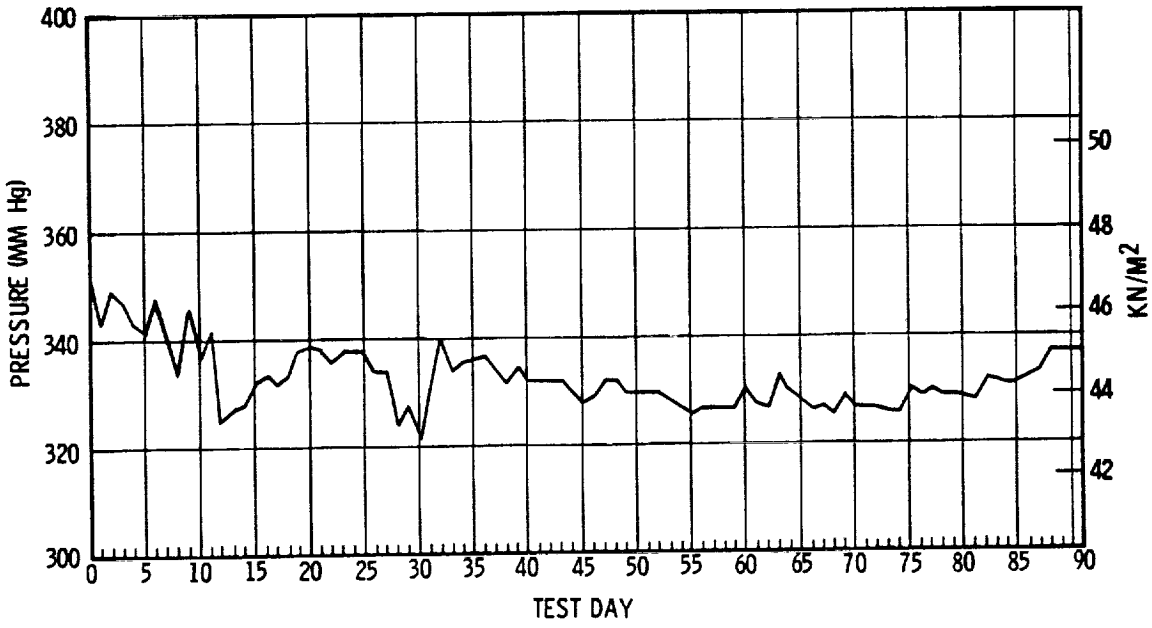


Figure 2-119. Nitrogen Partial Pressure

days 28, 29, and 30 is attributed to leakage through the pass-through port while replacing the catalyst in the Sabatier reactor. The relatively large fluctuations in nitrogen partial pressure are partially due to the leakage being considerably higher than expected. The low mass flow per pulse resulted in many more pulses to correct an error than desirable. The input circuit sensitivity was also much lower than that for the oxygen channel. Improvements in these parameters would result in much more accurate nitrogen partial pressure control.

Figure 2-120 presents a record of total atmosphere pressure showing both the minimum and maximum pressures recorded for the day. This figure also reflects the dips in nitrogen partial pressure previously described. Figure 2-120 also reflects the general difference in operation of the solid amine unit (before day 81) and the molecular sieve unit (days 81 to 90). The lowering in total pressure is attributed to a decrease in cabin humidity and a lesser decrease in carbon dioxide partial pressure.

One feature of the oxygen circuit design caused a loss of accuracy in the mass flow measurement feature of the two-gas flow. On periods of high oxygen demand, which occurred regularly during the crew's morning exercise period, the LMSC electrolysis unit was unable to maintain accumulator pressure. The low-pressure alarm would sound at 207 kN/m^2 (30 psia), and crewmen could either manually switch to the backup supply or wait until a lower pressure was reached. When switched to the backup supply, the absence of demand on the O_2 accumulator resulted in a rapid buildup in pressure with automatic switchover back to the primary source. In this event, the accumulator would again be depleted, and so on. Frequently the crew delayed manual switchover to the backup supply to avoid

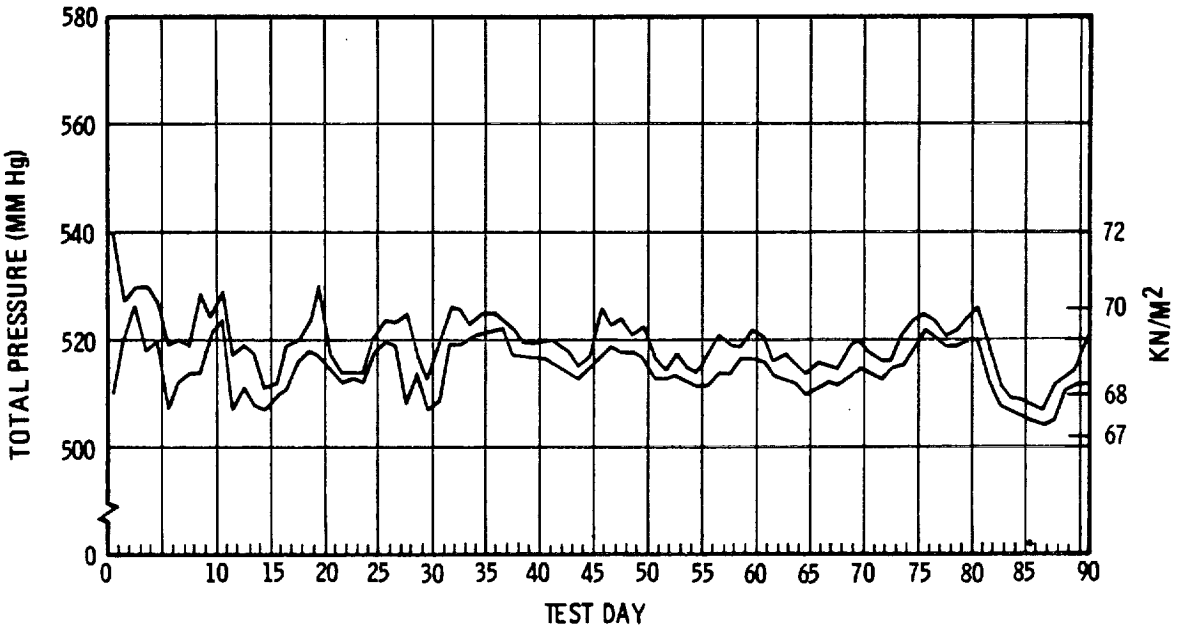


Figure 2-120. Total Atmosphere Pressure

repeated requirements, until the accumulator pressure had dropped well below that required to maintain the regulated pressure to the sonic orifice. As a result, the mass flow indicated by the pulse counter was frequently larger than the actual flow. Changes in the switchover logic should be made to provide automatic change in both directions, with a wider band between switching points to allow longer periods of accumulator recharging. Reduction in oxygen channel sensitivity would also reduce the response to transient oxygen demands. The resulting slight loss in oxygen channel accuracy would be quite acceptable.

No malfunctions requiring corrective action occurred at any time on the flight type two-gas control. A Beckman polarographic oxygen sensor was changed once during the mission as the original sensor had lost sensitivity. Since the mass spectrometer signal was used as input to the two-gas control, the polarographic sensor was not actually required, but was operated to obtain test experience. The calibration of the mass spectrometer unit was checked five times during the test. No adjustments were required, however, at any time to achieve the required accuracy of the unit. This checkout took a total of 5.0 hours of the crew's maintenance time.

2.5 FOOD MANAGEMENT

The food provisions available to onboard crewmen during the 90-day test consisted of a primary freeze-dried menu, supplementary snacks, frozen dinners, glycerol (sweetener), and a small amount of ice cream. Packaging, storage accommodations, supporting equipment, and acceptability of the food supplies are discussed.

In response to frequently reported negative reactions to food provisions for previous crews of long-term missions and simulation involving confinement, MDAC established the policy, early in the planning phase of the 90-day test, to select and provide food with emphasis on acceptability. Acceptability was felt to be a function of diversity of menu, mission duration, and initial reaction to the aesthetics of food consumption: flavor, color, consistency and aroma.

This approach permitted the collection of information to determine whether attention to these factors could eliminate negative reactions to food provisions or whether such negative reactions could be expected to accompany all future long-term operational or simulative confinements.

2.5.1 Description

Potential supplies of acceptable food provisions for space missions were contacted and requested to submit samples of their products. A list of potential suppliers was obtained through the cooperation of cognizant personnel at the U.S. Army, Natick Laboratories. Oregon Freeze-Dry, Inc., Albany, Oregon, was selected as the principal supplier of onboard food from this review of products, their availability, diversity, and projected ability to meet criteria on microbiological control. Table 2-50 presents the freeze-dried menus that were provided.

Requirements placed upon the supplier of freeze-dried, uncompressed food consisted of: microbiological control deriving from NASA/Army requirements, vacuum packaging, a 10-day menu cycle, and 10.460 MJ (2,500 kilocalories)/man/day. An additional 2.092 MJ (500 kilocalories) of snacks were provided. These consisted of nuts, raisins and candy bars.

Table 2-50

MENU

DAY 1 10.590 MJ (2,531 total kilocalories)

Breakfast - 3.874 MJ (926 kilocalories)

(49) Orange Juice
(57) Grapenuts w/Milk
(73) Sugar
(30) Diced Ham
(31) Scrambled Eggs
(91) Toast (2 slices)
(75) Jelly
(68) Milk (8 oz)

Lunch - 3.130 MJ (748 kilocalories)

(23) Pea Soup
(56) Crackers (6 crackers)
(14) Ham and Green Beans au Gratin with Rice
(96) Peanut Butter Cookies

Dinner - 3.568 MJ (857 kilocalories)

(1) Sliced Beef
(70) with Gravy
(42) Mashed Potatoes
(35) Chopped Broccoli
(26) Cottage Cheese w/Pears
(76) Brownies
(74) Margarine (1/2 tsp)

DAY 2 10.293 MJ (2,460 total kilocalories)

Breakfast - 2.736 MJ (654 kilocalories)

(55) Strawberries
(28) Creamed Beef
(90) on Toast (3 slices)
(94) Chocolate Milk (6 oz)

Lunch - 3.067 MJ (733 kilocalories)

(20 Consomme
(56) Crackers (6 crackers)
(9) Beef with Rice
(24) Carrot-Raisin Salad with Almonds
(95) Date Filled Oatmeal Cookies

Dinner - 4.489 MJ (1,073 kilocalories)

(4) Sliced Ham
(59) Noodles with Cheese Sauce
(33) Asparagus
(85) Chocolate Pudding
(74) Margarine (1/2 tsp)

DAY 3 10.724 MJ (2,563 total kilocalories)

Breakfast - 2.916 MJ (697 kilocalories)

(53) Dried or Stewed Prunes
(61) Ralston with Milk
(73) Sugar
(91) Toast (2 slices)
(75) Jelly
(68) Milk (8 oz)
(93) Cheese Scramble

Lunch - 3.029 MJ (724 kilocalories

(64) Chicken Noodle Soup
(56) Crackers (6 crackers)
(13) Crab Imperial
(27) Sweet Corn

Table 2-50

MENU (Continued)

Dinner - 4. 778 MJ (1, 142 kilocalories)

(19) Shrimp Cocktail
(3) Diced Checken
(71) with Gravy
(58) Noodles
(36) Carrots, diced
(77) Coconut Macaroons
(85) Chocolate Pudding
(74) Margarine (1/2 tsp)

DAY 4 10. 284 MJ (2, 458 total kilocalories)

Breakfast - 2. 920 MJ (698 kilocalories)

(48) Grapefruit Juice
(60) Oatmeal with Milk
(73) Sugar
(54) Raisins
(31) Scrambled Eggs
(91) Toast (2 slices)
(75) Jelly
(68) Milk (8 oz)

Lunch - 3. 908 MJ (934 kilocalories)

(16) Tuna ala Neptune
(90) on Toast (2 slices)
(45) Applesauce
(83) Fruitcake

Dinner - 3. 456 MJ (826 kilocalories)

(7) Beef Almondine with Macaroni
(43) Spinach
(50) Cheese
(56) Crackers (6 crackers)
(80) Filled Sugar Wafers
(74) Margarine (1/2 tsp)

DAY 5 10. 180 MJ (2, 433 total kilocalories)

Breakfast - 2. 736 (654 kilocalories)

(47) Raspberries
(28) Creamed Beef
(90) on Toast (3 slices)
(94) Chocolate Milk (6 oz)

Lunch - 3. 310 MJ (791 kilocalories)

(17) Turkey Tetrazzini
(24) Carrot-Raisin Salad w/Almonds
(86) Lemon Pudding

Dinner - 4. 134 MJ (988 kilocalories)

(2) Beef Tenderloin Steak
(70) with Gravy
(62) Rice
(44) Squash
(97) Bread Sticks (2 sticks)
(55) Strawberries
(76) Brownies
(74) Margarine (1/2 tsp)

DAY 6 10. 556 MJ (2, 523 total kilocalories)

Breakfast - 3.766 MJ (900 kilocalories)

(49) Orange Juice
(61) Ralston with Milk
(73) Sugar
(30) Diced Ham
(31) Scrambled Eggs
(91) Toast (2 slices)
(75) Jelly
(68) Milk (8 oz)

Table 2-50

MENU (Continued)

Lunch - 2. 715 MJ (649 kilocalories)

(8) Beef Chop Suey
(98) Chow Mein Noodles
(41) Peas
(25) Cottage Cheese
(79) Fig Newtons

Dinner - 4. 075 MJ (975 kilocalories)

(6) Pork Tenderloin
(72) with Gravy
(42) Mashed Potatoes
(33) Asparagus
(65) Jingle Jell
(76) Brownies
(74) Margarine (1/2 tsp)

DAY 7 10. 196 MJ (2, 437 total kilocalories)

Breakfast - 3. 138 MJ (750 kilocalories)

(48) Grapefruit Juice
(32) Sausage
(31) Scrambled Eggs
(91) Toast (2 slices)
(75) Jelly
(68) Milk (8 oz)

Lunch - 3. 753 MJ (897 kilocalories)

(13) Crab Imperial
(37) Carrots and Peas
(46) Apple Slices
(83) Fruitcake

Dinner - 3. 310 MJ (791 kilocalories)

(1) Sliced Beef
(70) with Gravy
(42) Mashed Potatoes
(39) Green Beans and Mushrooms
(51) Pearsauce
(89) Chocolate Chip Cookies
(74) Margarine (1/2 tsp)

DAY 8 10. 431 MJ (2, 493 total kilocalories)

Breakfast - 3. 088 MJ (738 kilocalories)

(49) Orange Juice
(60) Oatmeal with Milk
(73) Sugar
(54) Raisins
(91) Toast (2 slices)
(75) Jelly
(32) Sausage
(68) Milk

Lunch - 2. 665 MJ (637 kilocalories)

(98) Chow Mein Noodles
(11) Chicken Chop Suey
(45) Applesauce
(78) Gingersnaps

Dinner - 4. 678 MJ (1, 118 kilocalories)

(97) Bread Sticks (2 sticks)
(18) Crabmeat Cocktail
(12) Chunk Chicken with Rice
(38) Green Beans and Almonds
(87) Vanilla Pudding
(82) Sugar Cookies
(74) Margarine (1/2 tsp)

DAY 9 10. 343 MJ (2, 472 total kilocalories

Breakfast - 3. 515 MJ (840 kilocalories)

(92) Pineapple Juice
(31) Scrambled Eggs
(32) Sausage
(91) Toast (2 slices)
(75) Jelly
(94) Chocolate Milk (6 oz)

Table 2-50

MENU (Continued)

Lunch - 2.469 MJ (590 kilocalories)

(21) Fish Chowder
(56) Crackers (6 crackers)
(34) Diced Beets
(46) Apple Slices
(76) Brownies

Dinner - 4.360 MJ (1,042 kilocalories)

(15) Pork and Potatoes au Gratin
(35) Chopped Broccoli
(84) Butterscotch Pudding
(81) Oatmeal Cookies
(74) Margarine (1/2 tsp)

DAY 10 10.749 MJ (2,569 total kilocalories

Breakfast - 2.866 MJ (685 kilocalories)

(52) Plums
(66) Cold Cereal with Milk
(73) Sugar
(29) Eggs and Bacon Bits
(91) Toast (2 slices)
(75) Jelly
(68) Milk (8 oz)

Lunch - 3.782 MJ (904 kilocalories)

(10) Beef Stew
(40) Lima Beans
(24) Carrot-Raisin Salad with Almonds
(88) Banana Pudding

Dinner - 4.100 MJ (980 kilocalories)

(22) Onion Soup
(56) Crackers (6 crackers)
(5) Lobster Tails with Butter
(63) Rice with Mushrooms
(43) Spinach
(77) Coconut Macaroons
(74) Margarine (1/2 tsp)

For the frozen meals, Stouffer Foods, Cleveland, Ohio, was required to supply a minimum of 5 percent of the onboard meals, preferably complete dinners amounting to approximately 3.347 MJ (800 kcal)/meal. NASA microbiological standards were to be met. Meals were to arrive in frozen form and were to be packaged to require no more than 0.122 m^3 (4.3 cu ft) of storage. The latter requirement was imposed because of the capacity of the onboard freezer.

In addition, at the request of crewmen, 1.9 liters (4 pints) of commercially available ice cream were placed onboard.

The glycerol (a sweetening agent with nutrient value) was obtained as an experimental food supplement from Dr. J. Shapira, NASA-Ames Research Center. Interest in the glycerol as a food additive centered upon its acceptability as a sweetening agent, as well as on its physiological resolution after ingestion. A full description of this experiment is provided in Section 3.

Data on food consumption were provided daily throughout the mission via the TSCL data transmission terminal available to onboard crewmen. Information thus transmitted consisted of crewman identification, food items consumed, percentages of foods not ingested, water volumes required for reconstitution, and relative acceptability ratings (1-9: 1 equals "poor"; 9 equals "excellent").

Because of the late arrival of information on frozen foods, only the freeze-dried diet could be reported via the above-mentioned TSCL. Thus, data on frozen food consumption were obtained verbally from crewmen.

Freeze-dehydrated foods were supplied in vacuum packages of a multilayer laminate, which is used by the Army to package similar foods for combat field distribution. The packages consisted of polyethylene, aluminum foil, polyethylene, and an outer layer of Mylar, and were flammable in normal atmosphere.

Within some packages of food items was a dish composed of a waxy plastic (also flammable) which was to be used for reconstitution purposes. Utensils available to the crew were made of stainless steel.

Frozen food was supplied in aluminum containers similar to TV dinner trays. These were covered with aluminum foil.

Ice cream was packaged in cylindrical paper containers.

Because of the flammability of packaging materials in the food program, special precautions were taken in their onboard storage and disposal. Freeze-dried packages were grouped into four-man meal packages. These were constrained with the use of fiber glass cable tie cord and then overwrapped with three layers of heavy-duty aluminum foil. These were then stored in closed food storage cabinets which had been examined and shielded to eliminate the danger of high voltage or other sources of ignition.

Additional plastic food reconstitution dishes were stored in specially provided, tightly covered aluminum containers which were also located away from ignition sources.

Frozen meals were placed inside the onboard commercial freezer without additional preparation, as were the cartons of ice cream.

Storage requirements for all onboard food provisions approximated 2.8 m^3 (100 cu ft). Bulkiness and nonuniform package sizing of freeze-dehydrated food contributed to using approximately 1.1 m^3 (40 cu ft) more storage volume than originally allocated.

All foods requiring elevated temperatures to enhance palatability were heated in an onboard microwave oven (Litton Model 500.017).

2.5.2 Food Evaluation

Table 2-51 provides an indication of total food consumption for each crewman on day 90 of the mission and provides arithmetic means of daily caloric consumption for the crew over the entire 90-day duration. It can be seen that

Table 2-51

FOOD CONSUMPTION

Crewman	MJ 90th Day	Kilocalories 90th Day	MJ Mean 90 Days	Kilocalories Mean 90 Days
1	8.648	(2,067	11.468	(2,741)
2	10.092	(2,412)	11.807	(2,822)
3	16.968	(4,041)	12.042	(2,878)
4	14.899	(3,561)	13.125	(3,137)
		Grand Mean	12.108 MJ	(2,894) kilocalories

intake averaged 12.108 MJ (2,894 kcal)/day/man. Differences in daily consumption among crewmen are consistent with exercise regimes adjusted by crewmen to their own individual requirements. This table reflects caloric values of all consumed foods, excluding glycerol which was not a significant contributor to the total diet insofar as it was used for less than 10 percent of the mission duration and then only as a supplemental sweetener. Crew caloric intake is seen as inordinately high when compared with intake values from the previous 60-day test of a manned regenerative life support system wherein a mean daily consumption of under 8.4 MJ (2,000 kcal)/man was reported. Since the net crew weight change was not significant, it is indicated that the 90-day values are consistent with the caloric requirements to meet the actual crew activity levels that occurred during the test.

2.5.2.1 Food Acceptance

Referring to Table 2-52, the overall acceptance of food on a rating scale extending from 1 through 9 was quite high—all food items on a group mean basis received ratings of 6 and above. This is an unusual finding for space simulations or operational missions and reflects increased attention given to the selection of food on the basis on palatability.

It should be noted that although group mean acceptance values are high, individual food items within the overall menu were occasionally ranked by individual crewmen at lower levels. Food items falling in this category include such things as scrambled eggs and a gelatin dessert. Post-test crew remarks reflect the fact that scrambled eggs were rated low not because their palatability left something to be desired, but rather because it was the only form of egg available throughout the mission and was presented too often. The gelatin dessert was rated poor by three of four crewmen because of excessive sweetness.

Table 2-53 summarizes the frozen food available to the onboard crewmen during the mission. Forty-eight meals were provided by Stouffer Foods, Cleveland, Ohio, and were stored onboard in a 0.122 m^3 (4.3 cu ft) freezer. These foods (substitutes for dinners) were provided to the crew with instruction to use them as they saw fit approximately once weekly throughout the mission.

Table 2-52

90-DAY FREEZE-DRY FOOD ACCEPTANCE

Category	Crewman 1	2	3	4	Mean Model Preference	Rank Order
Soups	7.50	7.80	7.20	7.00	7.38	5
Salads	7.33	6.33	8.00	8.66	7.58	4
Entrees	8.04	8.21	7.95	8.07	8.07	1
Dairy products	7.21	7.14	7.28	6.92	7.14	7
Vegetables	7.07	6.69	7.23	7.53	7.13	8
Fruits and juices	7.90	7.40	8.36	8.54	8.05	2
Grain products	7.84	7.03	6.46	5.69	6.75	9
Desserts	7.79	6.08	7.55	7.26	7.17	6
Sauces and condiments	8.80	7.80	7.80	7.60	8.00	3
Mean Model Preferences	7.72	7.16	7.54	7.47		
Rank Order	1	4	2	3		

Crewmen chose to use these foods with a frequency of approximately once per week and otherwise employed them as a means of celebrating special occasions encountered during the mission. One such special occasion was a birthday party held for one of the onboard crewmen.

Generally, the frozen foods were well accepted by all crewmen, but the crew indicated that they could have done without them had they been required to do so. Since they were available, they found them a welcome diversion from the freeze-dehydrated primary food menu. Negative remarks reflected the feeling that, when compared with the primary diet, the frozen meals were overly rich. This, combined with differences in strength of seasoning, apparently resulted in some minor gastrointestinal difficulties. Interestingly, frozen meals were prepared utilizing the microwave oven, even though the use of that piece of equipment with the frozen meals required frequent pulsing. Our crew did not report that this was an annoyance as have others.

2.5.2.2 Microbiological Quality

All freeze-dried and frozen food items were tested for microbiological quality by the vendors. The following criteria were specified and met by the vendor's products:

Table 2-53

FROZEN FOOD (8 OF EACH)

Dinner No.	Constituents	Weight (kg)	Weight (oz)	Estimated Megajoules	Estimated Kilocalories
1	Sirloin steak	0.227	(8)	2.774	(663)
	Creamy potato bake	0.114	(4)	0.502	(120)
	Asparagus spears	0.085	(3)	0.084	(20)
		0.426	(15)	3.360	(803)
2	Pot roast of beef	0.085	(3)	1.109	(265)
	Beef gravy	0.057	(2)	0.209	(50)
	Duchess potatoes	0.099	(3.5)	0.502	(120)
	Glazed carrots	0.085	(3)	0.586	(140)
		0.326	(11.5)	2.406	(575)
3	Beef stew	0.284	(10)	4.477	(1,070)
	Spiced peaches (2 halves)	0.128	(4.5)	0.377	(90)
		0.412	(14.5)	4.854	(1,160)
4	Baked chicken breast	0.142	(5)	0.523	(125)
	Chicken gravy	0.057	(2)	0.377	(90)
	Rice	0.085	(3)	0.879	(210)
	Corn	0.085	(3)	0.251	(60)
		0.369	(13)	2.030	(485)
5	Lamb chops (2)	0.227	(8)	2.636	(630)
	Escalloped apples	0.114	(4)	1.109	(265)
	Green beans	0.085	(3)	0.084	(20)
		0.426	(15)	3.829	(915)
6	Chicken and dumplings	0.284	(10)	2.448	(585)
	Peas	0.085	(3)	0.251	(60)
		0.369	(13)	2.699	(645)

A. Total aerobic count = less than 20,000/g.

B. Total coliform count = less than 10/g.

C. Total fecal coliform count = none/g.

D. Total Streptococcus count = less than 20/g.

E. Total coagulase positive Staphylococcus count = none/5g.

F. Total Salmonella count = none/10g.

2.5.2.3 Spoilage and Waste

There was little, if any, spoilage of freeze-dried or frozen foods during the test. Several commercially packaged snack food items were found to be stale or otherwise unacceptable by the crew. Candy bars and cookies containing nut meats were found to have the shortest shelf life. The crew's discovery of a few fly larvae in the raisins provided an interesting diversion for both onboard and outside simulator personnel. Vacuum packaging, addition of antioxidants, and fresh delivery immediately before test start would alleviate this problem.

Reduction of food waste was accomplished primarily by careful selecting, trimming, and apportioning of both freeze-dried and frozen food items by the respective vendors. In addition, the crew was instructed in and fully accepted the inelegant, but effective, technique of licking their plastic food trays prior to spraying them with disinfectant. Leftover food waste exceeding several grams was scraped from the trays into No. 2 cans for canning following a heavy spray of the contents with disinfectant (8-hydro-oxyquinoline sulfate, 5 percent aqueous solution).

Post-test microbiological assays of treated food waste revealed complete sterilization of the food trays, but only partial suppression of growth in canned waste. Upon inspection of the can contents, it was evident that several cans had not been treated or had not been treated with sufficent disinfectant to completely inactivate the contents (see Sections 2.6 and 4.6).

Sprayed food trays (plastic) were stowed in environmentally sealed aluminum boxes. Each box held approximately 500 trays. By counting the number of trays and observing the box fill dates, an average use rate of 2 trays/man/meal was calculated.

This figure is lower than pretest estimates and the crew confirmed saving of trays by multiple-use techniques, such as using the same tray for preparation of more than one item or using one tray for preparing a double portion. The use rate of stowed trays would have been even lower had more care been taken during handling of several freeze-dried food items already packaged in trays. These trays had become cracked during the bundling and wrapping operations before stocking of the SSS.

2.5.3 Microwave Oven Evaluation

A microwave oven was evaluated during the 90-day test and its usefulness compared to that of a more conventional electric oven. Initially, either oven was to be used, at the discretion of the crew members, for preparing hot freeze-dried foods and beverages, as well as for thawing and heating frozen meals. In effect, however, the microwave oven was used as the primary heating device while the electric oven seldom used. The installation of both ovens in the SSS is shown in Figure 2-121.

The performance and design characteristics of the ovens used during the test are as follows:

	Microwave Oven	Electric Oven
Model Number	500.017	3600
Manufacturer	Litton Industries, Atherton Division	Labline Imperial, Harshaw Scientific Cleveland, Ohio
Power Source	115 vac, 60 Hz, 1 phase 20 amp	Same Same
Power Input, Watts	2,200	800
Power Output	1,000 watts nominal of RF at 2,450 MHz, not adjustable. Dial timer, adjustable 5 to 360 seconds.	Temperature range adjustable from ambient to 533°F (500°F).
Weight	52.3 kg (115 lb)	33.2 kg (73 lb)

2.5.3.1 Pretest Evaluations

The operating and design characteristics of several types of commercially available microwave ovens were reviewed before the test. It was decided that a rugged "portable" or bench-type unit operating at 2,450 MHz would be most easily integrated into the SSS. A Litton Model 500 was immediately available for on-site evaluation and extensive testing of its operating characteristics was initiated prior to purchase. The Labline oven was obtained from laboratory facility stock.

Use of a microwave oven at reduced atmospheric pressure increased the possibility of a spark hazard, outgassing, and thermal dissipation problem. The potential problem involved several electrical components common to all microwave ovens which may be susceptible to arcing or accelerated wear during operation at altitude. In addition, the cooling capacity of the blower at altitude was anticipated to be below that necessary to maintain the magnetron tube at operating temperature. Discussions with the vendor indicated the components most likely to arc (contactors, relays, motors) and the required squirrel cage blower rate [2,350 to 2,832 liters/sec (50-60 cfm)] to maintain the magnetron anode at 210°C. The arcing problem could be eliminated by installation of hermetically sealed relays and motors. Since calculated blower capacity at altitude was only 94.4 liters/sec below the required minimum, a proposed fix was to coat the anode fin and sleeve with silicone grease to increase thermal transfer efficiency.

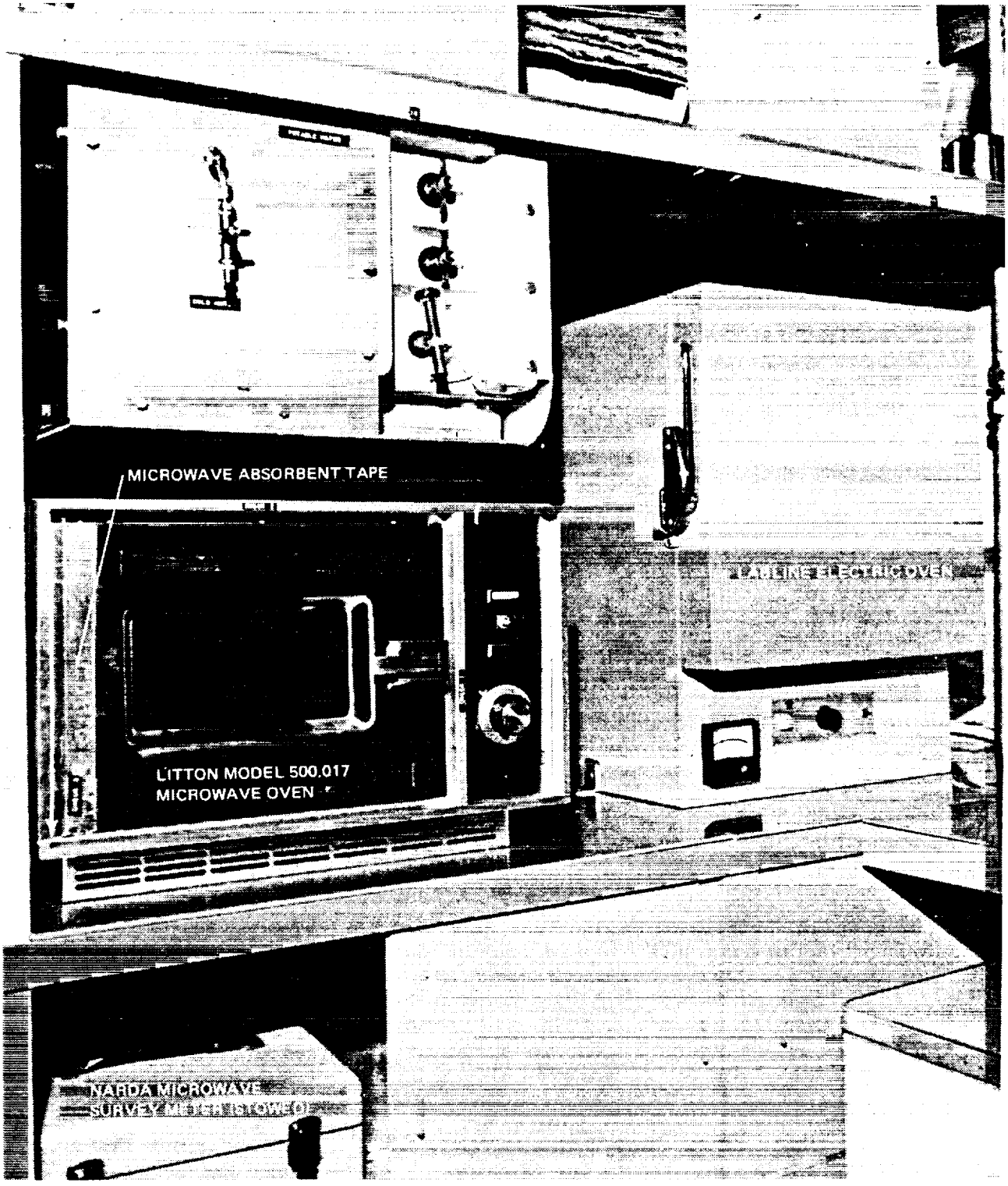


Figure 2-121. Food Preparation Area—Oven Installation

Altitude Evaluation

Before initiating the above-noted modifications, a test at 68.9 kN/m^2 (10 psia) was run to pinpoint two major problem areas, thermal protector operation and cook cycle relay arcing.

The microwave oven will shut off power to the magnetron automatically if the temperature of the anode exceeds 210°C. In this condition, the ready lamp and cook lamp go out and the oven cavity lamp and blower motor continue to operate. This condition will continue until the magnetron has cooled sufficiently, whereupon an automatic shutdown of all power occurs. Thermal protector operation was tested at altitude by continuously operating the oven for 1,800 seconds, approximately five times the anticipated continuous operating time. Approximately 2.3 kg of wet ice in a plastic container was used as a load for the oven cavity.

The cook cycle relay is activated when the cook button is depressed. The contacts normally arc under ambient conditions due to a cold-cathode surge current of 50 amps (1/60 second). In steady-state cook mode, the breaker switch current load is 18 to 20 amps. Relay operation was tested at altitude by cycling the cook button on and off for 100 cycles. This test was initiated immediately upon completion of the thermal protector test above. Since the relay is not visible during oven operation, the device was removed after the test and the contacts examined for excessive arcing.

After testing the oven for approximately 2 hours (45 minutes operating time), the oven load of ice had melted and the water appeared to be very near boiling. No malfunctions or automatic shutdowns of the oven occurred at any time during the 30-minute continuous operation. Examination of the cook cycle relay post-test revealed minimal pitting and discoloration of the contact surfaces after 101 cycles of on-off operation.

It was concluded from the results of these tests that the microwave oven would not require modification due to an arcing hazard or heat dissipation problem.

Microwave Radiation Safety Evaluation

At the start of the pretest evaluations, all Litton microwave ovens were being tested thoroughly on the production line to verify that they were well below the generally accepted RF leakage standard of 10 mW/cm^2 (References 2-12 and 2-13). Several publications concerning the potential radiation hazards associated with the use of microwave ovens were reviewed during the period (References 2-14 through 2-24). As a result of this review, it was deemed ncecessary that a survey of the oven should be made. The survey was conducted using an Empire Devices broadband power density meter, Model NF-157. Leaks of 0.25 and 0.70 mW/cm^2 were found at the lower right- and left-hand corners of the door frame. These leaks were well within the 10 mW/cm^2 limit specified by the Department of the Army Bulletin (Reference 2-13) and marginally within a recommended 1.0 mW/cm^2 limit proposed at a symposium sponsored jointly by the USPHS and the Medical College of Virginia (Reference 2-18).

The U. S. Bureau of Radiological Health had recommended to the Department of Health, Education and Welfare that the 1.0 mW/cm^2 standard for pre-purchase leakage be officially adopted (Reference 2-25). Based on this finding and faced with several unknown factors concerning the reflection and absorption of microwave energy within the confines of the Simulator, the ORIC report (Reference 2-26) made a mandatory recommendation that the microwave oven shielding, closures, and interlock devices be adequate to protect the SSS crew members from exposure to emanations of microwave radiation measured to in excess of 1 mW/cm^2 at approximately 5 cm from the oven door. It was also recommended that a monitoring device be placed onboard and frequent measurements (once/day minimum) be made. Accordingly, a Narda Model 8100 Electromagnetic Radiation Meter and probe, Model 8121A (100 μW to 20 mW/cm^2), were purchased and calibrated for onboard use during the test.

Surveys of the oven with the Narda meter before installation in the SSS indicated that the air choke door seal had loosened sufficiently since the previous survey to allow leakage in excess of 1.0 mW/cm^2. The oven vendor was consulted and it was suggested that a new door and modified latch assembly be installed. Resurvey of the door seal post-modification indicated leakage of approximately 0.7 mW/cm^2 at one site along the door hinge area. This leak was reduced to an estimated 0.1 to 0.2 mW/cm^2 by the application of one layer of microwave absorbent tape (aluminum) over the entire hinge area involved (see Figure 2-121). An additional supply of tape was provided for replacement of the shielding should it be necessary during the test.

Outgassing Tests

A series of outgassing tests were performed by the Life Support Branch, LRC, on another Litton Model 500 oven specifically purchased for this purpose. These tests were conducted to determine the possible level of contaminants which might be evolved during the 90-day test and were performed in a vacuum facility at 68.9 kN/m^2 (10 psia) with normal atmospheric constituents.

The test setup (Figure 2-122) consisted of a microwave oven, a vacuum facility, the contaminant collection traps, and a total hydrocarbon analyzer for measuring outgassing rates. The oven was modified for these tests to permit initiation of the cooking process outside the vacuum chamber. The foods were cooked in small, Mylar-lined plastic bags to concentrate a sufficient quantity of contaminants that could be detected by the instrumentation and to prevent introducing outgassed products from sources other than the foods. The microwave oven was isolated in a Mylar-lined bag in the "oven only" tests to identify those contaminants which could be attributed to oven outgassing. Outgassing rates were measured by means of a total hydrocarbon analyzer installed in the lines in place of the contaminant traps.

The food samples were reconstituted with warm water, sealed in the plastic bags, placed in the oven and the bag attached to the trapping lines. The oven timer was normally set for about 45 seconds of cooking time before sealing the vacuum chamber. The chamber was then pumped down to 68.9 kN/m^2 (10 psia), after which the cooking and trapping processes began. The trapping duration was normally 8 hours.

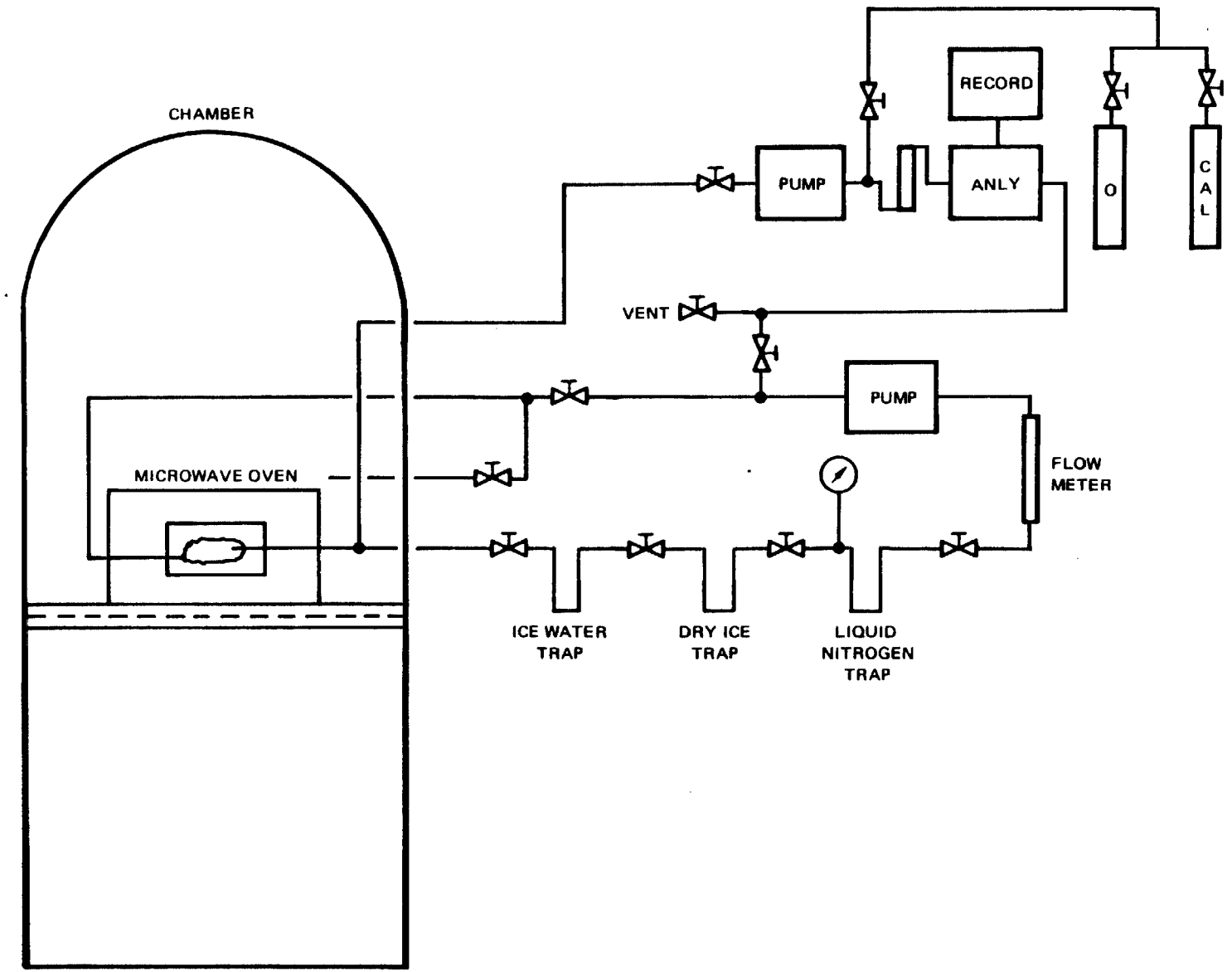


Figure 2-122. Outgassing Test Setup

The extended period of time for trapping was necessary in order to accumulate a sufficient quantity of outgassed products in the traps for identification by the analytical instrumentation.

The contaminant analyses were run on an F & M 810 chromatograph, with a 6.1 m by 0.48 cm (20 ft x 3/16 in.) stainless steel carbowax 20M on chromasorb W column with a flame ionization detector, and on a Bendix 12 Time-of-Flight Mass Spectrometer.

The oven contaminants identified are listed in Table 2-54. A heating mantle which surrounded the external surface of the vacuum bell jar provided the heat for the oven elevated temperature test. It is extremely unlikely that the oven temperature, except in the immediate vicinity of the food, will rise

Table 2-54

OUTGASSED PRODUCTS MEASURED

	*Oven (mg)		**Food (mg)
Contaminant	Cold	Hot (366°K)	(Chicken Chunks)
Hexane	0.25	33.0	
C_6		18.0	
MEK	0.09	1.8	
Acetone		0.7	
Nonane	0.22	7.5	
Ethyl Alcohol		1.3	
Trichloroethylene	0.22	4.7	
Toluene	0.10	1.5	
Isobutyl Alcohol	0.27	21.6	
Butyl Alcohol	0.27	13.2	
Ethyl Benzene		6.3	
Hexanol			2.0
Methyl Formate			0.5

*Bag Volume—132 Liters
**Bag Volume—14.2 Liters

above the ambient level from the internal heating source because of built-in safety features. The elevated temperature test does indicate that such outgassing could occur due to flame propagation from an external heat source. Of the foods tested, only the outgassed products from the chicken chunks were of a quantity sufficient to be identified. The portions of food tested were equal to one serving per meal per man. The rate of outgassing tests indicated that about 75 percent of the outgassing, after cooking, occurred about 2 or 3 minutes after the food was cooked. Outgassing rates leveled off about 7 minutes after completion of cooking. A slight amount of outgassing was observed prior to cooking, probably caused by the addition of hot water during the reconstitution phase.

All the chromatograph peaks could not be identified within the test time available because of the minute quantities collected and the lack of sufficient food supplies. In applying these data, consideration should be taken of the number of meals prepared, the length of time the food is exposed to the atmosphere, the effects of the atmospheric removal system, the chamber volume, and the duration of the mission.

Thermal Mapping of Oven Cavity

Microwave ovens employ radio frequency (electromagnetic) energy to heat food directly without an intervening heat transfer medium. A magnetron tube produces the microwave energy which is directed into the oven cavity whereupon it is absorbed more or less uniformly throughout the food mass and converted directly into thermal energy. Because of the direct heating quality, the oven heats food very quickly, usually within a few minutes or less. Interlocks prevent the oven from operating unless the door is latched or whenever either the front or rear access panels are removed. The correct cooking time is selected by a variable dial timing device.

It was apparent early in the pretest evaluation period that the distribution of microwave energy within the oven cavity, despite provision of an RF stirrer, was quite nonhomogenous. This was initially evidenced by measuring the temperature of various frozen foods and reconstituted freeze-dried items after heating in the oven. The temperature of identical portions of food placed at various locations on the cooking shelf varied depending upon the location, other factors such as type, mass, and initial temperature of the item being constant. These parameters are not different from conventional food preparation criteria, except for the speed at which the microwave oven can heat the food. A frozen item can actually be charred at one location on the cooking shelf while an identical portion at another location is left ice cold.

Heating guidelines had to be developed in order to preclude an excessive outgassing or fire hazard associated with indiscriminate use of this device in the SSS. These criteria were developed by actually preparing a majority of the various types of freeze-dried and frozen items noting the time and loads required to heat the material to eating temperature. The crew members participated in the preparation of the freeze-dried items and were given instruction as to the precautions and preheating manipulations required for thawing and heating frozen food items. As a part of this study, thermal maps of three Litton Model 500.017 microwave ovens were made before the start of the test. The maps were developed by measuring the change in temperature (ΔT) of water samples placed at various locations on the cooling

shelf before and after 30 seconds of heating. Four loading configurations were tested and each test was performed in duplicate. The results of the test are presented in Table 2-55.

The data indicate that, although microwave distribution within the cavity is not uniform, the distribution between ovens, especially those with consecutive serial numbers, is essentially the same. It would appear that the nonuniformity is, therefore, a function of the design of the oven. Homogenous heating of food items is facilitated in microwave ovens by stirring the microwaves as they leave the waveguide antennas and/or turning the food item as it is being heated. The latter technique is possible in the

Table 2-55

THERMAL MAP OF THREE MICROWAVE OVENS

Litton Model 500-017 Oven Serial No.	Cavity Loading Configuration (View From Above), Max ΔT			
	A	B	C	D
	1 2 / 5 / 4 3	1 / 4 5 2 / 3	1 4 / 2 5 / 3 6	1 2 3 / 4 5 6
33687 FK	T_5 = 52.78°C T_1 = 35.00 ΔT = 17.78°C	T_5 = 47.22°C T_2 = 35.00 ΔT = 12.22	T_6 = 40.56°C T_1 = 32.22 ΔT = 8.34°C	T_2 = 41.11°C T_1 = 33.89 ΔT = 7.22°C
37343 LK	T_5 = 49.44°C T_1 = 32.78 ΔT = 16.66°C	T_5 = 41.94°C T_2 = 35.83 ΔT = 6.11°C	T_2 = 40.00°C T_1 = 32.22 ΔT = 7.78°C	T_2 = 38.61°C T_1 = 33.89 ΔT = 4.72°C
37342 LK	T_5 = 51.67°C T_1 = 33.06 ΔT = 18.61°C	T_5 = 41.39°C T_2 = 35.28 ΔT = 6.11°C	T_2 = 40.00°C T_1 = 32.50 ΔT = 7.50°C	T_2 = 39.17°C T_6 = 34.44 ΔT = 4.73°C

Test Conditions:

Plastic Beakers Containing 120 ml Distilled Water.
Start Temperature 26.67 - 27.78°C.
Each Loading Configuration Tested Twice, Indicated Temperature is the Average.
Heating Cycle = 30 Seconds Using Dial Timer.

Litton Model 500 only by manually mixing the food item after it has been removed from the oven; it is then replaced in the cavity, heated again, and this process repeated until the item is of uniform temperature. This procedure was found necessary only for heating of the frozen prepared foods or multiman portions of reconstituted freeze-dried items. As noted previously, the loading configuration has a considerable effect on the temperature profile; i. e., the "hot spots" vary in location depending upon the configuration of the load on the shelf. The maximum temperature difference was obtained between a "hot spot" in the center of the shelf and the rear left-hand corner. Since a majority of the food items were prepared as individual servings, the nonuniform heating effect could be minimized by placing the food in the center of the shelf. If several items were to be prepared simultaneously, the location of the containers could be interchanged occasionally during cooking.

Cookware Evaluation

The use of nonstick, Teflon-finished cookware was considered as a means of facilitating cleanup after meals. Corning Ware Centura plates and bowl had already been purchased and the food contact surface of one of each utensil was Teflon-coated by the Fluorocarbon Company, Anaheim, California, for testing in the microwave oven. Approximately 3-minute microwave exposure caused, during separate trials, both coated bowl and plate to shatter. Subsequent discussion with Corning Glass Works and further in-house testing of uncoated Corning Ware revealed that this type of ceramic material cannot be exposed to microwave energy without running the risk of damaging the utensil. Corning indicated the presence of alkali ion in the parent body ceramic material as the cause of the effect. Both Centura and Pyroceram react similarly, resonating with the input frequency, until shattering of the crystalline structure occurs. Neither Corning nor Litton indicate in their customer instructions that this can happen.

Since Pyrex is a glassy material, it can withstand exposure to microwave energy and was, therefore, used for further testing. Several pieces of Pyrex tableware were obtained and Teflon-coated by Fluorocarbon.

Pyrex tableware, either coated or plain, was found satisfactory for use in the microwave oven. The coated utensils, however, were more easily cleaned of residual food, especially if the material had been charred or overheated. The major problem with the Teflon-coated plates was that the coating was too easily scratched or cut with sharp eating utensils. Since adequate cleaning of reusable plates and bowls could not be conveniently handled by the currently designed wash water unit (due to the potential load of organics), it was decided that disposable plastic dishes would be utilized during the test.

2. 5. 3. 2 Test Evaluations

Comparisons of Microwave and Electric Oven Usage

It was indicated by the crew members post-test that the electric oven was never used during the confinement for the preparation of food items. Crewman 1 used the electric oven for the drying of VD-VF product water samples in planchets for radiation surveys. It was found, pretest, that the electric

oven would probably dry out a reconstituted freeze-dried food item before it had attained eating temperature. Rather than cover these items with foil before heating in the electric oven, the crew utilized the microwave oven exclusively for heating water, reheating reconstituted freeze-dried foods, and thawing and heating of frozen food items. Since the latter meals were packaged in aluminum foil trays and, therefore, could not be placed directly into the microwave oven, the crew members transferred the items to plastic trays before heating.

Nominal Operation During the Test

The crew members reported no difficulties with operation of the microwave oven and developed their own modifications of the pretest heating guidelines over the course of the test. A habitability item ranking of 2 (out of 57 items), i.e., excellent, was given to the microwave oven by the crew. The crew found the versatility of the oven to be extremely useful since it allowed the rapid preparation, whenever required, of either large or small quantities of boiling hot water for beverages and for reconstitution of freeze-dried meals.

Usage Time and Power Consumption

A microwave oven usage time log was maintained by the crew only for the preparation of frozen food items. These items required either complete thawing and heating to eating temperature (steak, chicken, chops, various vegetables) or merely thawing (apple slices, peaches). A maximum of 9 minutes for the former type of item and a minimum of 2 minutes for the latter type of item were utilized. Many combinations of preparation schedules were tried by the crew but it appears that individual portions of entree and vegetable were usually thawed and heated rather than several portions at once. At a rough schedule of one frozen meal/man/week, the oven usage times were as follows: crewman 1, 2.17 hours; crewman 2, 2.53 hours; crewman 3, 1.78 hours; crewman 4, 1.43 hours. The usage times vary greatly between crew members because of individual meal preparation techniques, i.e., crewman 4 preferred to prepare the entire meal with a single oven loading run at 7 to 8 minutes; other crew members prepared individual items at shorter running times but higher total usage time. It is estimated that the oven was used approximately 9 minutes per day for the preparation of hot water or 13.5 hours over the test. Combined frozen food and water heating time was, therefore, approximately 21.41 hrs. At a power input of 2.2 kilowatts, a total of approximately 47.1 kwh was expended in operating the microwave oven during the test. This is a conservative estimate as the oven idle input of 275 watts or usage time during RF leakage surveys was not included in the calculations.

Radiation Surveys During The Test

Crewman 1 was responsible for making microwave radiation surveys during the test. The survey was performed on schedule throughout the test and readings were reported as consistently below 0.2 mW/cm^2 at 5 cm. The survey was made using the Narda meter and 8121A probe. This probe reads high and, therefore, the readings onboard were probably on the order of 100 to 150 $microwatts/cm^2$ at 5 cm from the door flange. A survey of the oven post-test confirmed readings below 0.2 mW/cm^2 at 5 cm during the test.

Current Radiation Specifications

Review of the radiation safety problem post-test has revealed that the Department of Health, Education and Welfare has set a limit of 5 mW/cm^2 leakage over the useful life of all microwave ovens manufactured after October 6, 1971 (Reference 2-27). These ovens may not emit radiation in excess of 1.0 mW/cm^2 prior to oven sale. It should be noted that the self-imposed 1.0 mW/cm^2 leakage limit utilized throughout the test was, therefore, five times more restrictive than the proposed nationwide regulations and that actual leakages were more than 25 times less than this limit during the test.

2.6 WASTE MANAGEMENT

The waste management subsystem included a commode unit, a urine collector unit and waste storage and disposal equipment. Waste storage and disposal equipment consisted of a waste storage container, a toilet paper dryer, a waste food canner, a dry waste baler and a waste liquid overboard dump. Figure 2-123 is a schematic diagram of those units requiring piping connections to other LSS units or parts of the SSS. The canner and baler did not require connections as they were utilized in packaging waste which was stored onboard for the duration of the mission. All other units accept some form of waste which is to be either vented or dumped overboard with the exception of the urine collector unit which pumped the urine, pretreatment solution, and flush water to the water management subsystem.

2.6.1 Commode

The commode was a "Dry John" type built for the Air Force Aerospace Medical Research Laboratory (AMRL). This type of commode contains a rotating shredder-impeller (referred to as a slinger) with air induction of feces, and a spherical bowl with replaceable liner for collection and storage. The 90-day test commode was improved over the one used in the previous 60-day test, in 1968, in that it had a replaceable liner, a sampling device, and disinfectant injection. The commode was designed for 200 uses with storage for feces and toilet paper. When full, the unit is disassembled, the full liner removed and stored, and a new liner assembly installed. The operation intends a minimum amount of handling of waste products by the crew, effective control of odors and bacterial contamination of the SSS.

Fecal sampling could be accomplished in a sanitary manner and disinfectant was administered by timed injection. Odor control was effected by a canister of "Purafil" odor control pellets manufactured by Marbon Chemical Company, and bacterial control consisted of two bacterial filters in the air stream through the unit. Figure 2-124 shows the installation of the commode, urine collector, and their controls. Figure 2-125 is a schematic representation showing a sectional view through the commode shell and attendant piping.

To operate the commode, the user switched on the power switch and turned the valve seat handle. This activated the blower, slinger motor, and solenoid valves, which closed off the vacuum vent and opened the liner interior to the cabin atmosphere.

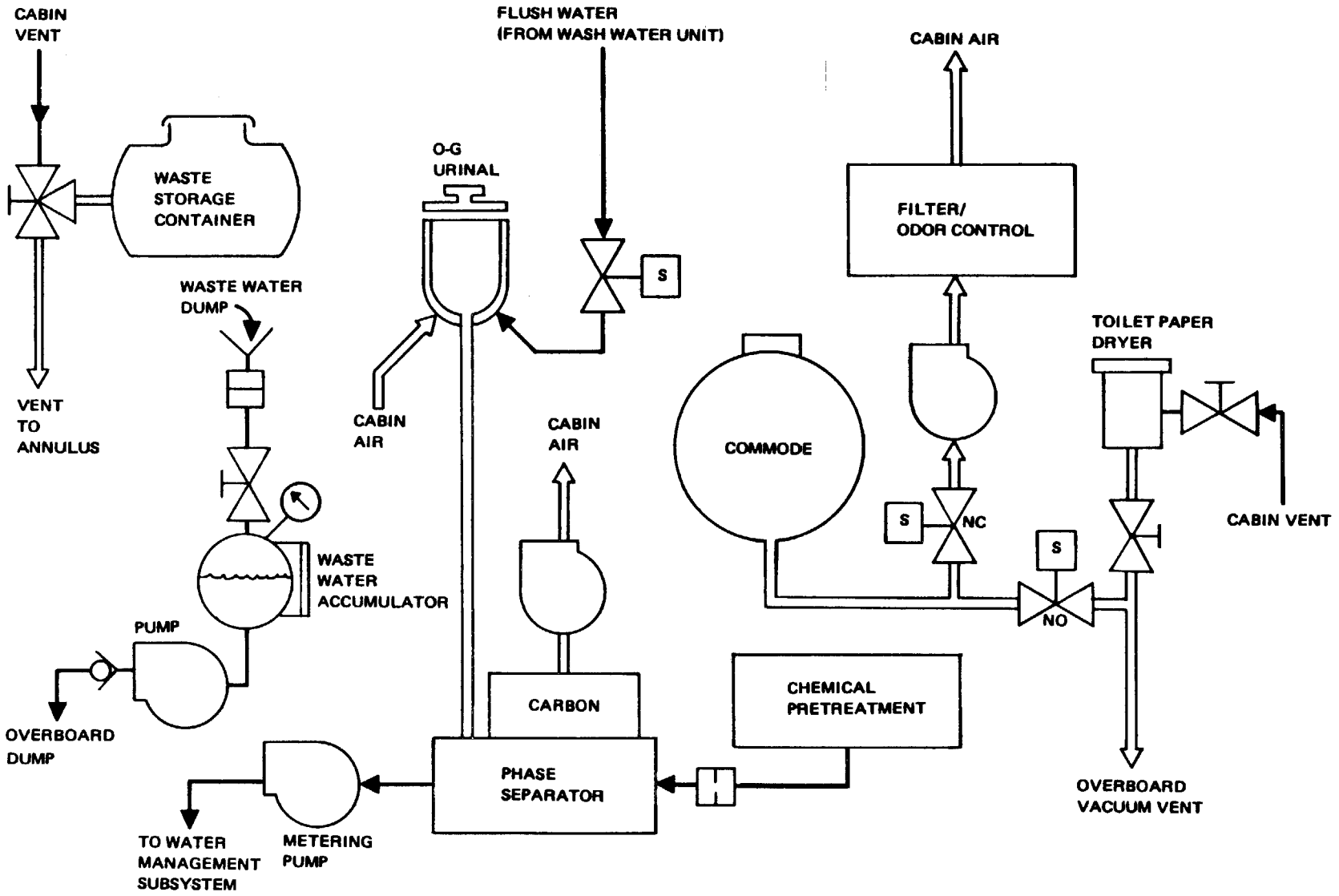


Figure 2-123. Waste Management Subsystem

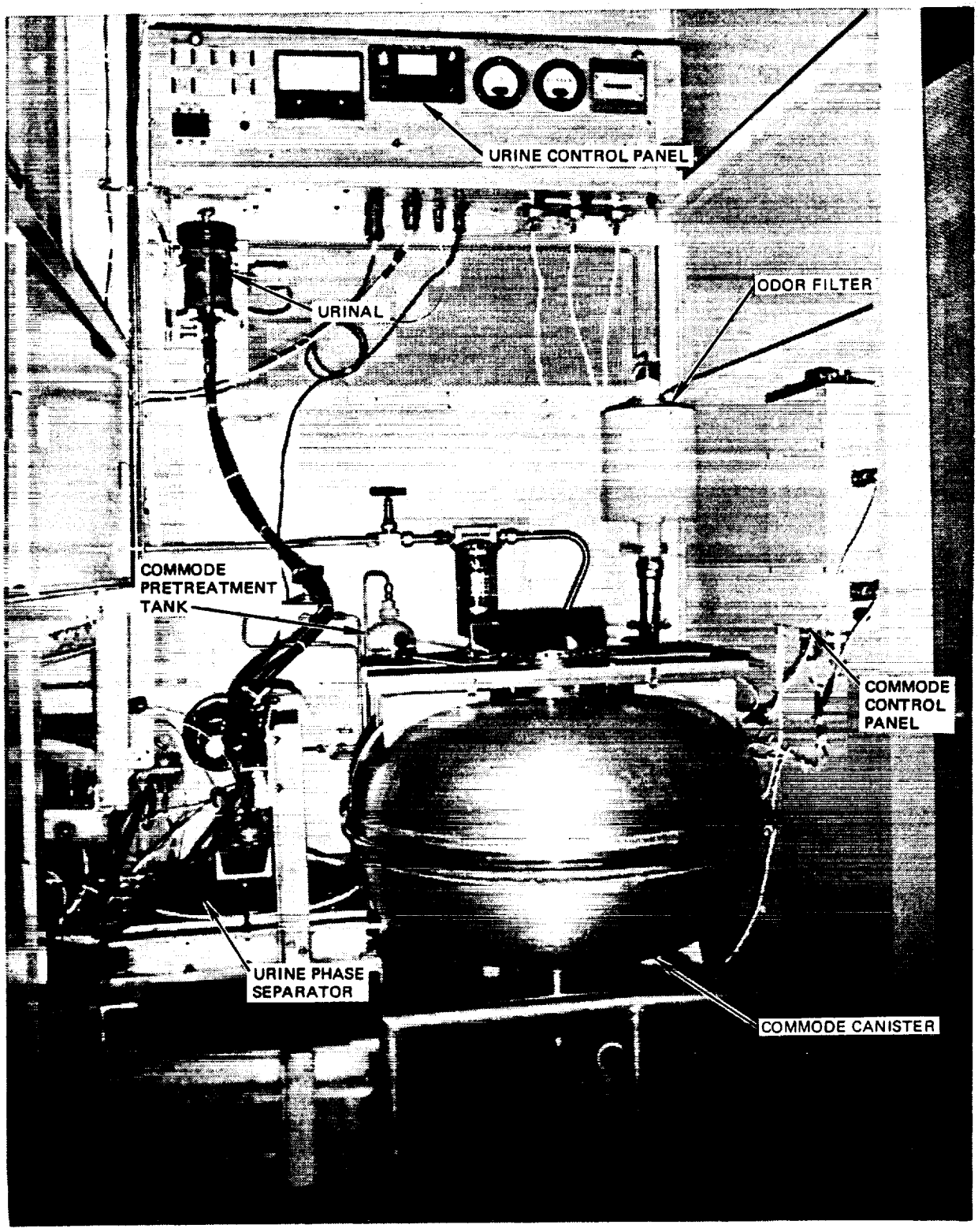


Figure 2-124. Commode/Urine Collector Units

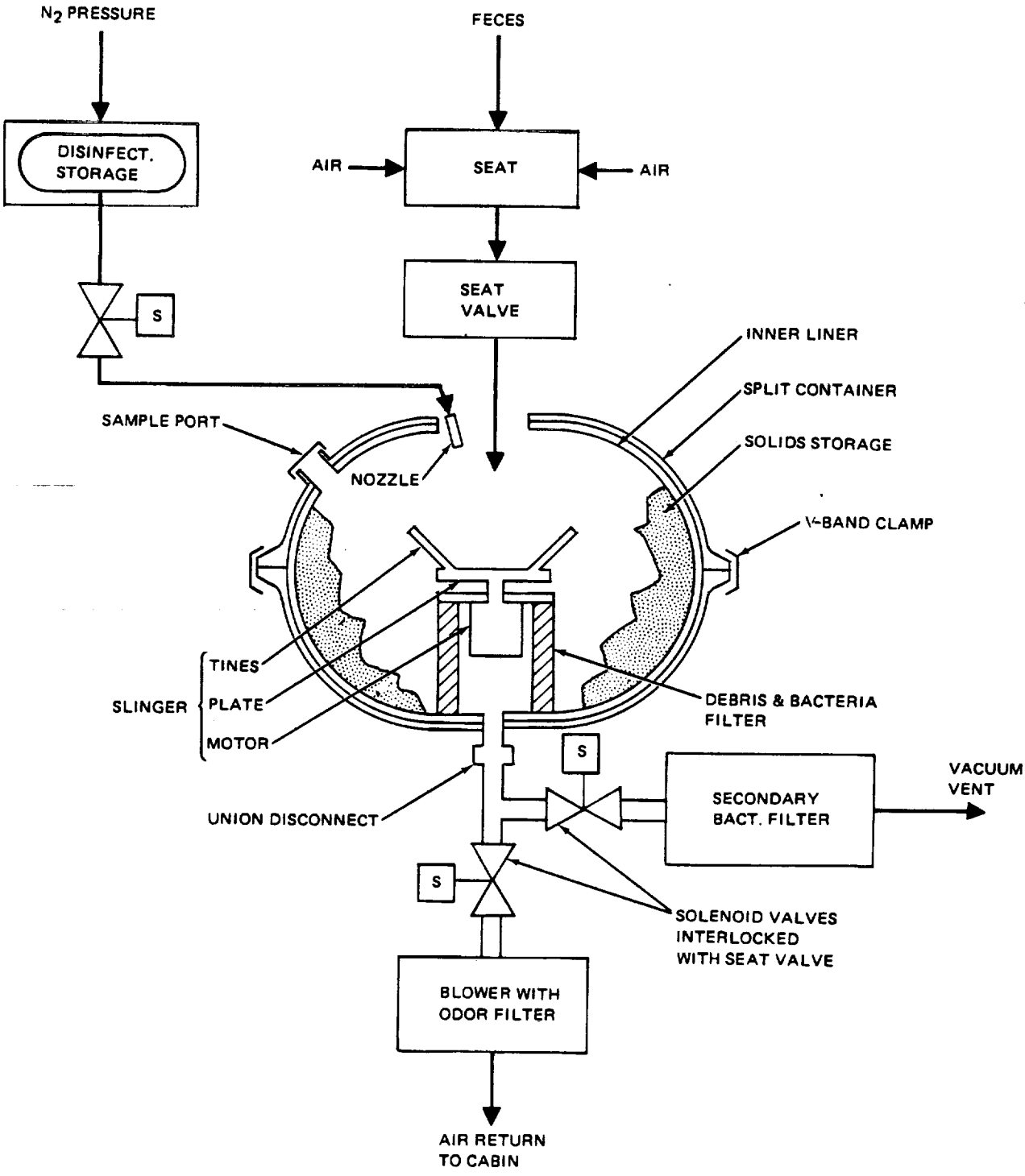


Figure 2-125. Commode Schematic

The seat valve was opened and air was drawn into the commode, preventing the back-streaming of fecal odors into the cabin. The air was also drawn through the bacterial filter and exhausted back to the cabin through the odor control canister. When the user seated himself, the air stream was drawn across his buttocks and carried the stool onto the rotating slinger plate. The tines in the plate shredded the stool and the pieces were thrown against the liner. This achieved packing of the feces and allowed quick vacuum drying of the resulting thin layer of moist feces. The user wiped himself with tissue and deposited it in the commode, the disinfectant button was pressed, and the unit was closed and switched back to vacuum.

The unit was installed in the SSS and used during the 5-day checkout test. After this, it was disassembled, cleaned, and then utilized by the crew members in the training program, which emphasized reassembly and the treating of vacuum leaks.

The commode was reinstalled just prior to the 90-day test and was first used on the second day of the test. Over the 90-day period, it was used 319 times, from none to seven times per day with 4 times per day being the mode. Figure 2-126 shows the distribution of the frequencies. The operating time for the commode and its components was 23.3 hours.

This unit was readily accepted and used without the delays that have occurred at the beginning of earlier tests. Observations of its performance and filling rate were done on a weekly basis. All tissues except those used during the initial liner's last 3 days of use were placed in the commode to assess its capacity and performance as a complete receptacle.

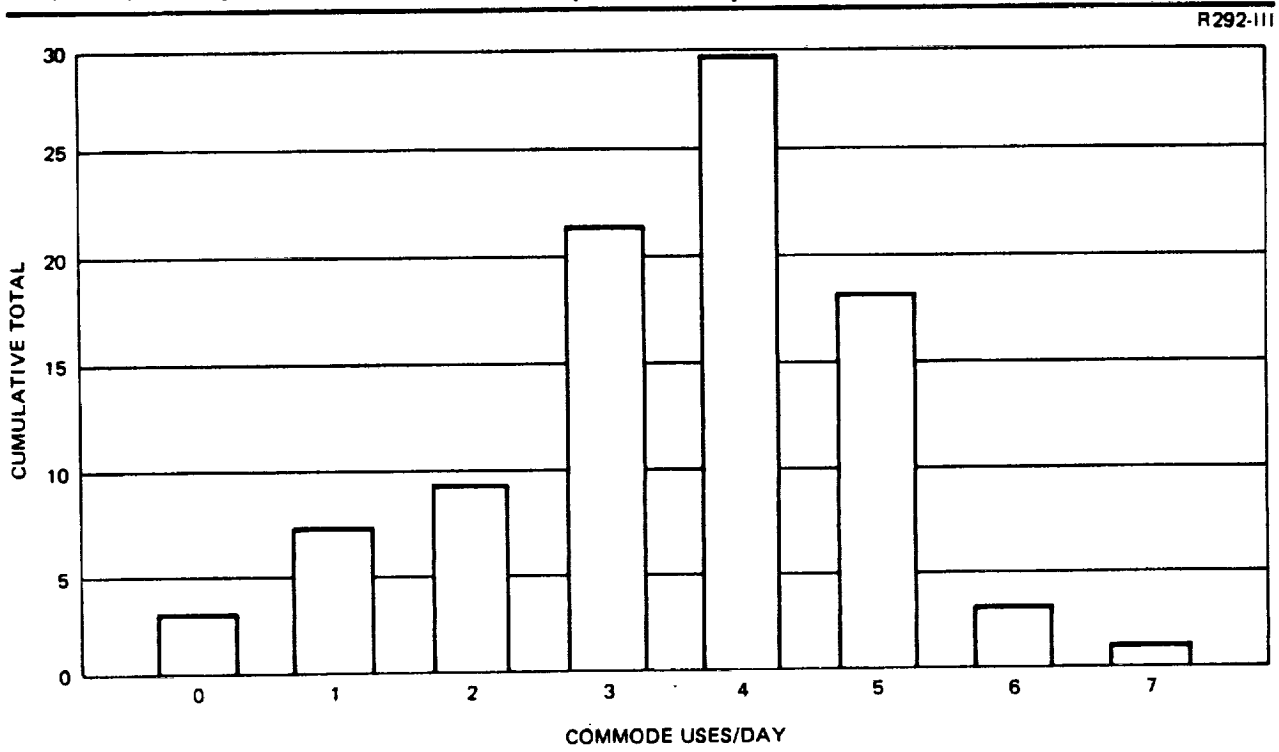


Figure 2-126. Commode Uses per Day

On day 38, it was observed that disinfectant was not being injected into the commode. Assuming the disinfectant tank to be empty, a crewmen began to shutdown the nitrogen pressure and discovered that the nitrogen line manual valve had been closed from the beginning of the test period and disinfectant was not being injected into the liner. The valve was opened, the regulator was adjusted to 68.9 kN/m^2 gage (10 psig), and between 15 and 20 injections of disinfectant were put into the commode. The disinfectant used was a 1:10 mixture of "Wescodyne"* general-purpose iodine disinfectant and water. Over the 90-day period, there were several observations of minor fecal odor in the equipment area and a few at the commode when the seat valve was opened.

The commode was used 145 times to day 44, and at this time it was decided that the amount of toilet paper floating loose filled the liner to its capacity. The air stream across the buttocks had a drying effect that increased the use of toilet paper. This increased volume of dry paper did not stick to the liner wall and took up most of the liner volume. Disassembly of the unit commenced about 1000 on day 44. The full liner assembly was removed, given a liberal treatment of disinfectant and closed with a screw cap cover. It was then placed in the unused pass-through port which was vented to the annulus. A spare liner assembly was taken from onboard spare parts storage, and the commode was reassembled and back on line with an internal pressure below 66.65 N/m^2 (0.5 mmHg) by 1330. This was accomplished by two crewmen with only minor difficulty in restarting one of the threaded fittings.

After this time, the auxiliary toilet paper dryer was used for most of the toilet tissue. The cover seal of the dryer leaked during early use and required additional attention by the crewmen to seal it.

The commode performed satisfactorily for the remainder of the run. On day 66, the disinfectant tank was refilled with 600 ml of the "Wescodyne" solution. The second liner was used 174 times and was estimated to be one-third full with about 10 percent of the volume being toilet paper. Figure 2-127 shows the slinger assemblies from both liners after the test. The assembly full of toilet paper is from the first liner used, and while there was no disinfectant sprayed on the slinger plate for the first 38 days of its operation, it is believed that the quantity of disinfectant used would not have been sufficient to reduce appreciably the amount of paper from adhering to the plate and tines. The fecal material did not adhere to the wall but fell in small pieces to the bottom of the liner. When the slinger motor was turned on, the toilet paper and some of the fecal particles would whirl around with the slinger plate. Occasionally, a piece would hit a seated crewman.

Fecal samples were taken by means of the sampling probe on days 31 and 32 and passed out for clinical analysis. Samples were also taken 9 and 3 days before the end of the run and stored onboard. The crew experienced some uncertainty in manipulating the fecal sampler cap. The recommended a larger handle to reduce turning loads and a way to check the seating of the seal. A summary of commode usage is shown in Table 2-56.

*West Chemical Products, Inc., Long Island City, N.Y.

R292-III



Figure 2-127. Slinger Assembly After Test

Table 2-56
COMMODE USAGE SUMMARY

	Liner 1	Liner 2	Total Test
Days used	1 through 43	44 through 91	
Uses	145	174	319
Gross solids collected, kg	6.66 (14.68 lb)	6.92 (15.25 lb)	13.58 (29.93 lb)
Toilet paper, kg	1.39 (3.08 lb)	0.11 (0.25* lb)	1.50 (3.33 lb)
Net fecal solids, kg	5.26 (11.60 lb)	6.80 (15.00 lb)	12.06 (26.6 lb)
Fecal water, from freeze traps, kg	8.98 (19.8 lb)	14.69 (32.4 lb)	23.67 (52.2 lb)
Total feces, kg	14.24 (31.4 lb)	21.50 (47.4 lb)	35.74 (78.8 lb)
Fraction water	0.63	0.68	0.66
Average uses per day	3.4	3.7	3.6
Maximum uses per day			7
Minimum uses per day			0
Average use, kg	0.10 (0.22 lb)	0.12 (0.27 lb)	0.11 (0.25 lb)
Average kg/day	0.33 (0.73 lb)	0.44 (0.97 lb)	0.40 (0.88 lb)

*Estimated

At the conclusion of the 90-day test period, the "Purafil" odor control pellets were approximately three-fourths expended, as shown by the change in color of the indicator dye. Later bacterial assay of the feces from both liners showed numerous viable organisms. The bacteria from the first liner were not identified. The samples from the second liner contained Bacillus macerans, Bacillus lichenformis and Bacillus cereus. The samples do not indicate any difference between liners as to the effectiveness of the disinfectant.

2.6.2 Urine Collector

The urine collector consisted of a zero-g urinal furnished by NASA-MSC, a phase-separator, pretreatment tank, blower, metering pump and controls. Figure 2-128 shows a schematic diagram of the urine collector. The urinal was located adjacent to the commode and could be used separately or in conjunction with the commode (Figure 2-124).

The phase separator consisted of a stainless steel bottom plate, a silicone rubber gasket and a pyrex cover. These items housed a shaft-mounted urethane foam rotor with a domed stainless steel cover. This rotor and housing subassembly were secured to an activated carbon-filled container. The phase separator had a capacity in excess of 1.0 liter so that four average-volume urinations could be accommodated if the unit were shut down for repairs. The unit was constructed of commercial components, and while functionally a zero-g unit, it should not be considered a flight-weight item.

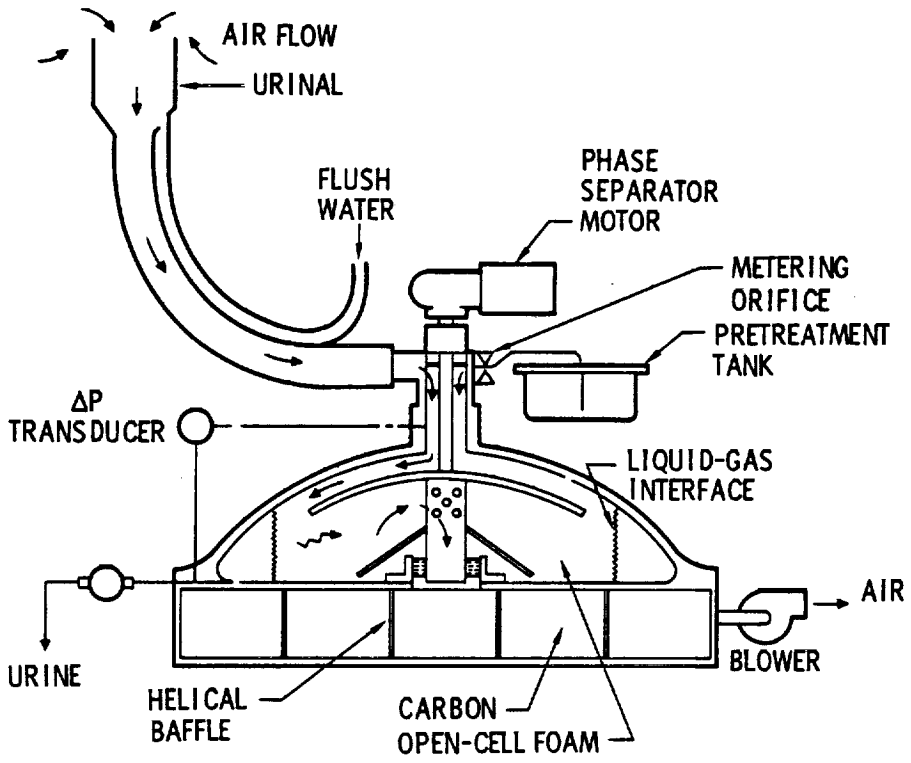


Figure 2-128. Schematic Diagram of Urine Collector

For use, the crewman was required to push his identification button to release the urinal from its support bracket. The identification button started the urine quantity recorder and controlled the initial part of the urination cycle. Lifting the urinal begins the cycle: the blower was activated, which drew 0.5 liter/sec (1.5 cfm) air flow through the urinal, phase separator, and carbon; and the phase-separator motor was activated, turning at 130 rpm.

As urination cintinued, the urine was carried by the airstream into the phase separator. Centrifugal force from the rotor held the urine against the outer edge of the pyrex cover while the porous rotor core demisted the air stream.

The air stream then passed through the carbon canister for odor removal and was returned to the cabin. The urine and air flow into the phase separator drew pretreatment fluid into the housing through a metering orifice. When urination was completed, the crewman replaced the urinal cover and pushed the flush button, which allowed a timed flow of flush water from the wash water unit to enter the urinal and flow into the phase separator. After the timed flush water solenoid valve closed, the blower stopped and the metering pump began pumping the pretreated urine into the water management subsystem. The metering pump was controlled by a pressure switch in the phase separator which controlled the level of the liquid remaining in the phase separator, preventing bubbles from entraining in the urine discharge line.

Urine quantity was recorded for each micturition by timing the metering pump. When the pressure switch opened and stopped the metering pump, the phase separator motors stopped and the cycle was completed.

The unit operated up to day 5 satisfactorily. The phase-separator pressure sensor showed some variability, displaying occasional hypersensitivity, but generally of adequate performance. On day 5 the time-delay relays, which controlled the flush water flow and part of the blower and phase-separator motor cycle, did not drop out after their timed "on release" period. Flush water and pretreatment entered the phase-separator in considerable quantity. The excessive concentration of pretreatment in the phase-separator attacked the foam core and the gasket sealant. Continuing relay malfunctions brought about shutdown by day 7, since the rotor foam was almost totally dissolved and the gasket leaking.

On day 16 the phase-separator was taken out, reassembled, without the rotor and motor, and inclined slightly toward the metering pump to function as a one-g unit. Continuing relay malfunctions were treated by shutting down the system, when the relay stuck, and then manually controlling the urine metering pump. The relays were replaced, but the alternate relays performed in the same manner. The additional running time during the flush part of the cycle again brought excess pretreatment into the phase separator and the gasket sealant failed again. The sealant was replaced, the unit adjusted, and worked with until day 27 when it was shut down. After this, urine was collected in a graduate, the urine volume recorded manually, and then poured into the urine accumulator of the water management subsystem. Pretreatment was added to the accumulator several times a day in quantity as required by previous urine volumes.

The urine pump was removed on day 28 and replumbed downstream from the urine accumulator feeding the wick evaporator. This was done so that urine could be manually poured into the accumulator and pumped to the wick evaporator while the VD-VF boiler was being replaced (see Section 2.2). The urine was then pumped into the wick evaporator on an hourly basis in 1-liter quantities. On day 41, the phase separator was removed from the unit and the urinal was connected directly to the urine accumulator. The pretreatment was still added to the accumulator several times per day as required. The flush water was added manually to the urinal after each use and the quantity recorded in the urine log.

On day 50, two crewmen set up a timer to control the urine pump operation so the wicks were fed on a hourly automatic cycle. This relieved the crew of a watch keeping function and allowed more attention to other tasks.

The urine collector processed 23 liters of urine and 4.9 liters of flush water to the end of day 5. On day 6, manual flushing and pretreatment was begun. Automatic flushing was restarted several times after this but the relay problem finally stopped all effort to achieve a reliability automatic cycle. A summary of the crew urine data is reported in Section 2.2.

2.6.3 Waste Storage and Disposal

The waste storage container is shown in Figure 2-2. It is an aluminum container 0.166 m^3 (5.86 ft^3) in volume with a gasketed cover and three-way manual valve which was used to vent the container either to the SSS annulus or the cabin. Figure 2-123 shows a schematic diagram of the container plumbing connections. It was used to store waste that was not to be baled and would require treatment with 8-hydroxy quinoline sulfate disinfectant and for waste which would outgas, such as the bags of toilet paper, used filter elements, and rags used to clean the floor. Other items deposited in the container included aluminum foil and some paper and plastic containers.

To use the container, the manual valve was turned to vent the container to the cabin. The cover was then opened, the waste was sprayed with quinolinol solution and placed in the container. The cover was replaced, latched down and the valve turned back to annulus vent.

A leak in the cover gasket was observed on day 6. The container was vented to cabin and vacuum grease was applied to the gasket. The unit was then revented to annulus. On several occasions over the next few days, drops in the cabin pressure were noted and the waste container would be revented to the cabin to assess the effect on cabin pressure. On day 17, the cover gasket was regreased and the unit vented to annulus for approximately 6 hours. A continued drop in cabin pressure indicated no change in seal effectiveness and a program was instituted of venting the container to the cabin, except for approximately 10 minutes prior to opening, at which time the container would be vented to the annulus. In 90 days the container accumulated 0.090 m^3 (3.18 ft^3) of varied wastes weighing 7.99 kg (17.6 lb).

The toilet paper dryer was added to the commode unit as a contingency in the event adequate collection capacity was not available in the commode. The dryer was connected to the vacuum system in parallel with the commode

and used a porous paper bag, such as is used in commercial vacuum cleaners, as a disposable collector. When filled, these bags were sealed and placed in the waste storage container. The toilet paper dryer was not used during the operation of the commode with the first liner. During commode operation with the second liner five bags of toilet paper were dried in the unit.

The cover seal on this unit leaked several times and as a result the dryer was vented to vacuum for a short time immediately after receiving toilet paper and then vented to the cabin at times when the commode was not in use. The dryer's volume of 0.0036 m^3 (0.127 ft^3) was quite effective in lengthening the life of the second commode liner. It allowed much greater compacting of the tissue and would allow approximately 50 percent more life for a liner assembly.

Wet garbage was treated with 8-hydroxy quinoline sulfate and then sealed in cans. The cans were coated with a plastic film on the interior surfaces to resist corrosion. The canner used to seal the cans was a No. 225 All American Automatic Master Can Sealer,* sized for No. 2 cans. Its installation is shown in Figure 2-129.

*Automatic Canning Devices, Inc., Manitowoc, Wisconsin.

R292-III

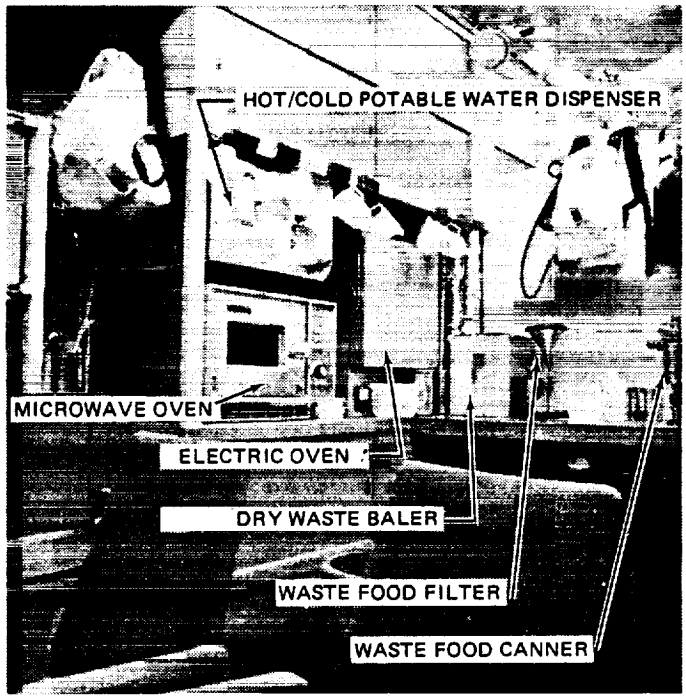


Figure 2-129. Food Preparation Area

The wet waste was stored in 42 No. 2 cans during the 90-day test. The crew was instructed to pass cans out of the SSS on the regular weekly pass-out if there were signs of bulging or indications of potential rupture. As a result, 23 of the filled cans were passed out during the test. Saving these cans in the room environment resulted in only five discernible bulges. One of these was opened and found to contain a high concentration of potassium hydroxide, apparently included in a wiping cloth, and much resulting corrosion. This had apparently been collected during cleanup of an electrolyte leak of the water electrolysis unit. With thorough instructions as to what waste is to be canned and how it is to be treated, this method of handling wet waste is safe and efficient.

The majority of meals for the crew were freeze-dried foods packaged individually in plastic trays (see Section 2.5). Trays for 4-man meals were wrapped in aluminum foil before being stored in the food storage cabinets.

Aluminum boxes of 0.012 m^3 (0.424 ft^3) volume with latchable sealing covers were provided for storing the used food trays. Five of these boxes holding 2,408 used food trays were used in 90 days. The trays were sprayed with 8-hydroxy quinoline sulfate before being placed in the sealed boxes.

Dry waste was to be tied into bales in a two-compartment aluminum box 0.305 m (1.0 ft) high by 0.22 m (0.722 ft) wide and 0.27 m (0.885 ft) deep with two hinged covers. Cloth strapping was stored in the smaller of the two compartments. The larger compartment was sized to accept the empty plastic food packages which were to be compressed tightly in the compartment and tied into bundles with strapping.

After brief use, however, the crew found it more convenient to wrap the food packages and some other dry wastes in the aluminum foil in which the food had been originally wrapped. This compression was adequate, the foil held its shape and there was ample storage space for the resulting waste.

The crew wrapped up 41 bundles of dry waste weighing 89.24 kg (196.5 lb) in the 90-day period. Forty of these bundles were stored in the food compartments as they were emptied of food. One bundle was kept in the freezer.

The overboard dump for liquid waste is shown schematically in Figure 2-123 and its installation in Figure 2-130. This unit was used to dispose of water, urine, and chemical reagents from the onboard laboratory that were not put into the water management subsystem. To use this unit, a funnel with a quick-disconnect end was connected to the accumulator. The manual valve was opened and the waste liquid poured into the accumulator. When the sight glass showed somewhere over one-half full, the outside personnel were notified and the outside receptacle was prepared to receive the waste which would then be pumped out. The pump was controlled by a momentary push-button operated by a crewman while watching the accumulator sight glass. The waste was received and measured by outside personnel. A breakdown of the material pumped through this unit is shown in Table 2-57.

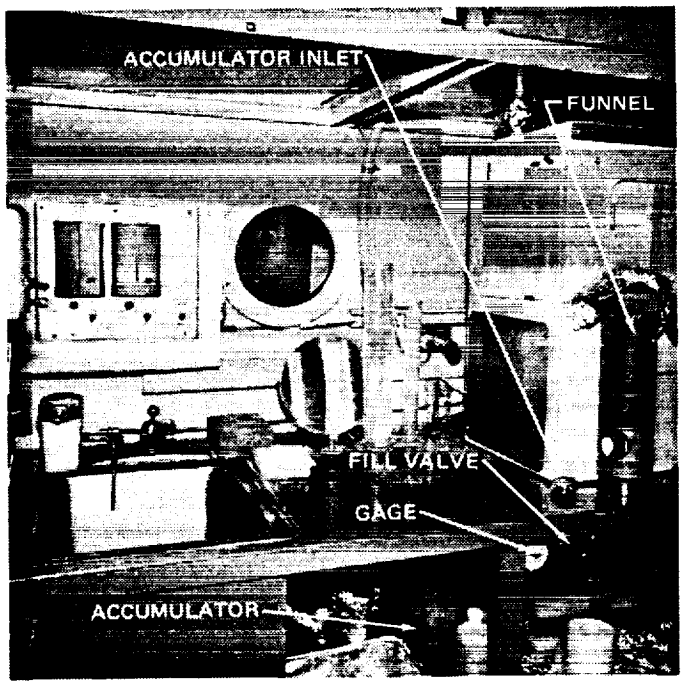


Figure 2-130. Waste Liquid Overboard Dump Installation

Table 2-57

OVERBOARD DUMP SUMMARY

	Volume		Weight	
	m^3	(ft^3)	kg	(lb)
Potable water from food preparation	0.0253	(0.8940)	25.18	(55.45)
Distilled water from carboy	0.0019	(0.0671)	1.90	(4.18)
Wash water	0.0044	(0.1555)	4.39	(9.67)
VD-VF spillage	0.0008	(0.0283)	0.82	(1.81)
Solid amine water	0.0026	(0.0919)	2.58	(5.68)
Urine and flush water (last day of run)	0.0011	(0.0389)	1.13	(2.49)
TOTALS	0.0361	(1.2757)	36.00	(79.28)

A summary of the types of waste with volumes and weights is shown in Table 2-58. This summary also shows the results of microbiological assays following the 90-day test.

2.6.4 Maintenance and Repair

Table 2-59 summarizes the major maintenance items on the waste management subsystem. Most of the repairs required on the commode and urine collector have already been discussed. The leakage of the trash container caused some concern because a permanent correction could not be made. As a result, venting of the container to the annulus was done only occasionally when a noticeable odor was generated in the container. On one or two instances, significant loss of cabin atmosphere occurred when the container was left venting to the annulus. This was detected by the resulting loss in cabin pressure and corrective action was usually taken within a few hours to close the vent valve.

2.7 CONCLUSIONS AND RECOMMENDATIONS

The 90-day manned test of a regenerative life support system has been completed with the accomplishment of all major objectives. A great deal of data have been collected that will be invaluable in the development of future life support systems. Among the major accomplishments during the test were:

- 90 days were completed without pass-ins of any kind, assuring the microbial isolation of the test chamber and crew.
- Radioisotope heat sources (^{238}Pu) were used to produce 350-watt thermal output and were shown to be highly safe, presenting no problems in handling during 76 manipulations of the capsules, and resulting in crew exposure well below design limits.
- An integrated, maintainable potable water recovery system reclaimed 1, 070 kg (2, 357 lb) which was certified for crew consumption in accordance with standards established by the ad hoc Committee of the Space Sciences Board, National Academy of Sciences.
- The wash water recovery unit processed and dispensed 4, 750 kg (10, 447 lb) of water for personal hygiene, laundry and other wash uses.
- 150 kg (332 lb) of oxygen was recovered from carbon dioxide removed from the cabin atmosphere, processed by flight-type water electrolysis units, and returned to the cabin atmospheres for crew consumption.
- A complete mass and energy balance was obtained on equipment and crewmen.
- Validation was obtained of methods for spares inventory selection and new data was obtained for improvement of these methods.

Table 2-58

WASTE SUMMARY

Waste Type	Volume m^3	Volume (ft^3)	Mass kg	Mass (lb)	Microbiological* Contamination Quantity	Microbiological* Contamination Quality
Dry						
Packaged bundles	0.340[1]	(12.020)	89.24	(196.5)	Heavy[3]	Yeasts, fungi, and species of Escherichia, Bacillus, and Staphylococcus.
Fecal solids	0.097	(3.430)	12.06	(26.6)	Heavy	Fungi and species of Staphylococcus and Bacillus and other unidentified bacteria.
Unpackaged material-2	No estimate		2.00	(4.4)	No samples.	
Wet						
Waste Storage container	0.090	(3.180)	7.99	(17.6)	Heavy	Fungi and species of Bacillus, Aerobacter, Staphylococcus, Escherichia, and Coryne Bacterium.
42 No. 2 cans	0.027	(0.955)	16.42	(36.1)	Heavy[4]	Fungi and spore formers primarily
5 boxes of food trays	0.108	(3.820)	37.70	(83.0)	None	
Overboard dump liquids	0.036	(1.276)	36.00	(79.3)	No samples.	
TOTALS	0.698	(24.681)	201.41	(443.5)		

Notes

1. Estimated from several measured bundles.
2. Empty jars, containers, etc., at end of test.
3. 6 packages sampled, 3 contaminated, 3 none.
4. 6 cans out of 42 sampled.

*Reference Section 4.6.

- Performance was measured on the life support system over a wide spectrum of operating conditions, including transient loads. Data was obtained during startup, shutdown, and power failure conditions to assist in designing for realistic operational failure modes.

- Contaminant control data was provided for the design of sensors for onboard monitoring systems.

- A flight-type two-gas control, operating with a mass spectrometer sensor, accurately and reliably controlled composition of oxygen and nitrogen in the SSS.

- An advanced regenerative solid amine CO_2 removal system was successfully operated for nearly 70 days and data on operating electrical and thermal loads and cooling requirements were obtained.

- Detailed data on an operating potable water recovery unit, a wash water recovery unit, and atmospheric trace contaminants have been obtained on 90 days of testing for presentation to appropriate committees of the National Academy of Sciences in their consideration of air and water standards for long-term manned space missions.

- Performance and operational data were obtained that indicates major emphasis should be placed on development of flight-type water electrolysis units.

- The waste management commode usage was very acceptable to the crew and ready for design into a flight-qualifiable unit for future spacecraft usage.

- The use of a microwave oven is an important contribution to the acceptability of prepared foods and it is recommended where adequate power is available.

- Uncompressed, freeze dehydrated food which was especially selected for its palatability was shown to be acceptable as a diet, although periodic frozen meals provided a welcome highlight in the diet provided.

- Techniques were developed for minimizing generation of waste and for handling and storage onboard. Further refinement is required, particularly in design of reusable eating utensils and processing of food waste water.

2.7.1 Life Support System Operation

The LSS operated effectively in producing potable water, removing atmospheric contaminants, and recovering oxygen from carbon dioxide. Since the life support equipment was installed within the SSS and the crew was required to maintain, monitor and repair this equipment, the test provided an opportunity to evaluate maintenance and operational requirements under realistic conditions.

Table 2-59

WASTE MANAGEMENT MAINTENANCE SUMMARY

Unit	Maintenance Activity	Spares Usage	No. of Times	Hours
Commode	Corrected vacuum leak	—	1	0.2
	Corrected low N_2 pressure on disinfectant tank	—	1	0.5
	Refilled disinfectant tank*	Wescodyne	1	0.5
	Replaced expended liner assembly*	Liner Assembly and Seals	1	5.0
			4	6.2
Urine Collector	Attempted modifications for one-g operation	Miscellaneous fluid fittings, tubing and RTV sealant	3	10.0
	Corrected time delay control malfunction	Relay	2	0.3
	Modified urine pump installation	Miscellaneous fluid fittings and tubing	1	0.5
	Modified to connect urinal to accumulator	Miscellaneous fluid fittings and tubing	1	0.5
	Modified to install timer for urine pump control	Timer and miscellaneous electrical items	1	3.0
			8	14.3
Trash Container	Corrected vacuum leak to annulus	Vacuum Grease	2	0.3
		Subsystem Total	14	20.8
		*Maintenance	-2	-5.5
		Repair	12	15.3

2.7.1.1 Maintenance and Repair

The performance of the equipment was excellent considering the system complexity and the extensive use of nonflight-qualified prototype equipment. The performance of the crew was outstanding in completing the many maintenance and repair tasks.

The stocked spares were sufficient to support the 90-day test, except for those required for the urine phase separator and the onboard water electrolysis unit, which were new prototype units that had not been previously used in extensive manned tests and had been evaluated by bench tests only. Since the failure mode, effects, and criticality analysis (FMECA) is only as good as the available data, the lack of adequate spares for these two units emphasizes the importance of adequate reliability data. Advanced life support equipment which exhibited a high degree of reliability during the test was evolved from prototype equipment with a long history of bench and manned system testing.

Recommendations for future long duration manned tests are as follows:

- All new prototype life support units must be subjected to extensive bench testing prior to installation in the SSS. These tests will provide the required performance and reliability data.
- Prior to the start of long duration manned tests, integrated system checkout tests must be conducted with realistic subsystem interface input/output conditions. These tests will permit an evaluation of the effect of subsystem interface interactions on unit and component reliability.
- Sufficient time must be scheduled into future long-duration manned test programs to permit upgrading of equipment between the bench, system checkout, and manned test phases.
- The FMECA must start early in the manned test planning phase and the analysis upgraded as additional reliability data is obtained.

2.7.1.2 Mass and Thermal Balance

Valuable data were obtained defining system and subsystem mass and thermal balance. The use of the onboard computer data link to maintain the mass balance inventory was not entirely successful. The mass balance computer program and equipment did not contain sufficient flexibility to provide for rapid corrections of data errors and instrumentation calibration variations. Therefore, much of the mass balance data was obtained manually from detailed records maintained by the inside crew.

For future long-duration tests, the rapid acquisition of mass and thermal balance data will be of prime importance. The following recommendations will provide this capability:

- The instrumentation requirements must be carefully reviewed early in the manned test program. Particular attention must be directed at obtaining accurate and reliable low-flow liquid metering devices.

- More flexible mass balance computer programs are required which will provide "real time" acquisition of data and facilitate programming changes as the situation dictates.

- The computer programming must start early in the manned test program. Sufficient schedule time must be provided to permit program checkout and upgrading during the life support system checkout tests.

- The computer system displays must provide an adequate presentation of the total system mass and thermal balance data. This display must be of sufficient detail to describe the effects of the interaction of various subsystem mass and thermal balance parameters.

2.7.1.3 Electrical Power Usage

The power distribution system was adequate for the 90-day test. However, the system was designed to industrial standards and did not provide sufficient distribution flexibility. As a result, a large number of circuits were provided and many were very lightly loaded.

Power recording instrumentation was provided and intended to show the power requirements for each life support unit, but constraints on circuit arrangement and available instrumentation prevented maximum data collection.

In order to provide improved power distribution and power usage recording during future long-duration manned tests, the following effort is recommended:

- Establish an ac power priority system for subsystems utilizing large amounts of power with low duty cycles.

- Incorporate an onboard ac power distribution box designed to facilitate rapid changes in ac power circuit loading during SSS design and system integration.

- Centralize power instrumentation for greater flexibility in design and subsystem analysis.

- Instrument ac and dc power lines to all major subsystems for improved power profile analysis and subsystem performance.

- Instrument all power-related events for correlation to power profiles and subsystem performance.

2.7.1.4 Trace Contaminants

The atmospheric trace contaminants were found to be generally far below the test contingency levels established by the NAS-NRC Committee. Excessive use of Freon 113 as a cleaning solvent during pretest cleaning operations was indicated by the detection of levels as high as 11.6 ppm during the test. Posttest analysis indicates that this high level of Freon 113 contributed to Sabatier and toxin burner catalyst bed poisoning during the test. Maximum Freon levels measured were far below those established for personnel hazard.

Recommendations for future long-duration manned tests are as follows:

- The test contingency and abort levels should be reviewed by the NAS-NRC Committee and new levels established consistent with the 90-day test and previous manned test data.

- New pretest cleaning procedures must be established to eliminate excessive cleaning solvent residuals from the SSS atmosphere.

2.7.2 Water Management

The VD-VF unit and backup wick evaporator provided an adequate supply of potable water, which was reclaimed from urine and humidity condensate. Only two tank-fulls, out of 37, were not certified potable due to physical or chemical properties that did not meet potability standards. Water was not rejected due to bacteria contamination.

It was demonstrated that the VD-VF unit can produce water that meets the rigid potability standards without further processing. However, this was achieved for only short periods of time because of apparently limited catalyst life or capacity and the inability to maintain sterility downstream of the unit. The sterility problem was initiated by a liquid level control malfunction but subsequent recovery was not possible. No handling problems or radiation hazards were encountered during the use of the radioisotope heat sources. Further discussion of radioisotope handling and radiation monitoring is provided in Section 4.

The wick evaporator encountered some flooding problems, but these did not affect water quality in any way. The flooding was caused by an above-normal feed rate that exceeded the evaporation rate capacity of the unit. The unusually high humidity inlet condition was also a contributing factor.

Heat sterilization provided positive bacteria control throughout the entire test, but water sampling techniques must be monitored closely to prevent accidental contamination. Contamination of the cold water supply in the distribution system did occur and must be eliminated in future manned tests.

The backup iodine-treated water supply was maintained sterile without additional iodine required during the 90-day period.

Recovery of used wash water by multifiltration was generally successful. Expendables were minimal in spite of a much larger usage rate than anticipated. It was found that carbon column changes contributed more to improved water quality than resin column changes.

Whole-body sponge baths were not considered adequate by the crew for this time duration. The inability to rinse away the cleansing agent residue left them with a slippery feeling and the residual odor was objectionable. Shower-type facilities and other system-compatible cleansing agents should be investigated for future long-duration testing.

Recommendations to improve water management system design and operation are as follows:

- Develop positive means to prevent bacteria contamination in potable cold water supplies, such as alternately heated heat exchangers, chlorine generators or iodine injection.
- Develop positive feedback controls to eliminate wick evaporator flooding.
- Develop means to wash dishes and reprocess food waste water.
- Increase multifilter column life with possible elimination of resin columns.
- Provide better whole body wash facilities.
- Find other cleansing agents that are compatible with both the subsystem and crew.
- Re-evaluate and update potable water standards.
- Development of faster microbiological sampling techniques could effectively simplify the subsystem by reducing the number of water storage tanks required.
- Establish wash water quality standards.
- Prolong VD-VF unit life by the development of an improved catalyst and/or method of removing urine concentrates from the boiler.
- Provide more reliable liquid level control devices that will perform under both zero-g and one-g conditions.

2.7.3 Atmosphere Purification

The solid amine unit demonstrated its effectiveness for maintaining cabin CO_2 concentration. The operational problems encountered may be solved by design improvements. This unit contributed a greater latent and sensible thermal load to the atmosphere than desired. Optimization of operation and hardware will undoubtedly improve this penalty.

The performance of the molecular sieve unit during the test was satisfactory. The only problems were attributed to a malfunctioning diverter valve.

Recommendations for improved CO_2 removal during future long duration manned tests are as follows:

- Eliminate the solid amine water balance problem by installing humidity level detectors in the beds and automatically or manually controlling the steam generation rate to each bed.

- Eliminate the condenser flooding problem by a redesign which will allow rapid filter changes.

- Provide automatic control of bed inlet temperature during absorption.

- Upgrade the solid amine unit to incorporate zero-g water separation feature. The molecular sieve zero-g water separator, which malfunctioned prior to the start of the test, must also be replaced with an improved design.

- Investigate the use of more efficient CO_2 adsorbent material.

The performance of the thermal and humidity controls units adequately met the mission objectives, even though several design parameters were exceeded. Deviations from design temperatures in the SSS equipment area resulted from excessive heat dissipation by the solid amine unit and lower than expected thermal control heat exchanger effectiveness. High cabin relative humidity can be primarily attributed to excessive water vapor from the solid amine unit. Despite some deviations from design values, the crew expressed satisfaction with performance from the two units.

Recommendations for improved thermal and humidity control would include elimination of deficiencies experienced, plus a general upgrading of the complete concept of temperature and humidity control within a confined area. Primary recommendations for future long-duration manned tests are as follows:

- Integrate the zero-g condenser/separator with the thermal control unit. This will eliminate the need for a separate humidity control blower. A study should be made as to the best integral configuration and optimum control technique for this application (i. e., modulating cooling fluid valve or bypass damper).

- Achieve at least 70 percent of the sensible heat removal from the SSS by use of cold plates located at the source of the dissipation. A large power penalty must be paid when removing this heat by circulation of a temperature-controlled atmosphere versus a temperature-controlled fluid.

- Design the thermal control unit to provide individual area temperature control. This can be accomplished without individual area heat exchangers if a bypass section with bypass dampers is installed in parallel with a main heat exchanger equipped with face dampers.

- Minimize the quantity of primary atmosphere circulated by use of high induction diffusers. Sound generation in a thermal control unit is a strong function of the atmospheric flow rate and system pressure. If the atmospheric flow rate can be significantly reduced by only slightly increasing the pressure, the sound generation will be lower.

2.7.4 Atmosphere Supply and Pressurization

The integrated Sabatier reactor/toxin control unit performed as expected after catalyst poisoning problems were resolved. The Sabatier reactor produced twice the weight of the Sabatier/toxin unit in water and contributed a considerable amount of thermal energy to support the operation of the toxin burner. The negative pressure device, which controlled the zero-g separator, failed early in the test and repeated attempts at repair were unsuccessful.

The operation of the toxin burner was satisfactory. However, post-test analysis indicates that the Hopcalite catalyst was also adversely affected by the presence of Freon in the atmosphere.

Recommendations for improved Sabatier reactor/toxin control operation during future long-duration tests are as follows:

- Future Sabatier reactor/toxin control development should include provisions to protect the catalyst from poisons.
- Quicker methods of initiating Sabatier reactor operation, such as a glow-plug type starter, would be a worthwhile convenience.
- Future development of negative pressure devices should tend towards a short-stroke configuration and utilize a separate pumping device to move the water to the storage reservoir.

All three water electrolysis systems were operated. The commercial unit experienced the least number of failures as was expected. The experimental units had more failures but still were able to supply 71.6 percent of the required hydrogen and 68.3 percent of the required oxygen. It is evident from the test experience that additional development and testing is required before advanced concepts of water electrolysis systems are ready for space applications. It is also evident from the test program that qualified personnel with the appropriate spare parts can complete very significant repairs. The Allis-Chalmers unit, being installed in the chamber, was not accessible by highly qualified personnel nor were spare parts available. The Lockheed unit, being installed outside the chamber, was accessible for complete rebuilding of modules when required. Should the roles have been reversed, less favorable results would probably have been obtained on the Lockheed unit.

Further development of water electrolysis is necessary to meet operational reliability requirements for future long duration manned tests. Primary recommendations for water electrolysis design improvements are:

- More emphasis must be directed to the evaluation and selection of better operating hardware. Components of a higher quality than off-the-shelf commercial items are required to meet the high corrosion and other design problems associated with water electrolysis techniques.

- The electrolysis modules of future units must be designated to withstand greater pressure differentials across the matrices.

- Two-phase liquid separators of improved design, capable of operation in zero-g will be required.

The flight-type two-gas controller and sensors functioned properly throughout the test, having no malfunctions and requiring no unscheduled maintenance. The control accuracy was excellent on the oxygen channel, holding within ±0.3 percent of the set point. Accuracy on the nitrogen channel was not as good, being ±2.4 percent over the major portion of the test. In addition, the mass flow measurement accuracy was compromised by the switchover logic on the oxygen channel, which required frequent manual attention during periods of high demand.

Recommendations for two-gas control design improvements for future long-duration manned tests are as follows:

- Provide improved nitrogen control accuracy by increasing the input amplifier sensitivity and the flow control orifice size.

- Improve the mass flow measurement accuracy by providing automatic switchover to the backup supply, increased differential pressure to switch back, and a reduction in oxygen channel sensitivity. The reduction in oxygen channel sensitivity would also reduce the transient demands on the electrolysis unit.

2.7.5 Food Management

Freeze-dehydrated food is an acceptable diet for long-duration missions. Frozen food and selected snacks can be utilized in order to improve crew morale. Generally, the frozen foods were well accepted by all crewmen but the crew indicated that they could have done without them had they been required to do so.

Negative reactions to food provisions can be eliminated through the combination of food selection oriented toward palatability, the provision and utilization of a means whereby foods can be heated to acceptable serving temperatures, and provision of an acceptable variety in available diets.

The microwave oven was simple to use and quite effective in reheating of reconstituted freeze-dehydrated food.

Recommendations for improved food management programs for future long-duration manned tests are as follows:

- The use of a microwave oven in future ground-based simulations is warranted. Primary tradeoffs of weight, volume and peak power consumption would have to be made before use of a microwave oven could be recommended over the direct thermal type now planned for orbiting vehicles.

- It may be desirable to defray the monotony of a single type of diet with foods prepared and stored utilizing other techniques.

- When employing combined diets, it may be necessary to adjust seasoning and "richness" to achieve greater acceptability.

- Greater attention must be given to the selection of containers and food packaging materials from the dual standpoints of flammability and storage density.

2.7.6 Waste Management

The commode performed overall in a satisfactory manner and was accepted by the crew. There were no component malfunctions. A considerable amount of crew training was necessary to ensure correct assembly of the unit after liner replacement. It was felt by the crew that the threaded fittings would have given them greater difficulty in a zero-gravity environment.

The fecal material did not adhere well to the wall of the liner and as the commode filled, the particles were whirled around by the slinger plate. In zero-gravity some particles would probably be thrown from the commode unless considerable preventive action is taken by the user.

Problems encountered with the urine collector emphasize that a device handling a dilute solution of a very corrosive fluid must also be qualified to survive failure modes in which much more concentrated solutions are improperly introduced.

The pretreatment supply injector should be provided with more positive control. As installed, it was a passive supply dependent on the adequate functioning of the blower, the flush water valve, and their electrical control components.

The extreme range of individual urinations, 16 ml to 924 ml during this test, makes simple proportional additions of pretreatment rather difficult, and careful design and test is required.

The waste storage and disposal equipment as a group performed in a satisfactory manner. The leaks in the waste storage container and the toilet paper dryer were minor and required procedural changes in waste handling but performed well otherwise. There should have been more specific instructions as to what kinds of waste to put into the No. 2 commercial cans. The procedure requiring passout or freezing of bulging cans appears overly cautious in review but it was felt that minimum risk should be taken of a can rupture onboard the SSS during the test.

The amount of waste for a 90-day period was less than that collected during the previous 60-day test. This was due mostly to a change in food packaging. Further refinements short of reconversion of wastes will require more effort and continuing attention during the test period.

Recommendations for improved waste management for future long-duration tests are as follows:

- The commode should be modified to replace threaded fittings with flanged and clamped connections wherever possible.
- The interior wall of the commode liner should be textured in some manner that allows better adhesion of the feces.
- Any future tests should make provision for the automatic recording of urine quantities and time of urination to provide design information for the development of urine collection equipment and for medical assessment of the crewmen's condition. Forms should be provided for manual recording of the data as a backup measure.
- An improved method of adding urine pretreatment is required. A suggested method for study would be to supply fixed amounts of pretreatment upon collection of a fixed volume of urine in an accumulator downstream from the phase-separator. This latter system would be independent of malfunctions of other components.
- The phase-separator requires development of suitable rotor materials and sealing methods that can tolerate the possible high concentrations of pretreatment acids.
- Handling of garbage and other general waste products requires further study. Perhaps the data on types and quantities produced will serve as a basis for system design to reduce the quantities and provide more effective means for handling them.
- Disinfectant procedures should be studied further and microbial sampling should occur periodically in all waste storage receptacles.

2.7.7 Program Aspects

The 90-day manned test of a regenerative LSS provided a great deal of data which will be useful in the development of future life support systems. The integrated LSS included advanced subsystem units, which were being operated for the first time in a manned test, and the evaluation of these advanced subsystem units required extensive integration with the previously tested baseline units.

Important performance characteristics were emphasized by this integrated system test that were not readily obvious from individual unit design studies or bench test experience. During the 90-day test, incidents occurred during which several units were subjected to transient output demands which exceeded their capacity. This emphasized the requirement for subsystem designers to provide for adequate margin to allow recovery from high loads, and for systems integrators to specify design parameters that minimize transient demands.

The vast amount of data collected during the 90-day test serves to emphasize the need for rapid collection and evaluation of test data. The 90-day data management system was adequate, but valuable time could have been saved if improved "real time" data acquisition and display had been provided. Future long-duration manned test programs must include an integrated information management system which will provide automation of LSS data collection and display.

Section 3

MAN-SYSTEMS INTEGRATION

This section deals with features of the man-systems integration program accomplished in support of the 90-day test. The program included:

A. Crew selection, training, and performance

B. Staff selection, training, and certification

C. Habitability

D. Psychosocial effects of confinement

E. Mission activity analysis

F. Audiometrics

G. EEG and sleep studies

H. Glycerol food supplement studies

I. Non-interference performance assessment

J. Psychomotor testing

The overall objective of the man-systems program was to establish an environment for onboard personnel which, in as many respects as possible, would simulate living conditions anticipated to exist under operational orbital constraints. All aspects of the interface between the onboard crew and supporting staff duplicated conditions which could reasonably be expected to pertain to an earth-orbital scientific laboratory staffed for a mission duration of 90 days. The primary interface, communications, was managed as necessary to replicate communications as they would exist during an earth-orbital journey.

Communications management, as well as life support system provisions and medical support, combined to establish a high-fidelity simulation environment. It is thus expected that measured reactions of crew members are relevant to space living conditions and data are applicable to crews for future long-duration space missions.

Reactions to confinement were generally minimal. Crew morale was good except for a period of approximately 10 days at the two-thirds point of the test. This point coincided with a reduction in the frequency and duration of

unscheduled crew tasks. Habitability provisions were well accepted. Interpersonal difficulties were minor. Crew interactions with support personnel were effective and highly professional. Sleep quality showed a tendency toward disruption. The crew activity schedule was adhered to, but some work underload occurred. Crew selection procedures were apparently helpful in identifying effective and motivated crew members.

3.1 CREW SELECTION, TRAINING, AND PERFORMANCE

Crew management for the 90-day test involved establishment of selection criteria and methods, application of these in recruiting and selecting the four participating and four backup crew members, training in preparation for the test, and evaluation of their performance during the test.

3.1.1 Selection

Crew selection for the 90-day test was the most comprehensive selection program ever applied in a simulation study. The objective of the selection program was to choose a crew that would function effectively and efficiently for the total test duration without subsequent pathology. Selection techniques were psychologically oriented, but also placed a great deal of emphasis on the more pragmatic aspects of crew suitability, such as mechanical skills, availability for training, physical fitness, health of close family members, motivation for participation, and acceptance of pay scales offered.

3.1.1.1 Procedures

Three lines of selection were follows: psychological, physical, and pragmatic. Criteria were developed within each area. Throughout the multistage selection process, consonance of volunteers with these criteria was sought.

Upon the recommendations of the NASA-sponsored symposium at Texas Christian University, Fort Worth, crew members were sought who could demonstrate:

A. Scientific and technical skills and capabilities.

B. Emotional maturity and mission motivation.

C. Physical health.

D. Ability to withstand isolation.

E. Leadership identification.

F. Crew compatibility.

A consultant in clinical psychology administered psychological tests, scored them, and recommended candidates from among those applicants sent to him for psychodiagnosis. He also generated a quantitative profile of scores on the various objective psychodiagnostic tests, which were thought to describe the kinds of person expected to be most effective in withstanding the rigors of confinement.

Physical criteria consisted of the ability to pass an FAA Class I physical examination (with waivers for visual acuity if necessary) and demonstrated compliance with normal values of a number of clinical biochemical indices.

Pragmatic criteria included:

A. Willingness to volunteer for the entire program.

B. A demonstrated life style indicative of innerdirectedness with little dependence on other persons for emotional stability.

C. No criminal arrests or convictions.

D. No serious speech impediments.

E. No evidence that participation in the program reflected an escape from life.

F. No previous history of serious emotional difficulties.

G. Commitment to the achievement of higher academic goals in graduate school.

Applications were solicited from graduate schools in the Southern California area within the disciplines of engineering, physics, biology, and the social sciences. Approximately 45 applications were received.

A package of screening questionnaires consisting of eight devices was mailed to all applicants for completion at home and return by mail (Table 3-1). Based upon a review of qualifications as evidenced in these questionnaires, the applicant group was reduced and 27 applicants were invited for personal interviews. Copies of questionnaire results were transmitted to Dr. E. K. E. Gunderson at US Navy Medical Neuropsychiatric Research Unit (NMNRU), San Diego, California, and to Dr. W. Haythorn at Naval Medical Research Institute (NMRI), Bethesda, Maryland who then provided numerical acceptability rankings based on agency experience with the questionnaires in the selection of Antarctic crew members and experimental isolation study groups. Although strong correspondence was not characteristic of the two agencies' rankings, assigned ranks were employed to assist in reducing the size of the applicant pool. The applicant pool was further reduced on the basis of personal interviews with the Medical and Behavioral Directors and a review of screening questionnaire data.

Psychodiagnostic tests (objective and projective) were next given to 16 individuals identified as most desirable of the 27. Test profiles were developed by MDAC and its consultant at this point, which were thought to be descriptive of the "classical" crewmen. Objective tests given were:

A. MMPI (Minnesota Multiphasic Personality Inventory) (Reference 3-9) (All tests)

B. FIRO-B

Table 3-1

SCREENING QUESTIONNAIRES AND ORIGINS

Questionnaire	Agency	Investigator
Cornell Medical Index	Cornell Medical College	J. R. Wamsley
Personal History (References 3-1, 3-2, 3-3)	NMNRU	E. K. E. Gunderson
Hobby Inventory (Reference 3-4)	NMNRU	E. K. E. Gunderson
Meyers Activity Inventory (Reference 3-5)	NMRI	W. Haythorn
Fitzgerald Experience Inventory (Reference 3-5)	NMRI	W. Haythorn
Life Crisis (References 3-6, 3-7)	NMNRU	E. K. E. Gunderson
Opinion Survey (Reference 3-8)	NMRI	E. K. E. Gunderson
Demographic and Educational	MDAC	J. S. Seeman

C. 16 PF (16 Personality Factors) (Forms A and B)

D. MAT (Motivational Analysis Test)

E. Study of Values - Allport/Vernon/Lindzey

F. Edwards PPS (Personal Preference Schedule)

G. Rokeach Dogmatism Scale

H. Eysenck Personality Inventory

Projective tests used were:

A. Rorschach

B. Thematic Apperception Test

C. Sentence Completion

D. Early Parental Recollections

E. Future Autobiography

The formal crew pool (eight) was chosen on 26 January 1970. Training began the following week. Throughout the training period, the men were observed for group formation and the evolution of a leader. Immediately prior to the 5-day run, a sociometric test was given as an adjunct to aid in crew selection. This, combined with training results and, to an extent, individual availability, led to the selection of a four-man crew. Crew performance was outstanding during the trial run and gave a great deal of confidence in the selection process. Subsequent to the 5-day run, a review and evaluation was accomplished that gave valuable information for hardware and procedural modifications.

Final crew selection took place on 26 May 1970, and was achieved through the consensus of the Program Manager, Medical Director, and Behavioral Director following an evaluation of all pertinent data, i.e., training results, psychological data, subsystem knowledge, health data, etc. Personnel selected and employed as onboard crewmen are described in Table 3-2.

3.1.1.2 Results

The success of the selection program is established because all four selected men withstood 90 days of confinement with no serious hostilities developing and no indication of any intent to abort the mission. All scheduled tasks were performed promptly and conscientiously throughout the 90-day period.

Review of post-test objective psychological test results indicates no apparent consequent pathology. Personality changes were measurable on all crew members. The changes were, however, neither prominent nor disruptive and can be characterized as reflecting active participation in a new life style rather than profound alterations in basic psychodynamics. These changes cannot solely be attributed to the 90-day confinement episode, but reflect alterations which may well have been a consequence of training by and exposure to operationally oriented aerospace personnel. These demands of the program necessitated reduction in time commitments of crew members to academic pursuits and promoted radical departures from life styles possible in academia. Reports from crew members after the test attest to a relatively rapid readaptation and assimilation into academic life with basic goals of scientific advancement unaffected.

Selection criteria for the objective psychodiagnostic tests have been developed which are quantifiable and apparently valid. This is considered to be a major contribution to future quantitative crew selection procedures. The objective of scientific and technical capabilities was obviously met as the crew learned the subsystems and they operated well with outside crew support.

A feature of selection not originally planned, but of considerable value in the ultimate choice, was the demonstrated ability of selected candidates to comply with the many irritating, time-consuming, and constantly changing infringements on their time throughout the training program. Crewmen were thus additionally selected on the basis of accepting these requirements without complaint.

Table 3-2

INFORMATION ON CREWMEN

Crewman	Age	Academic Discipline(s)	Degree(s)	School(s)	Relevant Experience
Stephen Dennis	23	Life sciences Neurobiology and Behavioral genetics	BS, 1969 toward MS	MIT California Institute of Technology	Biochemical and microbiological skills
Terry Donlon	31	Chemistry Physical chemistry	BS, 1961 MS, 1964	Reed College Washington State University	Radioisotope technician
		Medical physics	PhD, 1970-1	UCLA	Clinical medicine laboratory technician
John Hall (Crew commander)	26	Chemistry Medicine	BA, 1965 2 years	Reed College Harvard Medical	Electronics instrumentation repair technician. Small groups in isolation (Alaska and Peru)
		Geochemistry Geochemistry	MS, 1968 toward PhD	California Institute of Technology	
Wilson Wong	22	Mechanical engineering Aeronautics	BSME, 1969 toward MS	CCNY California Institute of Technology	Repair and test of oil refinery hardware

Observation of group structure by staff throughout training was of value in identifying crew makeup. Sociometric questionnaires were administered periodically during training and confirmed observations that certain potential crew members seemed to display distinct preferences for particular others. With few exceptions, preferences were maintained throughout training among those who had begun training earliest. Although preferences existed, they were not judged to be strong and did not lead to establishment of a cohesive group. Attention to the personality characteristic of inner-directedness during the selection process apparently worked toward mitigating the development of a strongly cohesive group. These individuals were too inner-directed to permit the social-emotional penetrations necessary to the establishment of such a group. Nevertheless, attention to expressed and observable interpersonal preferences of potential crew members seems of value in crew selection if for no other reason than obvious incompatibles can be eliminated.

3.1.2 Training Program

The goals for training emphasized the need for crew competence and safety. The basic requirements of the program included candidates with good basic scientific training and aptitudes, experienced instructors, a thorough curriculum, and a flexible schedule. The course work under the major headings in Table 3-3 covered those aspects of each subject particularly concerned with the test. The courses under biomedical procedures included sampling procedures for bacteria, urine, and blood which were of interest to test experimenters and health monitors. Medical monitoring concerned itself with the use of equipment for measuring those parameters desired by the principal investigators and medical monitors. Life support system courses stressed the operation and maintenance of the life support equipment. Theory of subsystem operation was always presented, but the primary goal was to train competent operators and maintainers.

Crew training served the dual functions of providing information to the crew on test objectives and operational requirements, as well as providing information on the crew regarding levels of motivation for use by program management as pragmatic inputs to crew selection.

3.1.2.1 Background of Crew Candidates

The candidates were graduate students from several local universities and adapted very readily to the laboratory and the type of training. Typically, their graduate studies were more arduous than the SSS training. All of the candidates had previous training that was directly applicable to some area in the program. One candidate was experienced in veni-puncture techniques and blood handling, several had taken bacteriology classes, and all had taken sufficient chemistry courses so that they readily understood the life support processes. All had experience in operating test equipment and computer techniques. Their advanced degree goals in engineering and the sciences also demonstrated the very important attribute of being concerned with this type of program, the experiments, and knowing the value and need for good data.

3.1.2.2 Organization and Curriculum Development

A training staff was appointed consisting of a training director and instructors for each course. The training director reported to the Behavioral Director and was responsible for curriculum development, scheduling, and all crew/staff interactions. Instructors were drawn from the MDAC Biotechnology Department and from other contributing companies and Government agencies. The instructors for the biomedical and man-systems areas were specialists in those disciplines applicable to specific classes. Table 3-4 summarizes instructor backgrounds and capabilities.

Each instructor submitted a course outline that specified subject matter to be covered and performance requirements for the crew candidates. The preliminary schedule was developed by the staff from these outlines and the scheduled availability of test equipment.

The basic curriculum consisted of lectures, demonstrations, and practice sessions. Lectures were used to familiarize the crew with the equipment operation and maintenance, medical and behavioral methodology,

Table 3-3

SSS CREWMEN TRAINING CURRICULUM

A. Biomedical Procedures

- Microbiology
- Medical Monitoring
- Blood Sampling
- Urine Sampling
- Physical Fitness
- Experiments

B. Life Support Systems

- Water Subsystems
  - Air Evaporator
  - Wash Water
  - VD-VF
  - Sampling
  - Contamination
- Atmosphere Control
  - Two-gas Control
  - Thermal Control
  - CO_2 Concentrator
  - Sabatier/Toxin Unit
  - Electrolysis
- Mass Balance Operations

C. Man-Systems Integration and Operation

- Human Factors
- SSS Procedures
- Support Functions
- Experiments

Table 3-4

TRAINING INSTRUCTORS

Biotechnology and Related Experience (yr)	Degree	Field	Biotechnology and Related Experience (yr)	Degree	Field
12	BS	ME - LSS	14	MS, MD, MPH	Medicine, physiology and preventive medicine
8	MS	Chem E - LSS			
5	BS	ME - LSS	10	MA	Psychology
8	MS	Chem - LSS	9	MA	Psychology
10	BS	ME-LSS	4	MA	Psychology
4	BS	ME - LSS	7	BS	ME-Computer techniques
2	MS	Microbiology			
20	PhD	Physiology	1	PhD	Psychology
7	PhD	Radiology and Medical physics	9	BSMEE, MS	Physiology
			15	BS, MS	ME, mathematics
12	MS	Microbiology	15	PhD	Physiology
8	BSEE, MD	Medicine and EE	20	PhD	Psychology
		200 Man-years technical experience			
		18 Advanced degrees			
		9 Technical disciplines			

test procedures, and requirements. The distribution of course work for the three major headings in Table 3-3 is given in Appendix F of NASA CR 111882.

3.1.2.3 Cross-Training

Cross training of the crewmen was quite extensive early in the training program. All candidates practiced veni-puncture techniques, urinalysis, and sterile techniques for microbiology. All attended the lectures on life support equipment and practiced the man-system procedures and psychomotor devices. As training progressed and particularly after final crew selection, the amount of cross-training was lessened and with some experiments none was done. The particle counting experiment procedure, light-level measurement, and mass balance data management were assigned to particular crewmen. The microbial monitoring technique was taught to two crewmen. Two crewmen were selected for EEG monitoring and taught the required procedures.

3.1.2.4 Cohesion Training

Cohesion training was a form of sensitivity training oriented to the development of a cohesive group consisting of crewmen and communications monitors. It was undertaken in an attempt to eliminate difficulties between and within the inside and outside crews. Cohesion training consisted of six sessions of varying length. The group director was an MDAC consultant, Dr. MacFarlane, who also managed the psychodiagnostic program. The first session was 6 hours long with seven crewmen and four communications monitors participating, divided into three groups. Within the groups, the members exchanged capsule autobiographies after a considerable amount of speculating about the personalities and characteristics of the other participants. The groups were then rejoined for a general discussion about each person's history to validate the stereotyping that had occurred in the previous speculation. After this more general information was exchanged, the remainder of the time was used for physical exercises, such as placing one person in a ring of six people, having him close his eyes and fall in any direction. He was caught and moved back to an upright position. This type of exercise is generally intended to indicate the degree of trust a person will place in other people and is thought to promote a sense of trust toward the other members.

The other five sessions were each 2 hours long and consisted of discussions about test-oriented attitudes and situations. Discussion subjects included possible food shortage and hoarding of items, such as nuts and candy bars; the investigation of recreational possibilities; and housekeeping and personal habits discussion. The second through the fifth sessions included only the crewmen. The session following the 5-day pretest was devoted to an analysis of the feelings and concerns of the onboard crewmen. The last session included the eight crewmen, two communications monitors, and Dr. MacFarlane. During this period, there was some discussion of continuing the cohesion periods among the onboard crew on a weekly basis during the run. This was left to the management of the onboard crew, but once the test began, the periods were not instituted.

Most of the participants in cohesion training were initially reserved about its possibilities, and afterward felt that it had been minimally helpful because of the short time allocated. They recommended that more time be devoted to cohesion training for subsequent manned tests. This seems particularly applicable to test crewmen who are inner directed and do not tend toward the formation of teams or groups. Further training could be used to develop a behavioral format with which information concerning irritability and encroachment may be transmitted in a benign way. Such an extension of cohesion training and particularly continuation during the test could have been helpful in alleviating the morale decline occurring approximately from test day 60 through 70, which appeared to be related, at least in part, with continued, unexpressed grievances between crew members.

3.1.2.5 Psychomotor Training

Psychomotor training was accomplished on all three available devices (LaRC-CC, RATER, and CTT). In the case of the LaRC-CC, all crew members accomplished at least 25 sets of 100 trials with one crew member completing 38. Training on this device was completed on 14 May 1970, approximately 1 month before 90-day test initiation. Asymptotic performance was not seen during training. Final pretest scores are shown in Section 3.4.2.10, together with test scores.

Training on the Critical Task Tester began early in February 1970 for onboard and backup crewmen. Training sessions lasted 30 to 40 minutes for each man and continued on a regularly scheduled basis through May 1970. During each of the training sessions, approximately 6 trials were accomplished on the first-order critical task, 10 trials on the second-order critical task, and 3 trials each on the first- and second-order steady tracking tasks. Approximately 45 training sessions were accomplished for each crew member prior to the 90-day test. Pretest asymptotic performance was judged to have been obtained by crewmen 2 and 3 on all tasks. The other two crewmen achieved asymptotic performance levels on all tasks except the second-order steady tracking task. Detailed graphical material on the pre-test performance values is depicted in Section 3.10.

3.1.2.6 General Training

The training hour distribution in man-hours is as follows:

Lecture and Demonstration	Practice	Miscellaneous (EEG Sleep)	Written Test	Total Training
853	893	44	80	1,870

There was some difference between crewmen in the number of hours each attended training. After crew selection, there was more demand to train those selected for special functions relating to their anticipated onboard roles.

A further breakdown of man-hours utilized throughout the training period is shown in Figures 3-1 and 3-2. Figure 3-1 shows that instructor training time totaled 406 hours over an approximate 5-month period and that the rate of training accelerated approximately 1 month before test initiation. Figure 3-2 provides crew man-hour expenditures for all training activities and demonstrates that physical fitness training, medical examinations, and psychomotor training consumed a major portion of the 1,870 crew man-hours expended.

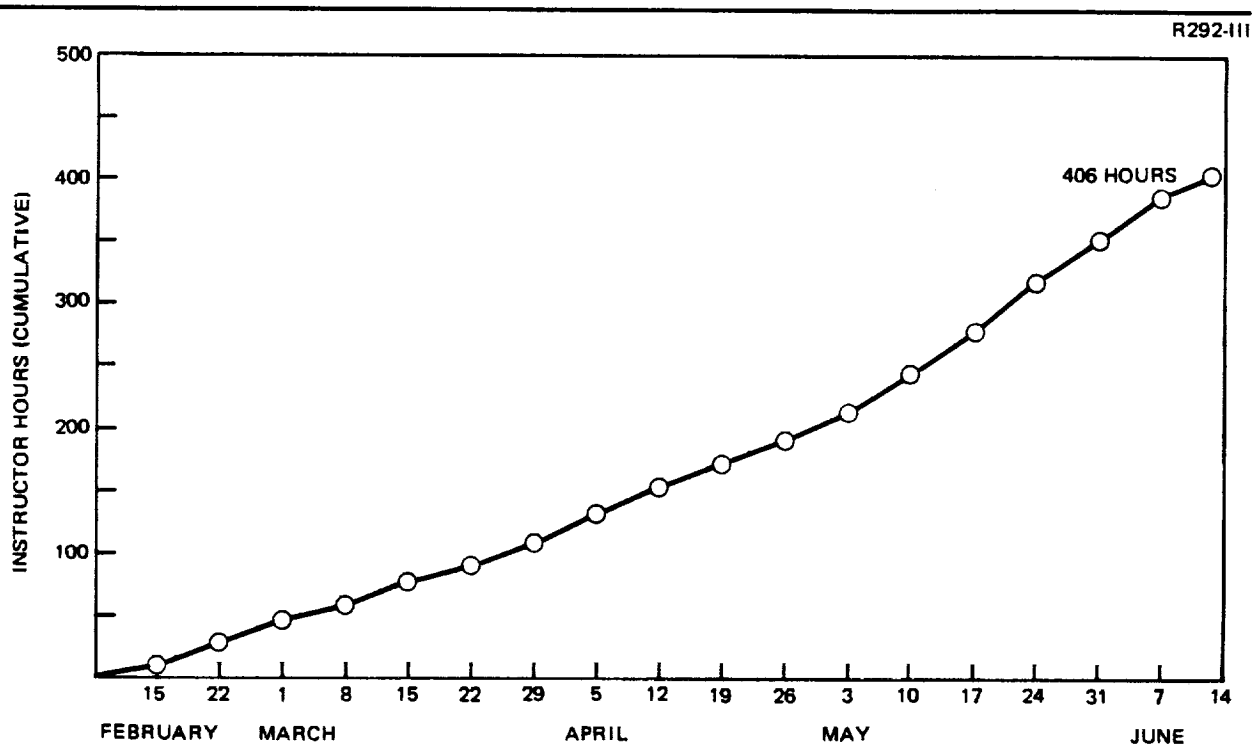


Figure 3-1. Instructor Utilization

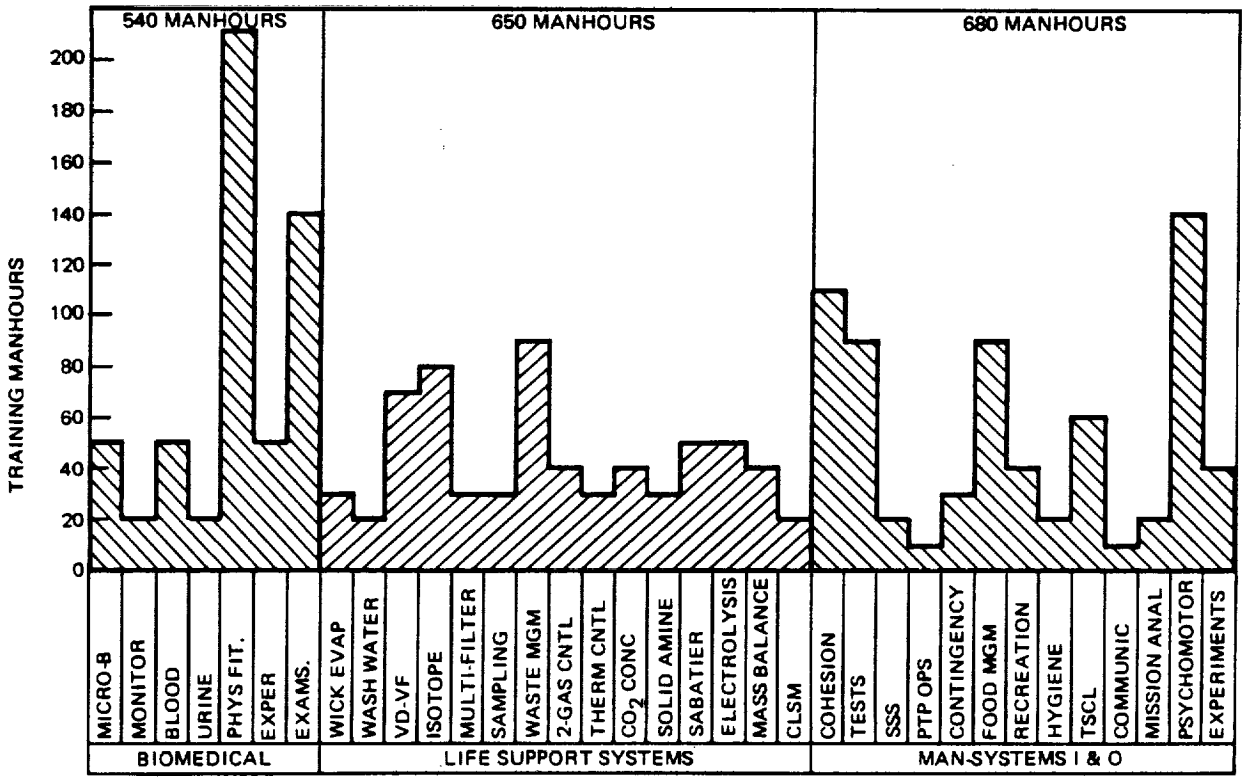


Figure 3-2. Distribution of Trainee Hours

3.1.2.7 Proficiency Evaluation

Crewman performance evaluation for this curriculum consisted of a crew proficiency rating filled out by each instructor after completion of his class and evaluation period, a crew course rating filled out by the crewman candidates, a self-evaluation by each candidate of his own knowledge of the systems, and three written tests administered periodically during the course of training.

The first of the three written tests was relatively unstructured and requested that the crewmen describe what they knew of the systems they had studied and what they understood of the objectives of the 90-day test. The intent in giving this type of test was to assess the effectiveness of the training to date, to find those areas the crewmen were interested in and responded best toward, and to see how each crewman structured his concepts of the whole program, i. e., whether he responded with detailed analyses of the equipment and processes or was concerned with the larger view. The crewmen's scores on this test were not used for comparative evaluations because they responded in different ways. Some went into little detail system by system, but gave a good comprehensive view of the program. Others provided considerable detailed description of the processes and hardware of the life support equipment. These differences had a beneficial effect because in this competitive situation it demonstrated the various viewpoints and grasp of detail possessed by the candidates and clearly defined the nature of the selection competition. The second written test concerned the life support systems and asked for details of hardware and processes. The last was, in effect, a final examination consisting of questions submitted by instructors from areas requiring detailed system descriptions and procedural methodologies. This last test and the instructors' evaluations were given the most weight in evaluation of the candidates and is included as Appendix B.

The final written examination given at the conclusion of training resulted in the following scores:

Crewman	Raw Score	Percent Score
1	198	90
2	208	94
3	182	83
4	173	79
5	174	79
6	162	74
7	150	68

3.1.2.8 Scheduling of Training

Occasionally, the availability of a particular instructor or equipment required rescheduling of a class and reduction in the number of crewmen given certain kinds of training. This was true of the electrolysis units and the solid amine CO_2 concentrator because other companies that had developed these units provided assistance in the crew training. Some computer training was given after regular work hours to have more nearly uninterrupted access to the computer.

Maintenance training was variable for each item. On some items, installation and instrumentation occurred late in the prerun period and the available training time was used to teach operation. Major overhaul-type maintenance was not taught as it was felt that most equipment would operate with only minor electrical and mechanical malfunctions. Some units had a considerable history of operation without failure before the 90-day test. In-depth maintenance training was not practical for most of the life support equipment because of the complexity of their respective control systems. The schedule seldom permitted adequate time to practice maintenance on equipment undergoing final test, instrumentation, and installation.

A type of training added later in the training period was the instruction in the techniques of tube flaring, bending, and sealing procedures; and in wiring, crimping lugs, and soldering. This training proved beneficial during the test as a number of alterations required both piping and wiring changes. Typical examples included an electrical timer which was added to the urine feed for the wick evaporator, a diode which was changed in the electrolysis unit, and a signal light that was added to the communications system. Piping changes included replumbing the urinal and urine feed pump and adding a gas line to the solid amine unit to supply pressurized N_2 for valve operation.

In the biomedical lectures and demonstrations, there were few difficulties and the practice requirements allowed adequate scheduling flexibility. As blood analysis was begun, the crew arrived in a fasting condition every Tuesday morning and practiced blood and urine sampling, microbiological techniques, food management, and waste material handling.

Similarly, the man-system lectures and demonstrations introduced few difficulities and permitted flexibility in scheduling. The final sessions of cohesion training had to be postponed once or twice. This apparently had little impact on the class. Practice on the psychomotor devices was interrupted for approximately one week while they were being installed in the SSS, but this was a relatively small amount of time compared to the whole practice time of 3 to 6 months.

3.1.3 Crew Performance

During the 90-day test period each onboard crewmen performed 25 to 30 scheduled tasks per day. This totaled approximately 9,400 crew tasks for the entire mission of 8,640 man-hours. These tasks comprised all those considered essential to the operation and scheduled maintenance of the life support system (LSS) and the everyday tasks of living, eating, and sleeping. Not included were (1) maintenance tasks which were expected to be essential, but were not of a nature to be scheduled; and (2) maintenance tasks resulting from equipment failures. Crew tasks were classified as either "mandatory" or "recommended". A mandatory task had a financial incentive, while recommended tasks were not associated with the incentive plan.

The test crew was required to monitor, maintain, and repair the life support equipment within the SSS. The only life support unit that was not installed within the SSS was an electrolysis unit developed for NASA by the Lockheed

Missiles and Space Company (LMSC). This advanced subsystem was provided as a backup to the onboard Allis-Chalmers electrolysis unit and, because of space and time limitations, was installed outside the SSS.

The approach to life support equipment operation, repair, and maintenance simulated that aboard a space station vehicle. The test crew was trained to operate subsystems, complete normal repairs, and maintain the LSS through component replacement. Standby procedures and units were provided and used until repairs could be completed on the primary unit. All repairs and maintenance on inside equipment was accomplished by the onboard crew using available stowed spares and an onboard tool kit. Verbal assistance, when required, was provided by the outside staff. The crew worked a two up/two down work-rest cycle in the interest of safety and equipment monitoring coverage (Figure 3-3).

3.1.3.1 Procedures

Performance of the onboard crew was monitored during the period of the test by television cameras, microphones, computer readouts, displays of simulator parameters outside the chamber, and via the communications link. Evaluation of scheduled tasks was concerned with whether all tasks were performed, if they were performed as scheduled, time to perform tasks, and effectiveness of task performance. Performance of unscheduled tasks was evaluated in terms of willingness to perform unpleasant tasks, ingenuity in performance of unanticipated tasks, and effectiveness of task performance. The crew activity schedule (Section 3.5) was used as the basis for crew task evaluation. Communications monitors, observing the crew 24 hours a day by closed-circuit TV, noted in their communications monitor log the start and stop times for each of the tasks in the crew activity schedule. They also noted difficulties encountered, schedule deficiencies, and performance on unscheduled tasks. Additional evaluation data were available from observations obtained in the Non-Interference Performance Assessment (NIPA) experiment (Section 3.9) in which the physical activity of the crew was observed and recorded every 2-1/2 minutes during most of each day.

As the test progressed, periodic discussions were held with communications monitors, NIPA observers, mission analysis monitors, and medical monitors to obtain additional evaluation data and subjective comments on crew performance. A final step in the evaluation process consisted of post-test interviews with crewmen.

3.1.3.2 Results

All scheduled mandatory and recommended crew events were completed with the exception of those deleted because of conflicts with the demands of unscheduled maintenance tasks. At no time did the crew request the deletion of an event and only occasionally would a crewman require permission to delay an event. Requests to perform events early were common as the crew frequently adjusted the time schedule to accrue a large block of uninterrupted free time for recreation and exercise. The actual manpower use may be seen in Table 3-5.

R292-III

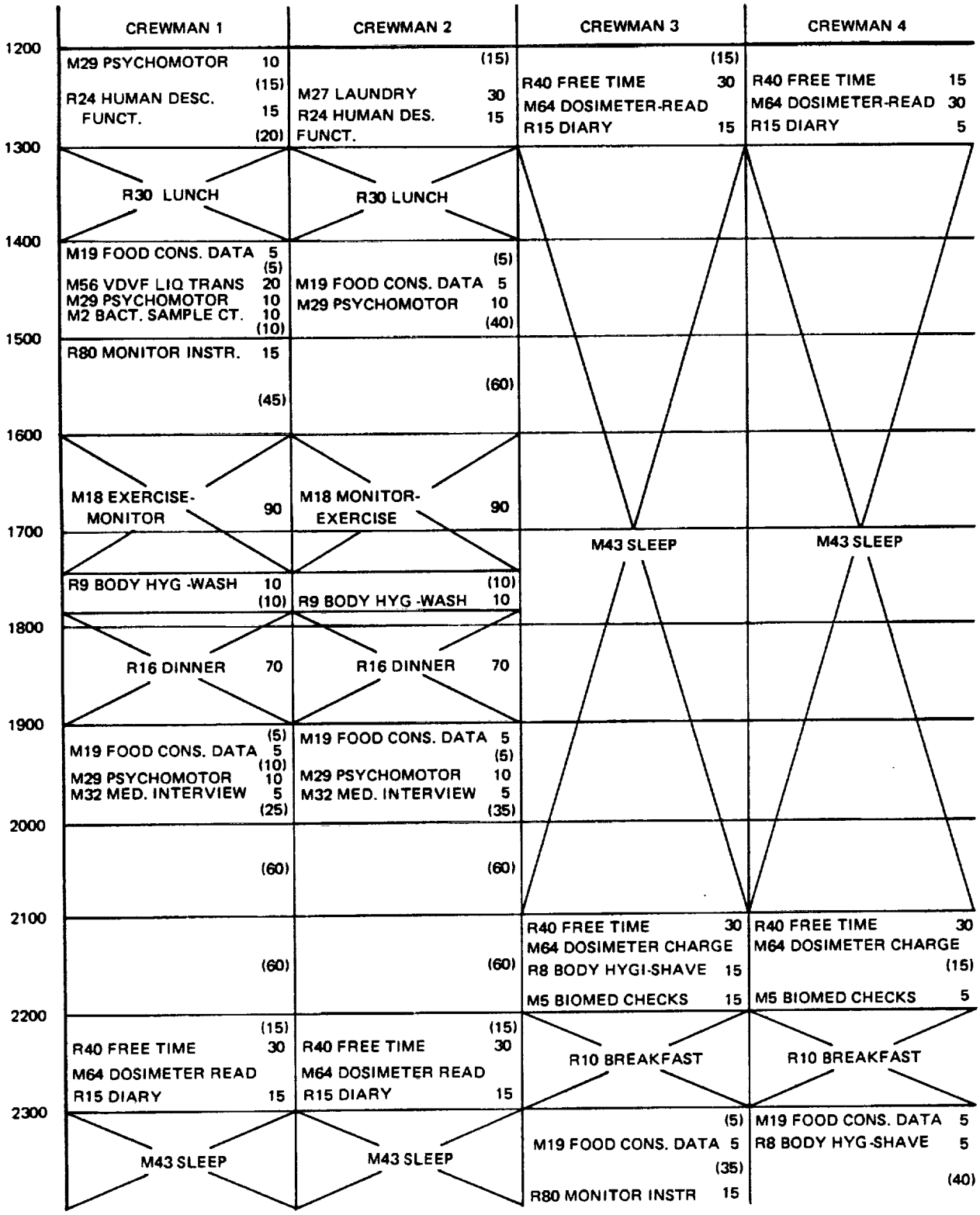


Figure 3-3. Sample Work Rest Cycle

Table 3-5

MANPOWER UTILIZATION—90-DAY VALUES

Crew Size	Availability	Mission Duration	Total Available Man-Hours
4	24 hr/day	90 days	8,640

Utilization Category	Man-Hours Expended	Mean Daily Expenditure (hr)	Mean Percentage Daily Utilization
Operational tasks	1,224	3.4	14
Meals	756	2.1	9
Free	3,204	8.9	37
Sleep	3,168	8.8	37
Miscellaneous and unaccounted	288	0.8	3
Total	8,640	24.0	100

Repair and maintenance operations on the LSS equipment are summarized in Table 3-6. The hours noted were obtained from the test logs maintained by the outside staff and the crewmen. As indicated, the onboard crew performed 152 repair tasks requiring 117.4 hours.

In addition to repair and maintenance of the LSS, the crew performed additional tasks on onboard experiments and other support equipment. The significant items are shown in Table 3-7. Not included in Table 3-7 is the scheduled maintenance which was required for items such as the TV cameras, radiation monitor, and aerosol particle counters. This scheduled maintenance was estimated to be a total of approximately 23 hours. Therefore, the total onboard crew time for all maintenance and repair activities was approximately 203 hours, or 2.3 hours/day.

Post-test interviews revealed the crew did not differentiate between mandatory and recommended tasks. The mere presence of a task on the event schedule (available onboard) was sufficient to the crew and they completed the task. In fact, post-test crew comments reflected the feeling that the incentive pay program was unnecessary. For this crew, the mission goals were incentive in themselves. This internalization of the mission objectives can probably be expected to occur with any crew of a high professional caliber.

The ability of the crew to perform most of the scheduled tasks in a significantly shorter time than allocated appears to be a result of the conservativeness of the initial time estimates and the rapid learning of procedures which occurred. Thus, the crew had too much residual free time. Further discussion on this point may be found in Section 3.5.

Table 3-6

LSS MAINTENANCE AND REPAIR TIME SUMMARY

Life Support Unit	Repair		Maintenance		Unit Totals	
	Items	Hours	Items	Hours	Items	Hours
Waste management						
Commode	2	0.7	2	5.5	4	6.2
Urine collector	8	14.3	0	0	8	14.3
Water Management						
VD-VF	20	19.9	1	4.0	21	23.9
Wick evaporator	0	0	4	0.3	4	0.3
Humidity control	3	1.2	30	15.0	33	16.2
Potable multifilter	3	5.3	1	0.3	4	5.6
Wash water recovery	18	4.1	1	0.7	19	4.8
Atmosphere purification						
Solid amine concentrator	33	30.1	14	3.3	47	33.4
Molecular sieve concentrator	7	3.7	1	0.7	8	4.4
Toxin control	0	0	0	0	0	0
Thermal control	0	0	0	0	0	0
Atmosphere supply and pressurization						
Sabatier reactor	20	18.6	0	0	20	18.6
Electrolysis (Allis-Chalmers)	47	26.5	0	0	47	26.5
Two-gas control	0	0	0	0	0	0
Mass spectrometer	0	0	5	4.1	5	4.1
Baseline two-gas control	0	0	0	0	0	0
Baseline two-gas sensors	0	0	1	0.5	1	0.5
Life support system totals	161	124.4	60	34.4	221	158.8
Maintenance performed by outside personnel	-9	-7.0				
Maintenance performed by onboard crew	152	117.4				

Quality of crew performance in maintenance and repair tasks is ultimately measurable by success or failure of the operation. In this sense, the crew was completely successful. However, a more sensitive gage of performance quality would consider their approach to the tasks. Interviews with staff personnel revealed an initiative and creativity in the crew that frequently contributed to the repair and subsequent return to operation of equipment after failures. This is true despite the unpleasant nature of many of the tasks. For example, in order to repair a malfunctioning float sensor in the VD-VF unit, the crew performed the task of draining the VD-VF boiler of 4 to 5 gallons of urine. This was placed in buckets on the floor in the equipment compartment. Similarly, a gage became filled with urine and had to be disassembled, cleaned, and reassembled. These particular tasks and several others were of such an undesirable nature that the staff had reservations about requesting them. The crew, however, volunteered to do them and successfully repaired the equipment.

Table 3-7

MISCELLANEOUS UNSCHEDULED MAINTENANCE AND REPAIR SUMMARY

Activity	Repair		Unscheduled Maintenance	
	Items	Hours	Items	Hours
Defrost refrigerator	0	0	9	4.5
Cleaned cabin floor	0	0	9	9.0
Cleaned dew pointer mirrors	0	0	4	1.5
Corrected leak in trash container	2	0.3	0	0
Repaired psychomotor pedal	1	1.0	0	0
Deactivated smoke alarm head	2	0.7	0	0
Repaired radiation monitor	1	0.3	0	0
Repaired particle counter	1	0.5	0	0
Replaced vidicon tube	1	0.5	0	0
Repaired TV coaxial cable	5	2.5	0	0
Installed intercom call light	1	1.0	0	0
Attempted repair of visual sensitivity tester	4	6.7	0	0
Totals	18	13.5	22	15.0

Another example displaying crew initiative and creativity dealt with an unanticipated failure of the Langley Research Center Complex Coordinator. On day 54, one of the pedal-return springs broke. After notifying the outside staff of the failure, the crew undertook and completed repairs without available spares. This was accomplished by cutting and stretching the failed spring. The repair was accomplished within 1 hour of the failure without outside assistance.

Such initiative was not without its drawbacks. In attempting to resolve a wash water problem, the crew decided to transfer a quantity of potable water into the wash water system without notifying the outside staff until the action had been completed. Subsequent staff evaluation concluded that the action had been ill-advised. A filter column replacement was required to provide a lasting correction of the problem.

3.1.4 Conclusions and Recommendations

Crew selection relies heavily upon human judgment and the intuition of the selection committee. No test or group of tests yet exists which is felt to provide quantitative data on the acceptability of potential crew members. Throughout the selection process, hypotheses as to acceptability must be continuously advanced, discussed, and re-evaluated. Thus, selection of the selectors looms as of paramount importance in successful selection of crew members for long-duration space missions.

Crew member candidates learned available material rapidly and thoroughly. This may be attributed to their high levels of intelligence and backgrounds in scientific fields related to SSS task requirements. Their interest and curiosity in all aspects of the program was maintained throughout the selection,

training, and test performance phases of the program and in most cases persisted beyond the conclusion of the test. It is felt that the original assumption concerning the advisability of selecting a crew from scientifically oriented graduate school populations has been supported. While a crew could possibly have been selected from non-graduate school populations, it is believed that these would have proven inferior by comparison.

The training program contributed to the success of the test in that the performance of the crew showed little of those characteristics of ineffectual training, such as operating indecision, poor or hasty procedural judgments, missed data, and overdependence on outside direction, especially as the mission progressed.

The training program must be flexible with respect to schedule and subject matter for long duration simulations of this type. The subgoals of these studies evolve throughout the preparation period. The equipment design and installation schedules must be altered and access periods to these units changed. All these contribute to changing the training curriculum in content and in schedule.

Thorough and complete maintenance training was not feasible before test initiation primarily because of scheduling problems and condition of equipment. Ideally, it might be advisable to develop training hardware, apart from operational hardware, to assist in overcoming this difficulty. Arguing against this is the obvious involvement and high level of interest displayed by crew members early in the test which at least in part may be attributed to the necessity for learning complex operational and maintenance procedures as the test was in progress. As this necessity waned, so also did crew morale. It is not known whether this was a causal relationship, but crew members expressed the belief that it was. In future tests it would probably be advisable to leave a certain amount of training for the operational situation. For this to be feasible, all critical tasks must be identified to assure that training on these tasks is accomplished to near perfect proficiency, thus assuring the success of the test.

Cohesion training seems to have been effective in reducing the frequency and severity of intercrew difficulties. Post-test interviews suggest that crewmen would have preferred to have had greater exposure to cohesion training. This finding is consistent with results obtained on the 60-day test concluded in 1968.

Performance of the crew was excellent in accomplishing the normal operation of the systems and in the successful completion of the many repair and maintenance tasks. All scheduled events were met and the few procedural mistakes that occurred were insignificant in frequency and effect. The crew enthusiastically undertook almost all the operational and maintenance tasks.

It was found that a trained and motivated crew will perform unpleasant and arduous tasks with no complaints when they are fully aware of and thus involved in what is being attempted and why. The crew preferred to be informed as to the purpose and rationale of all tasks, resisting those which were apparently not producing the desired results.

The financial task incentive program appeared to be unnecessary during this test program.

Autonomy in system maintenance and repair was strongly desired by the crew. This requires extensive training of the crew and confidence in their ability by the staff. In the absence of either, the procedural constraint of discussion with staff is essential and may also be required to obtain the performance data necessary for equipment evaluation. Data from the NIPA program (Section 3.9) correlating the drop in crew morale with a decrease in interactions between outside staff and crew members tends to indicate that increased autonomy may not be entirely beneficial.

Almost all crew procedural errors in systems operation may be attributed to the lack of consideration of the human element in the layout of controls and displays. Design specifications to contractors for the development of hardware to be included in future integrated LSS test programs should include a human factors engineering requirement and a demonstration of compliance.

The evaluation of crew task performance from manually recorded data was very cumbersome and slow. Techniques should be developed for automatic collection of these data, or at least computerized recording, as was done for NIPA (Section 3.9). If manual recording is necessary, assignment of the task should be given to personnel having no other responsibilities rather than to the communications monitor on duty.

An almost unanimous recommendation of communications monitors, applying especially to the 0800 to 1600 shift, was that communications duties combined with manual recording duties constituted a work overload which might be alleviated by reducing the duty period to approximately 4 hours. Behaviorally, this became apparent early in the test and efforts were made to provide communications log recording personnel to assist the communications monitor during heavy workload periods. The need for such relief personnel became significantly less after the test midpoint because of fewer equipment malfunctions and the increasing competence of the onboard crew to semiautonomously deal with difficulties which had, by that point, come to be thought of as routine.

3.2 STAFF SELECTION, TRAINING, AND CERTIFICATION

This section describes the selection, training, and evaluation of personnel required to support the operation of the simulator and associated facilities. These personnel, located in the control room area, adjacent to the SSS, were responsible for operating and maintaining the facility, monitoring and ensuring crew safety, and effecting those procedures that ensure mission performance with the required data collection and analysis.

The SSS staff consisted of twenty men comprising four rotating shifts of five men per shift to provide 24-hour daily coverage during the 90-day test. MDAC personnel filled four of the five positions and a contract physician filled the fifth position. All MDAC staff positions were assigned to personnel who were either already responsible for specific onboard equipment or who were believed to have the background necessary to filfill the position requirements. That staff selection was adequate is evidenced by the successful completion of all assigned staff roles.

3.2.1 Staff Selection

The selection of each staff member was the responsibility of the director of the discipline involved in the function, with final approval by the Program Manager and Chief Engineer of the Advance Biotechnology and Power Department. The goal of the selection was to minimize subsequent training needs and to produce an autonomous crew for each shift. Coordination among management personnel assisted in the identification of knowledgeable crews across disciplines.

3.2.1.1 Procedure

Staff roles were analyzed and subsequent requirements are described in the Test Plan (NASA CR 111882). A pool of potential qualified personnel was made available to each discipline director and selection was made from this pool.

Five men were selected and trained for each of the staff positions of communications monitor, engineering monitor, test conductor, and electromechanical technician. This provided one spare, trained man for each position to provide emergency coverage. Medical monitors were supplied from a contract pool of licensed physicians. Their training was supervised by the Test Medical Director and is described in Section 4. These permanent support roles were further augmented throughout the program by Principal Investigators, Project Management, and NASA-LRC resident personnel.

Communications monitors were given screening tests identical to those used for initial onboard crew screening. The communications monitor task was central to all inside-outside communications and thus necessitated a compatible individual for the role. Attempts were made to match characteristics of the communications monitors with those of the onboard crew to minimize personality-based incidents of intercrew hostility. Final selection of the communications monitors was by the Behavioral Director, with the agreement of the Program Manager, and utilized all selection information available.

Test conductors and engineering monitors were selected by the Program Manager on the basis of experience, system knowledge, and specialty area. Shifts assignments were made to equalize distribution of areas of specialty across shifts. Test conductors were responsible for the overall functions of the staff, test protocols, and the operation of the SSS and facility. The engineering monitor had overall responsibility for operation of the life support system.

Electrical/mechanical technicians were selected from SSS support personnel by the Chief of the Biotechnology Laboratory. They were responsible for the maintenance of the test facility and data acquisition equipment.

Medical monitors were selected by the Medical Director and had responsibility for provision of immediate medical support in the event of an emergency.

3.2.1.2 Results of Performance

The four shifts of four men each (excluding the medical monitors), worked 21 days on and 7 days off. This enabled an equal distribution of days worked among the shift personnel and also was consistent with MDAC policies.

It is difficult to assess the success of the selection process in a quantifiable fashion. The staff personnel performed their assigned roles to the satisfaction of all concerned. Comments elicited from the onboard crew concur in the main with few minor exceptions. These exceptions concerned things like slow response time to information requests from the crew and were generally not related to the technical proficiency of the staff members.

Insofar as the psychological aspects of staff performance is concerned, the crew/staff relationship was satisfactory and productive. When problems developed with the onboard systems the usual technique of handling them was for the crew member to contact the communications monitor who then put the engineering monitor on line with the crewman. If discussion between these two failed to resolve the problem, then the specialist for the equipment in question was contacted and the problem was resolved. Occasionally, a caucus would have to be held by the staff members. The subsequent delay in feedback when they remained uninformed as to the events taking place would sometimes irritate the crew. Fortunately, this was the exception rather than the rule.

The irritation or hostility that did occur during the run was minor in nature. Crew hostility was invariably directed at the workings of the system rather than at a specific individual. Although it was never detected or reported by the communications monitors, the crew stated in debriefings that they occasionally used the communications monitors as "scapegoats." It was evidently felt by the crew that directing hostility at, or expressing hostility to the communications monitors to the exclusion of other staff members was an approved outlet. This is consistent with findings from other similar confinement and/or isolation studies.

3.2.2 Training and Certification Program

The training and certification program provided the mechanism whereby the individual staff member could be adequately trained to function in his assigned position. Additionally, enough cross-training was provided to understand the functions of the other members and to perform their duties in the event of an emergency.

Prior to implementation, the program received management review and, upon its completion, the operating staff members were formally certified. Successful completion of the program resulted in four certified operating staff teams and four backup members.

3.2.2.1 Procedure

Training for the operating staff, except for the medical monitor, was an interdisciplinary function. It was conducted in accordance with the plan outlined in

CR 111882, Section 9. Most of the MDAC personnel available had experience from past tests in one or more phases of mission accomplishment. As the staff members required considerable cross-training in several areas, specialists in each discipline were assigned to develop curricula, give lectures, and direct practice sessions so that each staff member would meet appropriate proficiency levels for the 5-day and 90-day manned tests.

There were varying degrees of cross-training required among the staff members. For some general operations, the test conductor, the communications monitor, and the engineering monitor had to be able to interchange positions with equal effectiveness. The engineering monitor had to be able to substitute for either the test conductor or communications monitor if they had to leave their stations. Emergency training required cross-training so that there would be an assurance of high reliability in the execution of various modes of test operations. Nine specific training courses were developed. Each consisted of classroom sessions and practical, on-the-job instruction. The courses, their duration, and the required operating staff attendance are indicated in Table 3-8. The curricula, lectures, and handout material for each course were developed by specialists in the discipline involved. Section 9 of the Test Plan (CR111882) describes the objective, outline, and certification criteria for each course. Upon successful completion of the training program, each staff member was certified. Formal records (Table 3-9) were prepared which indicated the courses successfully completed and the position(s) for which each staff member was certified.

3.2.2.2 Results

The operating staff training and certification program were considered adequate. The practical or on-the-job portions appeared to be more valuable than the classroom sessions. This may have been because the on-the-job portions were conducted when all systems were completely or nearly completely finalized, while the classroom portions occurred much earlier in the program. Handout material, prepared by each instructor for his particular course, proved of great value. This material was used not only as a training aid, but, after assembly into appropriate notebook form, as a reference manual for use throughout the test.

3.2.3 Conclusions and Recommendations

Selection of the outside staff was by all measures successful. The technique of having the director of each discipline select individuals to fill the various staff roles worked very well. Training needs were minimal and personnel participation was enthusiastic. Selection of the communications monitors for affability and tolerance was justified.

A staff debriefing was held at the completion of the test. The intent of the debriefing was to gather information and recommendations that might be of value in future studies of this nature. The following areas were covered:

A. Work Schedule--There were no strong objections to working the 21 days on and 7 days off schedule, but most agreed they would have preferred to work less than 21 days consecutively. Most staff members had great

Table 3-8

STAFF TRAINING COURSES

Course	Operating Staff Position: Test Conductor	Communications Monitor	Engineering Monitor	Technician	No. Students	Course Duration* (Hours)
SSS familiarization	X	X	X	X	20	4 (1)
Communications control console	X	X	X		15	8 (7)
Life support monitor console	X		X		10	8 (4)
Gas analysis console	X		X		10	12 (8)
Test conductor console (chamber operations)	X		X		10	8 (6)
Lock control console (lock operations)	X		X	X	15	2 (1)
Data systems operations	X	X	X		15	4 (2)
Maintenance procedures	X		X	X	15	8 (6)
Operating procedures	X	X	X	X	20	12 (8)

*( ) Represents number of hours of practical instruction per course

Table 3-9

SSS FACILITIES OPERATION TRAINING AND CERTIFICATION RECORD

Name:_____ Loc/Dept:_____ Emp No:_____

I (we) attest that the individual named above has successfully satisfied the criteria established for the following course(s):

Course	Instructor	Date
SSS Familiarization		
Comm. Control Console		
LSM Console		
Gas Analysis Console		
Test Conductor Console		
Lock Control Console		
Data System Operations		
Maintenance Procedures		
Operating Procedures		

In view of the above, I hereby recommend certification of this individual for the following operating staff position(s):

_____

_____ _____

Date Training Coordinator

I hereby certify this individual is qualified to perform the function of the aforementioned position(s).

_____ _____

Date Branch Chief, Space Simulation Lab

Endorsed by: _____

Training Director
Space Station Simulator Program

_____	_____	_____
Program Manager Space Station Simulator Program	Chief Engineer - Advance Biotechnology & Power Sys.	Medical Director Space Sta. Sim. Program

_____

difficulty in adjusting to the third, i. e., 0100 to 0800, shift. Adjustment would be expected by the end of the second week, according to the literature, but rarely seemed to occur in fact.

B. Communications--An audio recording system was recommended for the quick recording of problems and important information. Handwritten accounts were usually so condensed as to be very difficult to understand and lengthy shift overlap would result.

C. Logs--A log for each life support unit or system maintained by each principal engineer would be of value in determining system history and status. A clear and concise definition as to what entries are to be made in each log is necessary.

D. Communications--A TV monitor and selection capability at the engineering monitor and test conductor work stations would eliminate unnecessary conversation with the communications monitor.

E. Accommodations--An area should exist outside the control room for principal engineers to discuss and analyze system performance with the crew without interfering with test operation. This area should have a TV monitor, intercom tie with the communications monitor and data display.

The effectiveness of staff training was very good but some shortcomings were noted. These included:

A. More training and operational experience should be given the engineering monitor and test conductor on overall system operation. Each man was typically a specialist in operation of one or more of the subsystems, but many procedures important to overall system efficiency needed to be worked out during the early part of the test.

B. Cross-training of these men in each other's areas of interest should be increased. This would have enabled more rapid detection and diagnosis of equipment problems when the principal investigators were not present.

C. Cross-training of the inside crew and outside staff would have improved the appreciation of each group for the duties, responsibilities, and capabilities of the other.

3.3 HABITABILITY EVALUATION

An overview is provided of the more outstanding findings regarding crew reaction to the environment afforded within the SSS during the 90-day confinement. Such areas as lighting, clothing, acoustic environment, and responses to the onboard habitability inventory questionnaire are discussed.

An examination of crew responses indicates that the environment adequately supported the habitability needs of the four crewmen. In those instances where difficulties were apparent, recommendations are offered for design alteration in future missions.

3.3.1 Procedures

The primary source of habitability data was the habitability inventory questionnaire, consisting of over 60 items, which were subjectively rated by the crew throughout the 90-day test, at 2-week intervals. The questionnaire is included in Appendix C. Responses were converted to a numerical rating scale extending from 4.00 for the poorest items through 1.00 for the best. All crewmen responded to each item in the questionnaire. Questionnaire responses were divided into mean responses for various significant compartments or facilities in the chamber. For example, all questionnaire items relating to the equipment quarters are contrasted with all questionnaire items relating to the hygiene area. Other area groups included the crew compartment and miscellaneous facilities.

Supplementing these subjective evaluations were quantitative measurements taken before, during, and after the test to establish reference data. These included visual evaluations of wear and tear, measurements of sound and light levels, and engineering data such as compartment temperature and humidity. Also contributing to the evaluation were observations of recreational activity performed during the test. A post-test debriefing of the staff and crew provided the opportunity to clarify some of the comments and explain in detail crew reactions to many of the habitability provisions.

3.3.2 Results

The overall results of the habitability inventory questionnaires, averaged over the 90-day period (seven sets), and grouped by major areas, are shown in Figure 3-4, which displays the relationship among various areas and provides quantitative information on the overall habitability of the SSS. Also plotted is the mean habitability as a function of time which shows the progress of adaptation of the crewmen to the environment.

Of all the compartments within the chamber, the crew quarters was the most acceptable. The acceptability of the crew quarters was followed by the acceptability of the equipment compartment after an initial 3-week adaptation period. While the crew quarters displayed a trend toward greater acceptability as time increased, miscellaneous features of the facility displayed a reverse trend. After the first 3 weeks of adaptation, the hygiene area displayed no significant trend.

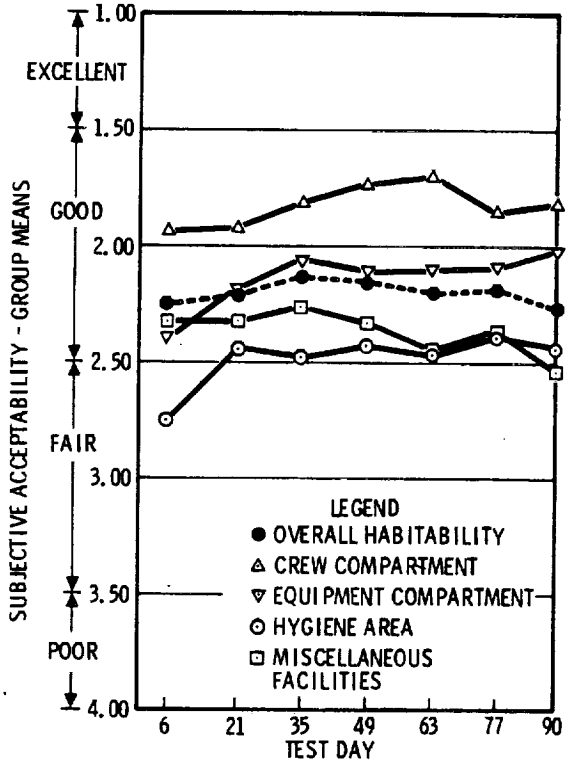


Figure 3-4. Habitability Inventory

Those areas initially judged to be least acceptable showed a rapid adaptation to a nominal level that tended to stabilize while those areas which displayed a higher initial acceptability show a gradual improvement over a longer duration. This can be seen in the difference between the curve for crew quarters compartment acceptability and that descriptive of the hygiene area. No area, while initially acceptable, showed decreasing acceptability as a function of mission duration. The overall mean for habitability over time shows an initial acceptability rising over the first 6 weeks and then gradually declining. This curve is affected to a large extent by the downward trend in the miscellaneous facilities.

3.3.2.1 Relative Acceptability of Habitability Features

Crewmen's individual responses to various inventory items were averaged over the 90 days and an item comparison was accomplished permitting the development of the habitability inventory item ranks (Table 3-10). Of 57 items indicated in the table, 55 fell within the fair through excellent range while only 2 were ranked poor. Various reasons were offered by crewmen for their rankings.

The floors were rated as the worst item with a score of 3.96 out of a possible 4.00. The reason for such a poor rating was not because of a structural inadequacy, but because of the floor covering, which was a material spray-painted onto the surface of the cold-rolled steel substrate. The Fluorel material was sprayed over a General Electric silicone primer and displayed very poor

Table 3-10

HABITABILITY INVENTORY ITEM RANKS (90-DAY GROUP MEAN VALUES)

Accept	Item	Mean Accept. Score	Rank Order	Accept	Item	Mean Accept. Score	Rank Order
1.00	Food storage	1.09	1		Haircut/shave	2.16	30.5
	Microwave oven	1.12	2		W/R Schedule	2.16	30.5
	Equip. compt gen vol	1.18	3	Good	Crew compt eff temp	2.20	32
	Crew compt light	1.21	4		Bunk lights	2.30	33
	Equip. compt light	1.29	5.5		Equip. compt eff temp	2.39	34
	Crew compt privacy	1.29	5.5		Fecal collector	2.41	35
	R&D chairs	1.30	7		Lab layout	2.42	36
	Crew compt volume	1.31	8	2.50	Bedding	2.50	37
Excellent	Equip. compt S vol	1.32	9				
	LRC-CC	1.43	11		Intercom/int	2.54	38
	Freezer	1.43	11		Food prep area	2.55	39
	Gen storage vol	1.43	11		Rater	2.58	40
1.50	Crew compt vibr	1.45	13		CTT	2.59	41
					Internal PA	2.60	42
	Dryer	1.54	14		Washer	2.64	43
	Ergometer	1.57	15		Bunks	2.66	44
	Towels	1.62	16		Electric oven	2.70	45
	Debris volume	1.64	17		ENT Headset	2.77	46
	Bunk area privacy	1.87	18		Intercom/out	2.80	47
	Eating utensils	1.89	19		Equip. compt noise	2.89	48.5
	Hygiene noise	1.93	20		Body hygiene	2.89	48.5
	R&D table	1.96	21.5		Equip. compt wk space	2.93	50
	Crew compt noise	1.96	21.5		Equip. compt wk L/O	3.05	51
	Refrigerator	1.98	23		PBI blankets	3.09	52
	Tools	2.07	25		Personal stor vol	3.11	53
	Clothing	2.07	25		ENT Speaker	3.25	54
	Equip. compt vibr	2.07	25	Fair	Urine collector	3.32	55
Good	Ladder	2.08	27				
	Rec provs	2.10	28		Pico projector	3.77	56
	PJ's	2.14	29		Floors	3.96	57
				3.50			
				Poor			
				4.00			

adhesion from the beginning of the test. As time progressed, crewmen removed significant portions of the floor covering material to reduce the annoyance of the peeling floor covering material. Of approximately 1,400 sq ft of material applied to the substrate before the test, about 500 sq ft remained intact on the floor at test completion. The remaining material was in very poor condition with many holes and tears through to the substrate.

Adhesion problems were probably the result of a long delay (approximately 2 months) between application of the primer and application of the Fluorel overlay. During this 2-month period, the primer became overly dry and coated with dust. Although attempts were made to clean and prepare the primer surface before application of Fluorel, they were apparently inadequate. Where adhesion was adequate, the material displayed satisfactory resistance to surface abrasion. Tears and holes in the flooring resulted from subsystem installation before test initiation and were rarely caused by onboard personnel during the test.

The Pico projector, also rated "poor," was a device supplied by the University of Chicago permitting compact storage of chromatic reading material, retrieval of this material, and display. The reason for its poor ranking resulted from a problem in the equipment design such that focusing of the display could not be properly accomplished. The inability to display the material resulted from the inadvertent insertion of a shim in the lens system during assembly at the University of Chicago. Insufficient operation instructions existed for either project personnel or onboard crewmen to remedy the situation. Had the information been available, the situation could have been corrected and the Pico projector no doubt would have received a higher ranking.

The urine collector received a low ranking simply because it malfunctioned and was not repairable. The failure occurred during the first week of the test, after which urine collection was accomplished through the use of graduated cylinders. This was an obviously unsatisfactory system for the collection of urine, but provided individual data on urine outputs that would have otherwise been unavailable.

Throughout the section characterized as fair may be seen numerous references to the inadequacies of the audio support equipment available to the crew either for communication with outside personnel or for recreational purposes. The cause of these inadequacies was low audio fidelity and pickup and transmission of ambient noise. This is a surmountable design problem which should be given increased attention in any future missions.

The appearance of the electric oven in this section yields the impression that it was relatively less desirable than the microwave oven for food preparation. In fact, the electric oven was not used at all for food preparation. Data are available which indicate it was used no more than six times during the test and then only for the desiccation of some biological samples.

PBI thermal-knit blankets presented difficulties in use by the crew. The primary reason for these difficulties was that they tended to slide off the bunks. Since they were required for thermal comfort, this was an unacceptable feature. Crew members sewed or pinned the blankets to Durette bedding to prevent them for sliding off the bunks during sleep. In addition, the crew recommended the use of heavier blankets for future missions under these thermal conditions.

Of all the storage volume allocations, personal storage volumes were least acceptable. The reason for the lack of acceptability of personal storage volume provisions is that they had been grossly under-estimated and their location was inconvenient.

At the other end of the acceptance scale, storage requirements for food were satisfactory; the microwave oven was extremely well accepted as a means of reheating previously prepared freeze-dehydrated food; volumetric provisions in the equipment quarters were adequate; and light levels for the crew and equipment quarters were adequate. The latter finding reflects the ability of the crew to alter and adjust lighting conditions for 60 days of the mission and resulting perfect acceptance (ratings of 1.00).

In contrast with previous studies, the habitability inventory indicates that privacy provisions were satisfactory and crew compartment noise characteristics were acceptable. Privacy was viewed by the crew as ability to be or feel alone without interference by other crew members. Thus, for this crew, privacy was attainable for the individual without regard to physical provisions for isolation. At times, privacy was accomplished for each while all four were seated at the dining table; each engaged in a different activity with no interactions evident. Except in the bunk area where additional bunk isolation curtains were recommended, privacy needs were felt by crewmen to have been satisfied.

The Langley Research Center Complex Coordinator received a rating within the excellent category. This is gratifying when contrasted with findings with similar missions under similar circumstances on other devices in which crewmen discontinued performing psychomotor tasks as mission duration increased. The crew continued to perform on this device throughout the 90 days with performance showing marked improvement throughout. Subjective comments of the crew indicated they enjoyed this device, not as a means of measuring their psychomotor performance, but as a test of skill. They enjoyed competing with their own times to improve their performance.

3.3.2.2 Personal Hygiene

The body hygiene facilities were rated rather low (48 of 57 items). This is supported by post-test comments of the crew that the wash cloth bathing method was less than adequate.

Particular difficulties mentioned by crewmen after and during the test were the feeling of oiliness as a residual to the use of Basic-H detergent which was the sole cleansing agent. This was reported despite the use of approximately 2 gallons of wash water per day by each man. Another difficulty with body hygiene cited by the crewmen was the dripping of excess water onto the floor area immediately in front of the sink as a consequence of wash cloth bathing.

In contrast, oral hygiene facilities were acceptable to the crew. Tooth brushing was accomplished using Oral B-60 brushes and "Nasadent," an ingestible toothpaste supplied by the NASA-MSC. Table 3-11 indicates the composition of this dentifrice. Of 2.26 kg (80 oz) supplied in 20 metal tubes, 1.59 kg (56 oz) were used during the test. This is equivalent to 0.045 kg (0.16 oz) per man per day.

3.3.2.3 Recreational Provisions

The low ranking (28) of recreational provisions on the habitability inventory indicates a mismatch in recreational provisions with the needs of the crew. This is corroborated by post-test crew comments as well as observations made throughout the mission. Because of a low level of interaction and because of personal proclivities, the crew chose not to employ the games which were available to them for recreational purposes even though they had been supplied at crew request. Rather, for recreation they engaged in individualistic activities such as reading, listening to music, creative writing, and watching television.

Table 3-12 lists recreational provisions available to crew members throughout the test. Each provision is rated on the basis of an estimate of its utilization (1 to 4; heavy to unused). Estimates are based upon observations of communications monitors. Within this table may be seen references to exercise provisions and the LRC-CC (Item 2). Although not originally intended as recreational provisions, these came to be employed as such as time progressed. Post-test debriefings and comments obtained by the Medical Director during the test reveal that exercise was employed competitively by one crew member; he attempted to improve his physical condition to the extent necessary to outperform another. Although this was never accomplished, a significant amount of time was used in the attempt. In a somewhat similar manner, all crew members continued to improve their scores on the LRC-CC (psychomotor tester). This device did not lend itself to intracrew competition because certain members of the crew could always be expected to outperform others. Competition was limited to competition with one's own scores, from which the crewmen appeared to derive sufficient satisfaction.

Table 3-11

"NASADENT" CONSTITUENTS

Ingredient	Weight kg	Weight oz
Glycerine	0.950	(33.9)
Stannous Fluoride, SnF_2	0.050	(1.8)
Sodium Carboxymethylcellulose, NaCMC	0.025	(0.9)
Flour pumice	0.960	(34.3)
Zirconium silicate, $ZrSiO_3$	0.480	(17.1)
Peppermint oil	0.016	(0.6)
	2.481	(88.6)

Table 3-12

RECREATIONAL PROVISIONS

1. Bicycle ergometer (2)
2. LRC-Complex Coordinator (3)
3. AD-Lib Exercise (2)
4. Commercial TV (1)
5. Commercial FM (2)
6. Commercial AM (3)
7. 16-mm motion picture film (projected from SSS exterior) (2)
8. Reading materials (20 books/man) (1)
9. Writing materials (1)
10. Art supplies (charcoal and water colors) (3)
11. Board games (chess, checkers, Scrabble, Monopoly, and Stock Market) (3)
12. Playing cards (4)
13. Dice (4)
14. Prerecorded musical tapes (2)
15. 16- and 35-mm cameras and film (2)
16. Musical instruments (harmonica, recorder) (3)
17. Pico-projector library (4)

Legend: Daily utilization based on duration

1 = Heavy; 2 = Moderate; 3 = Light; 4 = Unused

An interesting comment, obtained during post-test debriefings, revealed somewhat more about competition and recreational games. Apparently, competition based solely upon intellectual competence was viewed as too threatening to be employed. Preferably, competitive situations should provide a technique for "face-saving" by the losers of the competition. This

was cited as the reason why purely intellectual games were rarely, if at all, used. Preference was given to games in which the element of chance played a significant part. Such a game was "Scrabble" which allowed "face saving" due to the chance selection of letter-tiles. "Scrabble" was the most frequently employed (5 times) of the board games provided. Three to four crew members were engaged in its use when it was employed.

Most of the diverse recreational provisions were not heavily employed. This crew preferred dealing with LSS problems to recreation. When these decreased in incidence, morale declined. This relationship may not be entirely coincidental. The variety of recreational materials did not significantly assist in maintaining morale in this test.

3.3.2.4 Clothing

Onboard crew clothing consisted of three types: Durette (MDAC furnished), PBI, and Teflon. The latter two clothing types were supplied by NASA-MSC, Crew Systems Division, for evaluation by onboard crewmen. Material weights ranged from 3.75 oz/yd^2 for the Durette through 8.75 oz/yd^2 for Teflon. PBI materials were supplied in intermediate weights.

All clothing received consistently good acceptability responses from crewmen except the Teflon garments, which were described as too heavy, too warm, and somewhat clammy in the environment. Crewmen preferred the weight of the Durette clothing supplied, feeling that it was consistent with the clo values required in the environment. PBI and Teflon garments were preferred over Durette garments from the viewpoint of adequacy of tailoring. The primary difference between the tailoring of the two types of garments was a fullness of the PBI garment and a close, tight-fitting configuration in the Durette garments.

Durette clothing materials initially showed what appeared to be excess surface wear and exhibited "balling" of materials on the surface. These were the result of frequent contact with abrasive surfaces. This "balling" effect proved to be of no significance in the overall wear characteristics of this material. PBI garments displayed a "balling" effect also, but considerably less than Durette. PBI materials also wore quite well.

Clothing was laundered onboard using a portable clothes washer and a small electric dryer. The detergent used for all laundering was Basic-H. At the conclusion of the mission, an inspection of the clothing revealed that Teflon and Durette displayed more retained discolorations than PBI. Apparently, Basic-H serves as an adequate stain remover for PBI, but not for Durette or Teflon.

3.3.2.5 Acoustic Environment

Criteria for the acoustic environment within the SSS were provided by NASA. They consisted of noise criteria adjusted (NCA) curve 60 for the equipment quarters and NCA 50 curve for the sleep quarters (Reference 3-10). Figure 3-5 presents the NCA plots for the octave bands from 45 through 11,200 Hz. Comparing the criteria with obtained values measured onboard

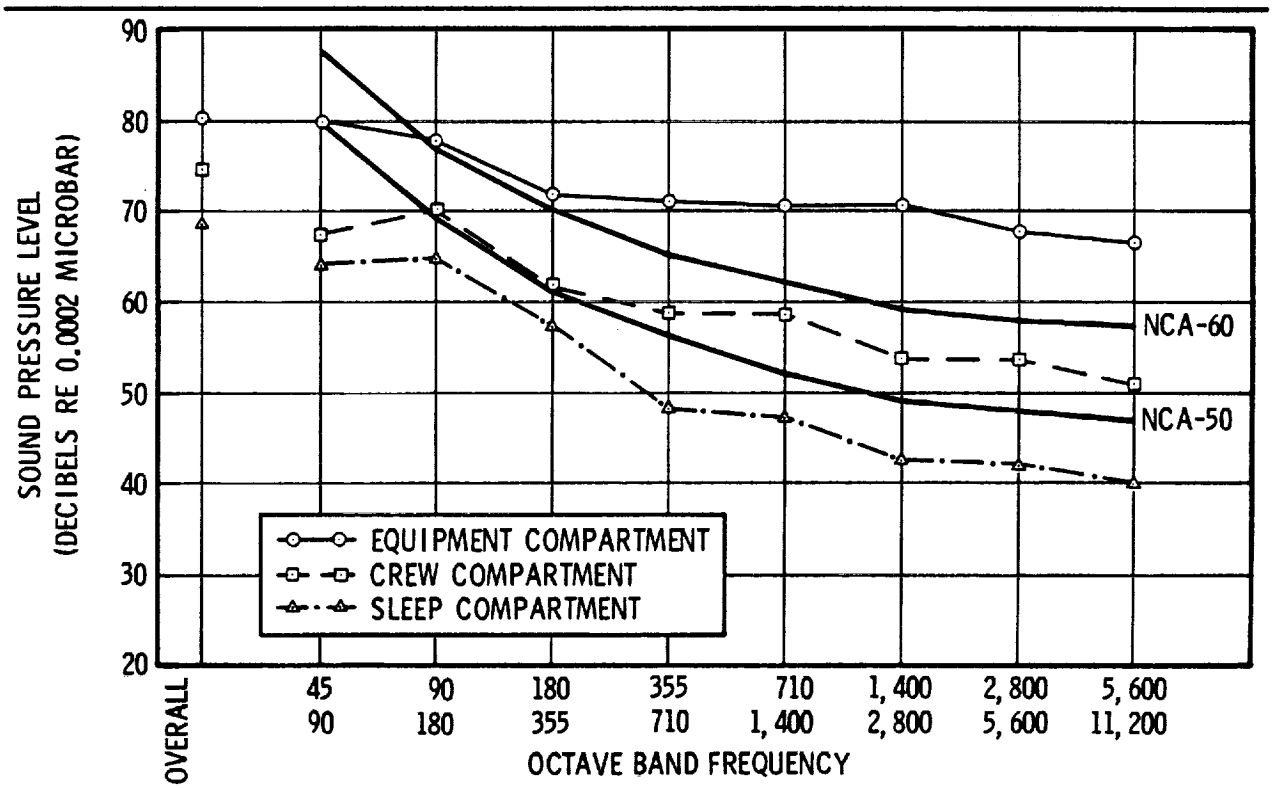


Figure 3-5. Acoustic Spectra and Criteria

during the 90-day test indicates that the sleep quarters, with an overall sound pressure level of 69 db, was well below the requirements imposed by NCA 50. The crew quarters more than satisfied the requirements imposed by NCA 60. The equipment quarters exceeded the NCA 60 requirements on 7 of 8 octave bands. The equipment quarters and the crew quarters were separated by a bulkhead to attenuate acoustic transmissions which affected an approximate 6-db attenuation on the basis of overall sound pressure levels and as much as a 15-db attenuation in selected octave bands.

Crew responses normally indicated that ambient noise levels were acceptable, but random crew and equipment sounds, audible above background levels, were major irritants during sleep. There was also some irritation due to sound levels in the equipment room. Additional data on acoustic studies is presented in Section 3.6 and Reference 3-11.

The data reported in Reference 3-11 were collected after the conclusion of the 90-day test. Figure 3-6 provides representative data from this reference on airborne noise in the crew quarters in the frequency range from 10 Hz to 40 kHz at a position between the onboard laboratory and the waste management area. Except for deviations at the 100 to 200 Hz and 350 to 550 Hz points, the pattern is one of decreasing power (db) with increasing frequency. Comparing this figure with Figure 3-5 shows a general correspondence at comparable frequencies. Detailed comparisons of data from both of these curves is tenuous because atmospheric pressure and chamber closure were

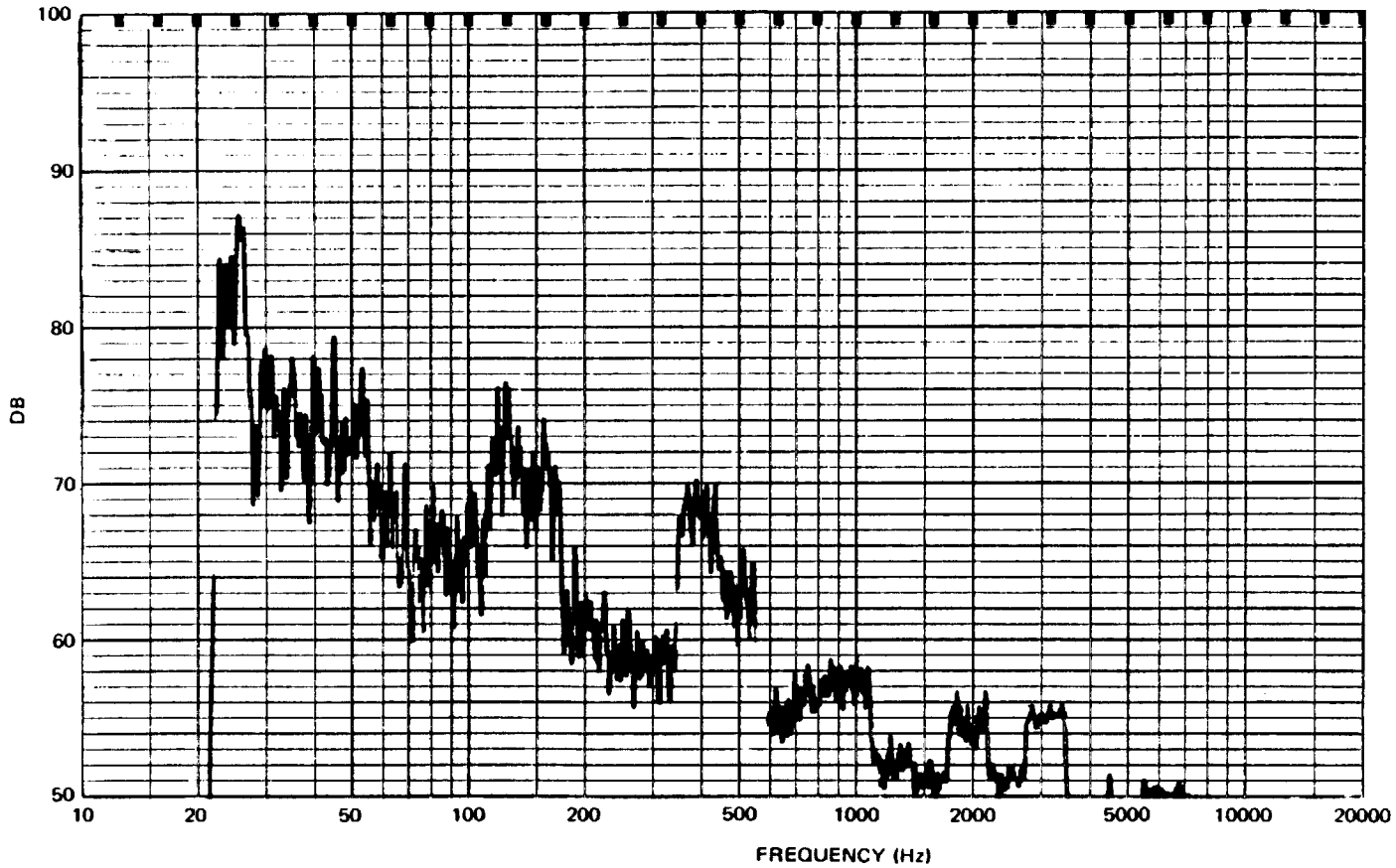


Figure 3-6. Acoustic Noise Background Recorded in the Crew Quarters With Equipment On

not identical for both sets of data. The data obtained in Figure 3-6 were collected while the atmospheric pressure was at 1 atmosphere, and the SSS airlock door was open. Measurements presented in Figure 3-5 were collected at 10 psia with the SSS airlock doors closed. Reference 3-11 provides further data on acoustic frequencies from 10^3 to 10^5 Hz measured under conditions of physical contact with noise sources. Throughout the 90-day test crew reactions appeared unrelated to frequencies above the auditory spectrum (>20 kHz).

3.3.2.6 Lighting

A lighting experiment was conducted using flourescent fixtures with adjustable controls. During the first 30 days of the test, the crew was required to live under lighting conditions closely approximating those expected onboard Skylab A. Reactions of the crew to these conditions were solicited during this period through use of the habitability inventory. During the middle 30 days of the test, the crew was encouraged to "experiment" with various light levels and to attempt to select the most desirable levels for their tasks. During the last 30 days of the test, the crew was asked to adhere to the light level they had selected as most desirable during the middle 30 days. All procedural requirements were met including onboard weekly measurement of light values. Table 3-13 summarizes the findings of this evaluation. Final settings reflect an approximate fourfold to fivefold increase in light levels compared with Skylab values. These reflect subjective preferences, not task illumination requirements.

Table 3-13

ILLUMINATION RESULTS

Location	Mean Intensity (foot candles)	Range
Minimum Skylab Levels		
Wardroom	5.0	
Waste management compartment	9.0	
Experiment area	5.5	
Skylab Levels as Set in SSS		
Crew compartment	6.6	4 to 9
Waste management compartment	10.0	
Equipment compartment	4.0	3 to 8
Final Levels as Set by Crew		
Crew compartment	30	16 to 36
Waste management compartment	36	
Equipment compartment	17	11 to 24

3.3.2.7 Interior Decor

Responses elicited during and after the 90-day test regarding features of the decor indicated that crew members would have preferred an environment decorated more as living quarters than as a modified laboratory. Almost unanimous agreement was reached on the recommendation that the design of living quarters should promote feelings of warmth by: (1) providing a sharp distinction between living quarters and laboratory or equipment areas; (2) utilizing decorative materials which provide enrichment of visual and tactual perceptual gradients, such as wood-grained paneling and carpets. Other comments dealt with the desire to have a capability of modifying features of the decor to provide greater interest in surroundings and to provide acoustic and visual isolation of bunks to permit greater use of bunks while other crew members slept. Under conditions of the test, an awake member in his bunk, using personal lights and turning pages, could be expected to disturb a sleeping crew member in an adjacent bunk.

3.3.2.8 Thermal Environment

Characteristics of the onboard thermal environment have been presented in Section 2. In terms of crew reaction, the crew quarters was somewhat preferable to the equipment quarters throughout the mission. Habitability inventory scores showed poorest acceptance of the thermal environment on days 6, 35, and 49 with relatively better acceptability on days 21, 63, 77, and 90. Complaints on these items in the habitability inventory centered upon excess humidity, undesirably high air flows in the bunk area (which were altered by onboard crewmen), condensation of moisture on cold surfaces (especially above the bunks), and high temperatures and humidity in the equipment quarters when high work outputs were required in that compartment.

The apparent inadequacy in thermal accommodation can be accounted for to a large extent by insufficient provision for the thermal and humidity loads imposed by the solid amine CO_2 concentration system. These loads were not predicted before the test start, and were therefore not included in the thermal control design requirements. Thermal and humidity load factors for this advanced subsystem were unavailable from the manufacturer at the time of its integration into the life support system.

3.3.3 Summary and Conclusions

All available evidence suggests that the vast majority of habitability provisions were well within the range of acceptability for the crew.

Factors have been identified which may be crucial to the acceptability of a habitat. These are:

A. Crew motivation

B. Crew adaptability

C. Duration of habitat utilization

D. Initial acceptability of accommodations

Complaints about habitability provisions were relatively quite rare during the test and usually were made in response to specific requests for evaluation. Most of the adverse comments were associated with areas in which the technical application was poor. Examples include the peeling floor, the Pico projector, and the audio system fidelity. Further conclusions in specific areas may be drawn as follows:

A. Personal Hygiene—Wash cloth bathing was acceptable, but a shower bath would have been appreciated by the crew. Lacking a shower, an area should be provided in which dripping during bathing would be acceptable. The ingestible dentifrice supplied by NASA was acceptable.

B. Recreation—Although a variety of provisions were included, this particular crew tended to use recreational methods involving solitary participation rather than group action. The variety of provisions did not alleviate a decline in morale, although it may have accommodated unexpected changes in taste that occurred after the test started, since the selection was influenced strongly by pretest crew preferences of recreational provisions.

C. Clothing—Tailoring of garments toward "fullness" is more desirable than tailoring oriented toward close fit or "style." Lighter weight materials were more acceptable than the heavier weight materials. All tested materials display sufficient abrasion resistance to be acceptable for test durations of 90 days. Laundering detergents must be matched not only to water recovery systems but also to clothing materials.

D. Acoustics—Crew response to noise levels indicated that the sleep area was the most acceptable from the standpoint of ambient noise. The crew quarters was next in acceptability. Least acceptable was the equipment compartment. Acceptance was inversely related to noise levels.

   More irritating than background noise were noises of other crewmen and equipment. These sounds were reportedly capable of awakening sleeping crewmen. This points to the inadequacy of acoustic isolation of the bunk area despite the overall attenuation of background noise.

E. Illumination—The crew definitely preferred light levels of a higher intensity than Skylab. It should be noted however, that no onboard tasks suffered as a result of using the Skylab levels. Accordingly, it may be concluded that the Skylab light levels are adequate for crew operations if auxiliary lights are available for those tasks with high acuity requirements. Given a situation wherein electrical power limitations are not as severe as Skylab, it would be desirable to use the higher levels.

F. Interior Decor—Provisions must reflect the needs of previously established habits of living. Greater attention should be given to the personal desires of potential occupants if satisfaction with the decor is to be expected. Personal desires will probably result in recommendations of greater "warmth" and "interest" in interior decor for the living quarters (non-work areas) of future long-duration manned vehicles.

G. Atmosphere Thermal Control—Greater attention must be focused upon effective temperature - a measure combining air flow, dry and wet bulb temperatures - and workloads for the provision of a more habitable thermal environment. Attention to each of these factors on an unintegrated basis results in less than desirable but adequate thermal accommodation.

In summary, it may be said that habitability provisions, although considerably less than sumptuous, were acceptable to the crew throughout the test duration. The crew seldom made voluntary complaints. When criticism was solicited, complaints normally dealt with deficiencies in communications and recreational audio fidelity, hygienic and urine collection inadequacies, some lack of attention to surface design details of the interior decor, insufficient attention to personal storage allocations and work surface area infringements, and minimally adequate volumetrics in the crew quarters when occupied by all four crewmen simultaneously.

It is felt that the lack of negative response to features of the habitat resulted from greater design attention to habitability provisions and a characteristic reluctance on the part of crew members to express annoyance.

3.4 BEHAVIORAL PROGRAM

The behavioral program assessed the effects of confinement on crew behavior in the areas of psychological status, sleep durations, and task performance. Psychological status and sleep durations were measured by objective questionnaires. As expected, the test did not impose severe psychological stress, but periods of low morale and mild hostility were noted. Certain psychological tests appear somewhat insensitive and are candidates for exclusion from future studies. More subtle or sensitive tests must be developed in their stead. Sleep durations were significantly shorter during the early part of mission for crewmen on the inverted sleep cycles and adaptation did not occur until approximately the mid point in the test. Task performance information indicates a relatively low proportion of crew time spent on assigned tasks, with a corresponding increase in free time. This shows the availability of the crew for conducting in-flight experiments, but appeared to result in this test in a deterioration of crew morale due to lack of stimulating activity.

Previous research has been directed toward determining individual and group reactions to isolation and confinement. Findings common to most of these studies have included: manifestations of boredom and monotony, declines in morale, interpersonal conflicts, conscious individual self-control to contain hostilities, scapegoating on outside personnel, impairment of memory, and low energy for intellectual pursuits with little or no loss in intellectual ability (Reference 3-12). To the extent that one or more of these similar developments

manifest themselves during an orbital or deep space mission, the efficiency and effectiveness of a crew may be compromised.

Repeated psychological testing in programs of this nature typically evoke negative and uncooperative responses among the tested participants (Reference 3-13). To preclude this occurrence, a very open philosophy was practiced with the entire psychomotor and psychometric program. The crew was trained to be thoroughly familiar with the purpose and techniques of each device.

The tests used in the program were those recommended in a NASA/MDAC panel held at the Institute of Behavioral Research at Texas Christian University (Section 3.1), with the addition of a hostility scale.

Listed below are the tests used during 90-day test and the area measured:

Area	Test
Subjective mood	Primary affect scale Hostility scale Group confinement inventory Subjective stress scale Isolation symptomatology questionnaire
Sleep behavior	Sleep log
Interpersonal behavior	Sociometric IBR personal space measure
Cognitive performance	Descriptive sentence test

All of the preceding tests, with one exception, have been used in previous studies of confinement and isolation and appeared to have substantial validity and reliability for this application. The exception is the IBR personal space measure which was included for possible correlation with the more established test results. The purpose of these tests and schedule of application is included in Table 3-14.

The assessment of mental state of individuals in confinement situations such as this may be measured directly or indirectly. The direct approach would be the use of relatively standard psychological testing devices. An indirect approach would be by measuring the performance of the individuals at actual tasks. Under the latter category would be included performance on psychomotor test devices assuming a correspondence with actual task performance.

3.4.1 Procedures

During the 90-day test, the various psychological tests were taken by the crew as scheduled in Table 3-14. The tests were self-administered and answered via an onboard computer link. One series of tests (A through E in Table 3-14), which was considered to provide the outside staff with timely information

Table 3-14

QUESTIONNAIRE DEFINITION AND USE SCHEDULE

	Questionnaire	Frequency
A.	Hostility Scale - measures mood on a continuum from pleasure to hostility	Weekly starting with sixth day of test
	1. Inter/onboard crew	
	2. Toward outside personnel	
	3. Toward acoustic environment in crew compartment	
	4. Toward acoustic environment in equipment compartment	
B.	Subjective Stress Scale - measures perceived stress on a continuum from none to incapacitating	Weekly starting with fifth day of test
C.	Descriptive Sentence Test - assesses cognitive functioning (reasoning)	Every two weeks starting with tenth day of test
D.	Sociometry - assesses changes in sociometric preferences (group structure)	Every three weeks starting with third week
E.	Sleep Questionnaire - assesses quantitative aspects of sleep	Daily
F.	Isolation Symptomatology Questionnaire - assesses individual mood reaction to isolation	Every four weeks starting at end of second week
G.	Group Confinement Inventory - assesses effects of confinement on individual relationship to the group	Every four weeks starting at end of first week
H.	Primary Affect Scale - assesses reaction of individual to environment on a feeling level	Weekly starting with sixth day
I.	IBR Personal Space Measure - an experimental test to assess changes in personal space requirements	Every 21 days starting with day seven

concerning crew status, was available for real-time analysis. The other series (F through I) provided data that were available for post-test analysis only.

The three psychomotor devices identified below were used onboard. Each had a fundamentally different orientation, and complete descriptions of each program may be found in the appropriate references noted.

A. Langley Research Center Complex Coordinator - A self-paced serial reaction complex coordinator psychomotor performance test (CR 111882 Section 10.4).

B. Critical Task Tester Experiment - a battery of compensatory tracking tasks designed to measure dynamic response behavior (Section 3.10 and CR111882 Section 12.3).

C. Response Analysis Tester - A short-term memory test device (CR111882 Section 12.2).

3.4.2 Results

Detailed results of the application of each psychological test are presented in the following section, followed by a general discussion and evaluation in Section 3.4.3.

3.4.2.1 Hostility Scales

Hostility scales were obtained each week, with the exception of one missed period on day 38. Hostility of crew members toward each other and toward the outside personnel is discussed herein. Hostility toward the acoustic environment is discussed in Section 3.6.

Intracrew hostility for crewman 1 peaked at a fairly high level around days 24 to 31 (Figure 3-7). Succeeding scores were quite low until the last test day when a moderate increase was recorded.

Crewman 2 maintained a level slightly above neutral for the first 24 or so days when a decrease to a neutral level occurred (Figure 3-8).

Crewman 3 evidenced an initial low level of hostility toward other crew members and then showed a sharp increase to a fairly high level around day 17 (Figure 3-9). Subsequently, low scores were recorded through day 31 with a moderate increase noted on day 45. This was followed by a low on day 52 which in turn was followed by a return to a fairly high score on day 59. The rest of the mission was completed with low level scores.

After beginning at a moderate level, crewman 4 showed a moderate increase on day 17 (Figure 3-10). A decrease then occurred to his baseline. Subsequently an upswing took place on day 57. Day 66 registered a sharp decrease to a very low score which was followed by a 2-week high level peak.

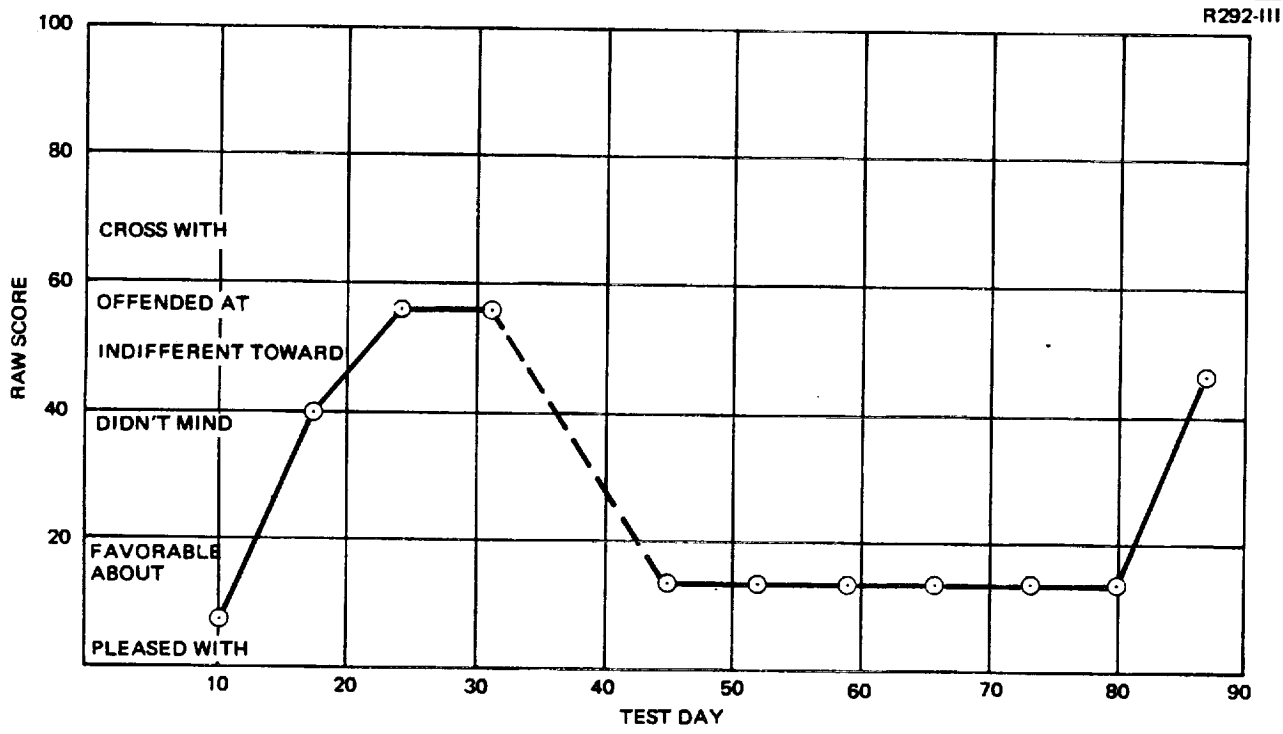


Figure 3-7. Hostility (Directed Toward Onboard Crew) Scale Results for Crewman 1

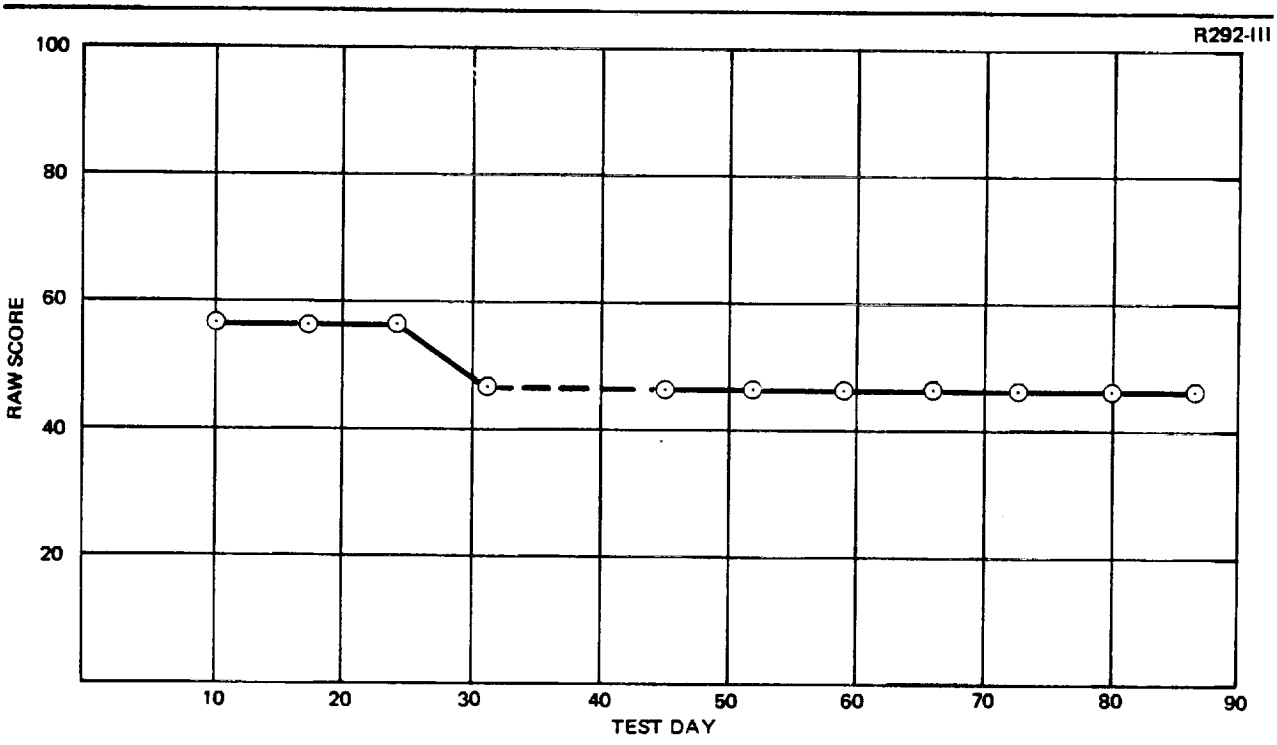


Figure 3-8. Hostility (Directed Toward Onboard Crew) Scale Results for Crewman 2

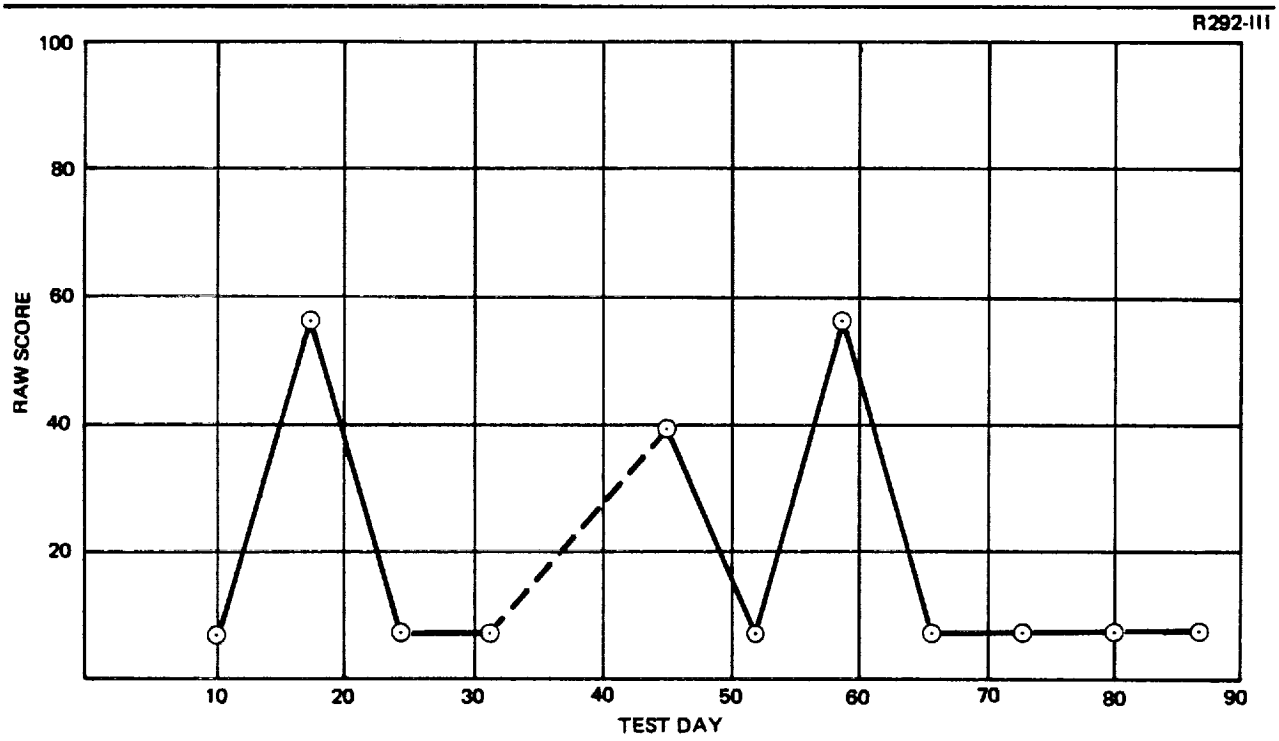


Figure 3-9. Hostility (Directed Toward Onboard Crew) Scale Results for Crewman 3

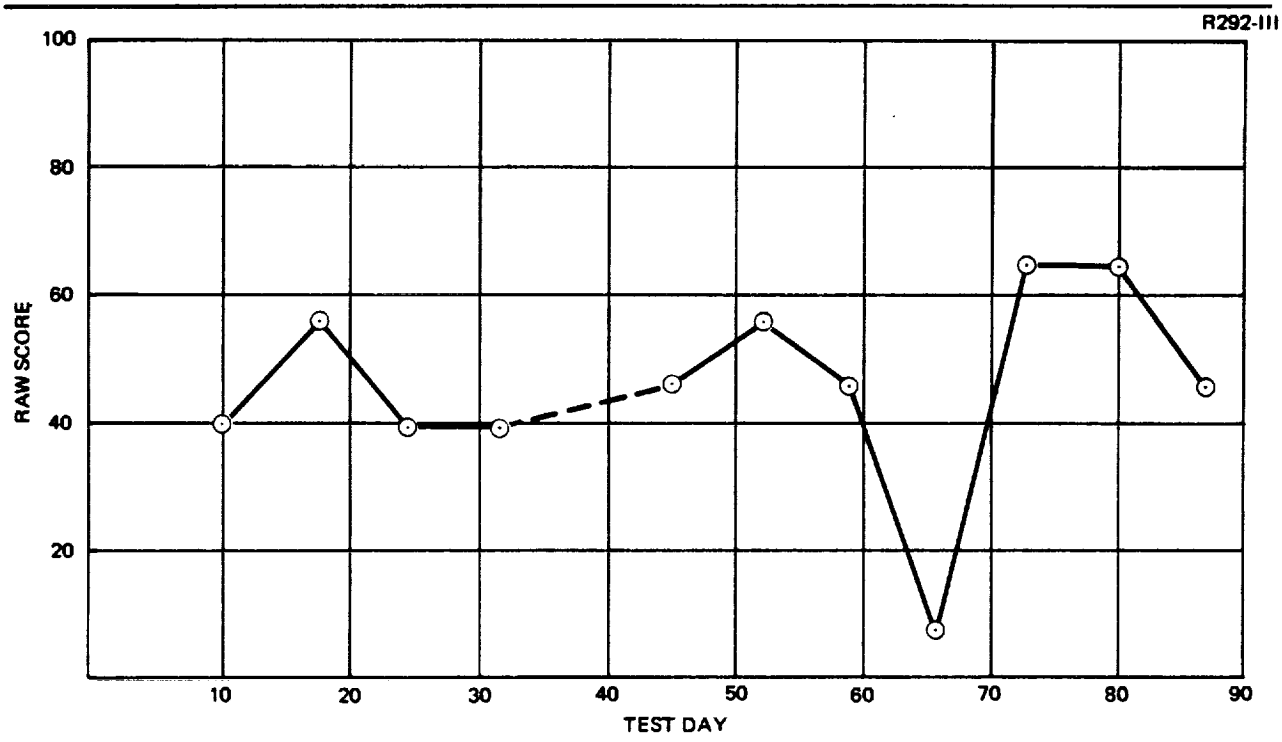


Figure 3-10. Hostility (Directed Toward Onboard Crew) Scale Results for Crewman 4

Hostility as directed toward outside personnel for crewman 1 showed a gradual increase from an initial low to a moderate plateau (Figure 3-11). A second low on day 45 was followed by a fairly high score which decreased to a moderate level for the rest of the mission. Crewman 2 displayed moderately high scores throughout the test with a very high peak occurring on day 31 (Figure 3-12). A very low score was maintained over the run by crewman 3 with minor fluctuations occurring at various times (Figure 3-13). Crewman 4 stayed at a fairly high level for most of the run with significantly high peaks occurring on days 45 and 59 (Figure 3-14).

3.4.2.2 Subjective Stress Scale

The Subjective Stress Scale was scored on a continuum from none (0) to excessive (100). This test was administered weekly, with only a few missed applications early in the test by some crew members.

Crewman 1's scores declined after the first administration to a low plateau on day 33 that remained throughout (Figure 3-15).

Crewman 2 showed no changes in his data throughout the test (Figure 3-16), remaining consistently at a moderately low level.

Crewman 3 began with an initial high with a reduction to a low plateau on days 19 through 66 (Figure 3-17). On day 68, a spike occurred followed by a return to the plateau and further decrease on day 89.

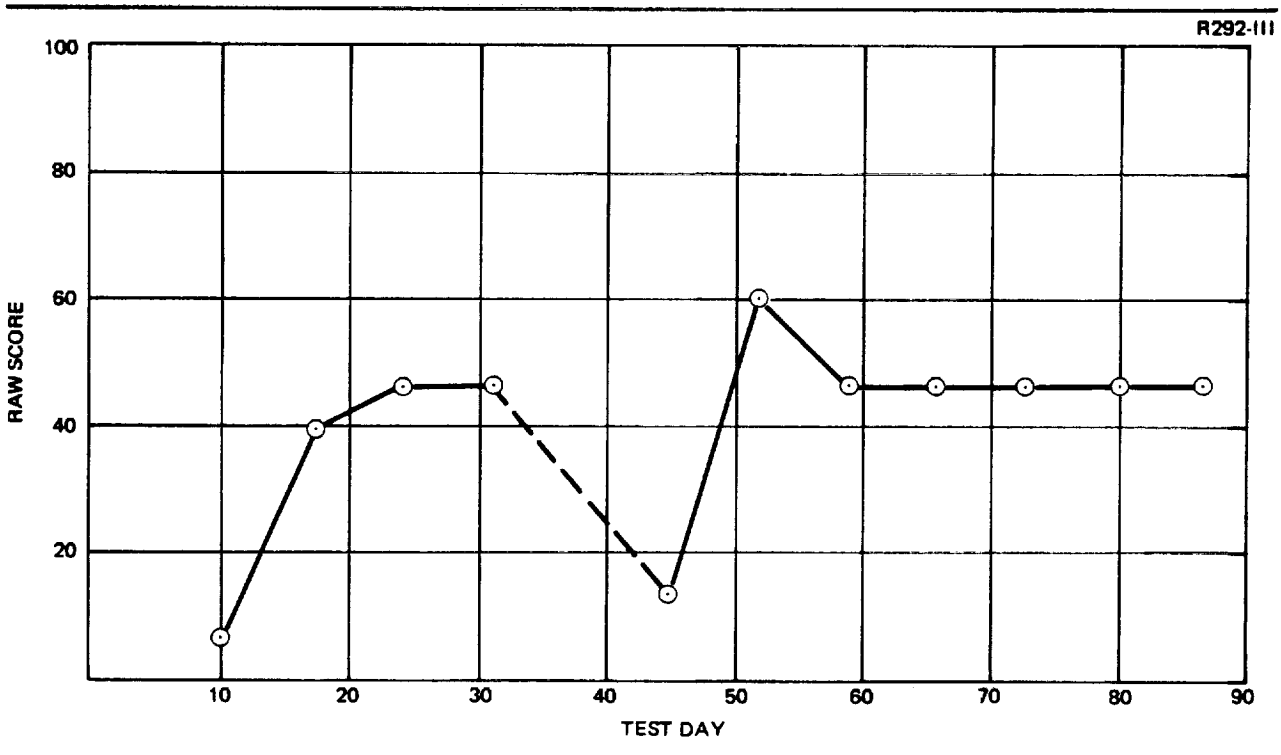


Figure 3-11. Hostility (Directed Toward Outside Personnel) Scale Results for Crewman 1

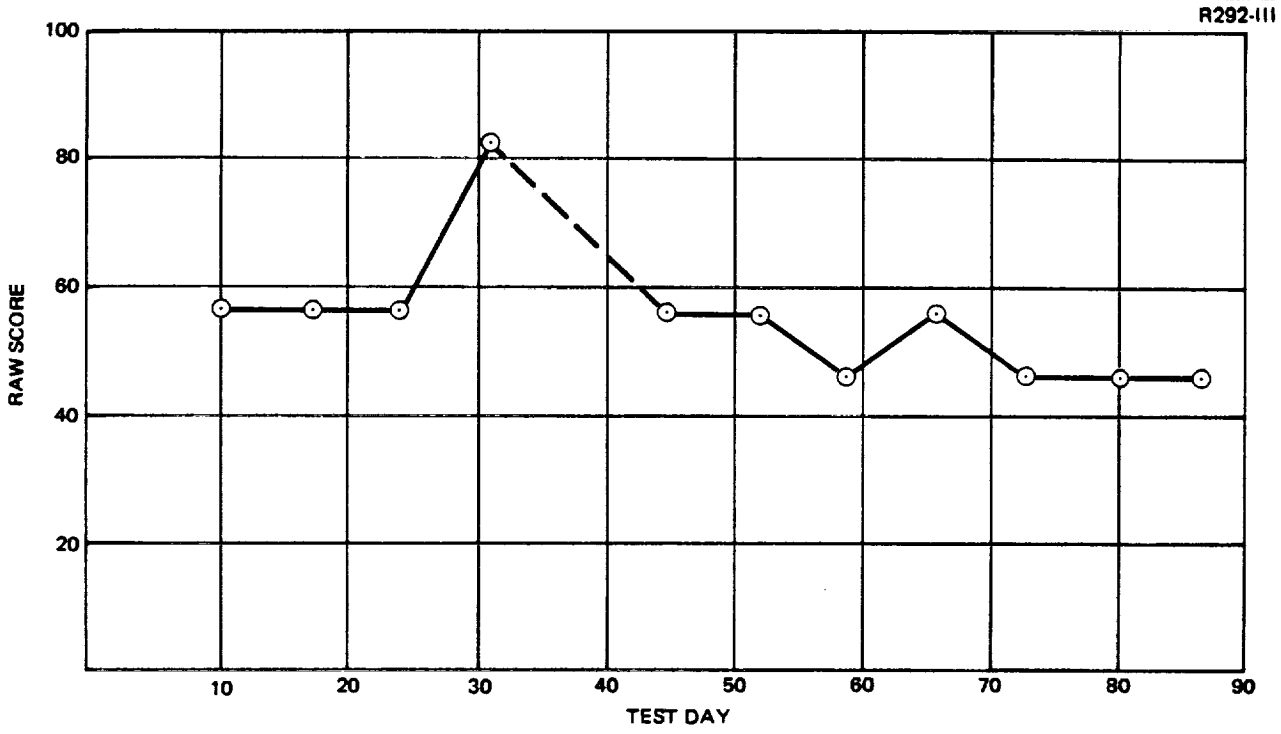


Figure 3-12. Hostility (Directed Toward Outside Personnel) Scale Results for Crewman 2

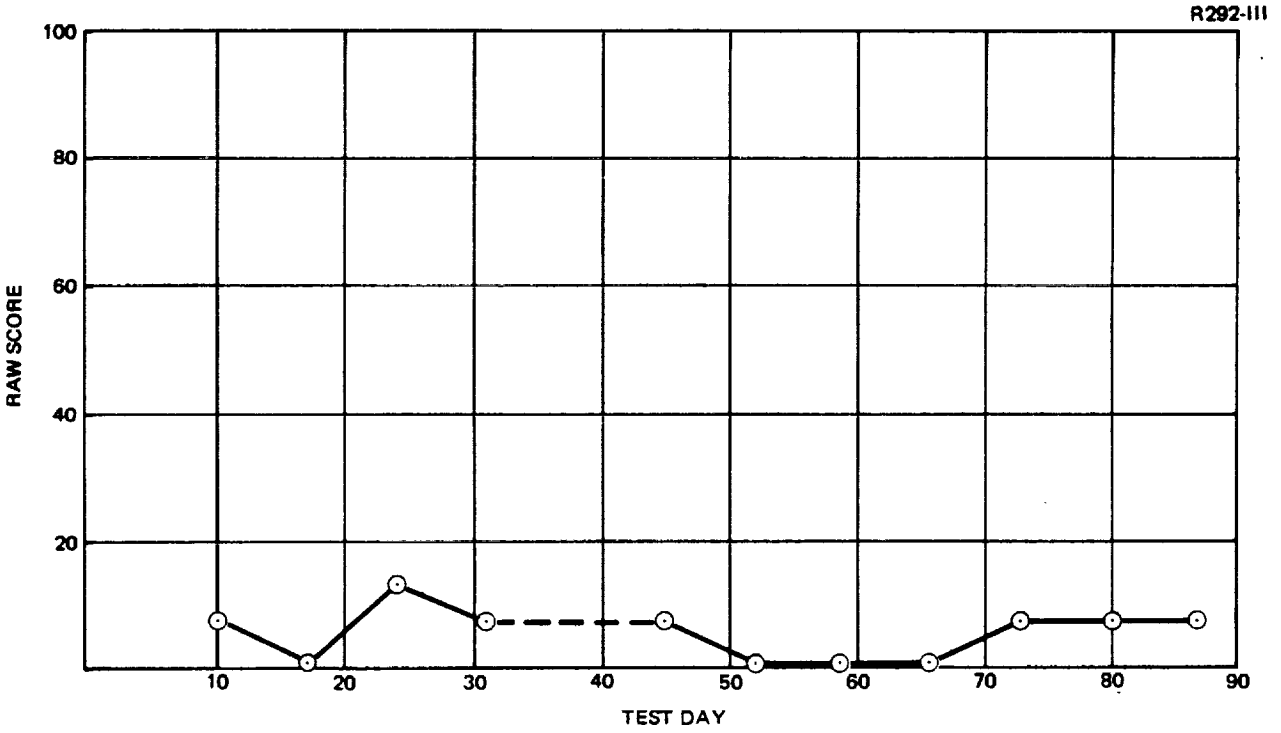


Figure 3-13. Hostility (Directed Toward Outside Personnel) Scale Results for Crewman 3

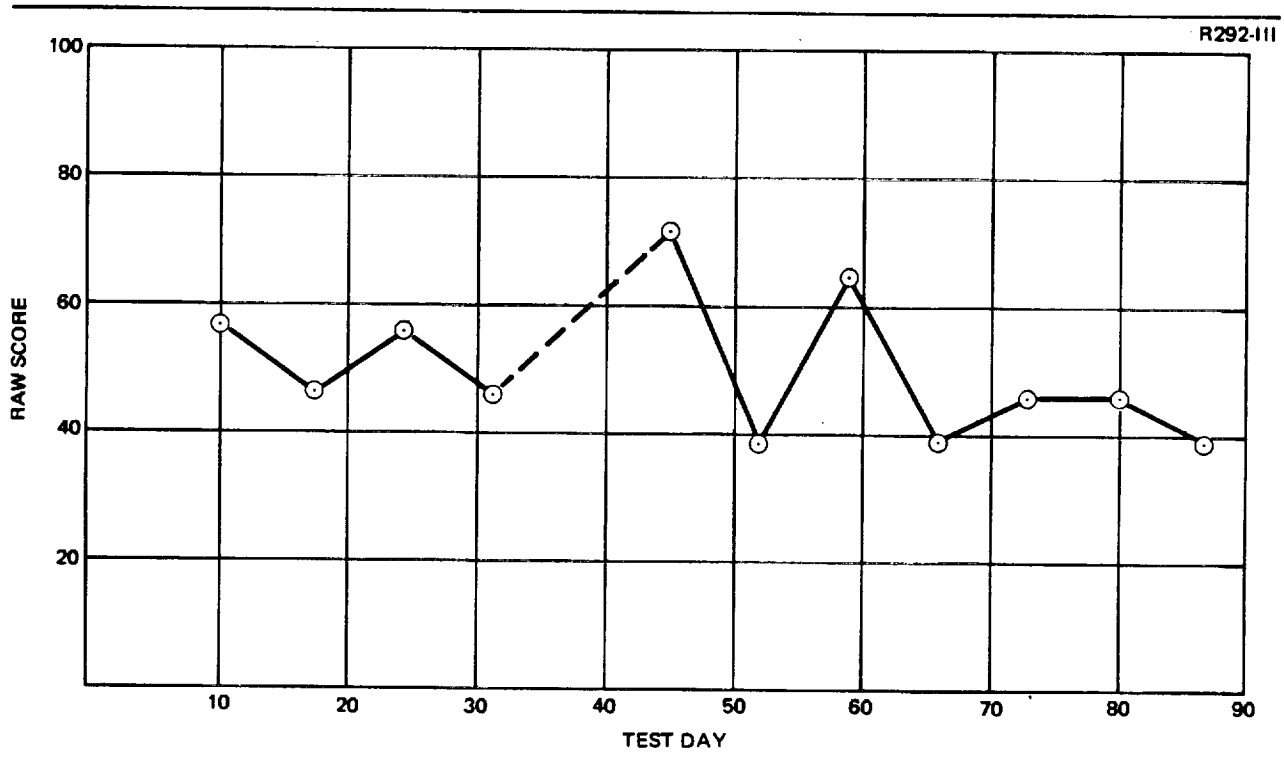


Figure 3-14. Hostility (Directed Toward Outside Personnel) Scale Results for Crewman 4

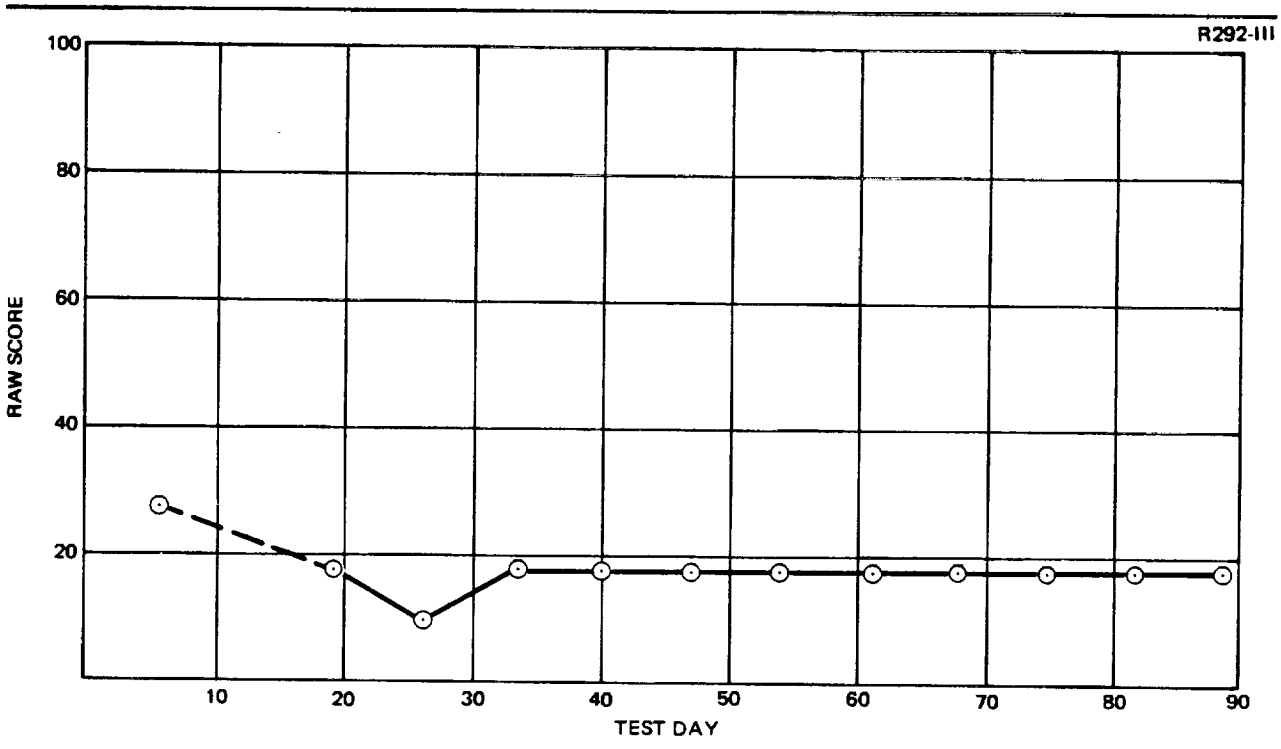


Figure 3-15. Subjective Stress Scale Results for Crewman 1

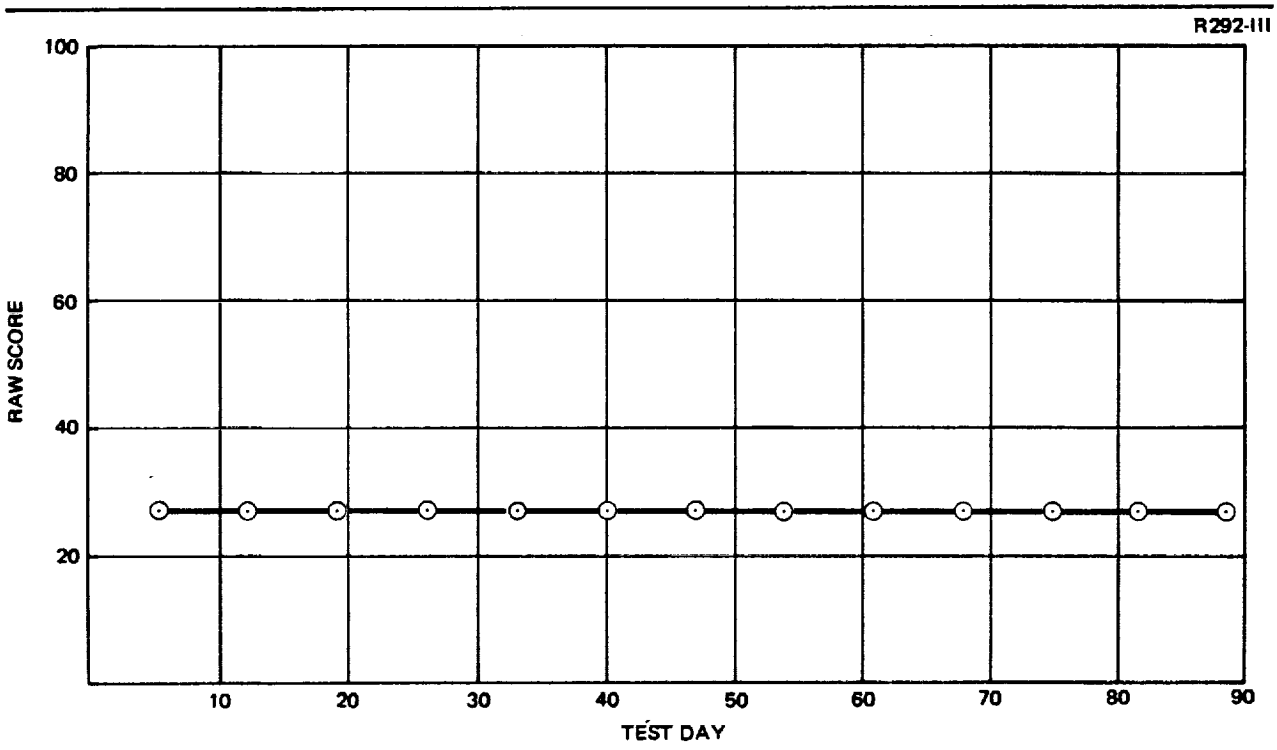


Figure 3-16. Subjective Stress Scale Results for Crewman 2

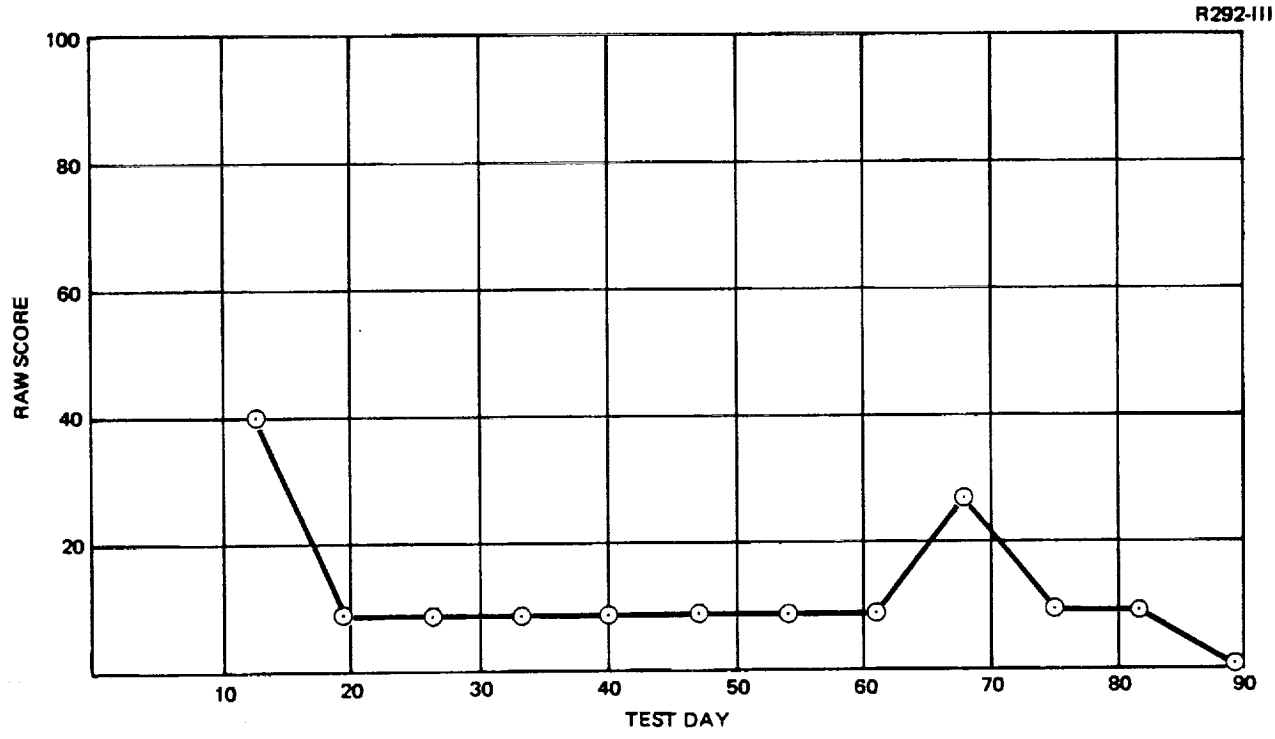


Figure 3-17. Subjective Stress Scale Results for Crewman 3

Crewman 4 showed an initial moderate high followed by a slight decrease on day 26, a rise on day 47, a decline on day 87, and a sharp increase on day 89 (Figure 3-18).

3.4.2.3 Descriptive Sentence Test

No significant changes were noted in the Descriptive Sentence Test results for any of the four crewmen. Performance remained at high levels through all administrations.

3.4.2.4 Sociometry

A measure of group integrity or cohesion was made via the sociometric test by comparing preferences of the onboard crew members for companions for a hypothetical future test, selecting from a pool composed of the three remaining onboard and the backup crew members. The heirarchy had six ranks. If the crewmen selected one another for the first three ranks, a score of 100 percent resulted. If a backup crewman was ranked in one of the first three positions, he displaced an onboard crewman and the resulting score was decreased accordingly. Compared to pretest data the crew evidenced a lessening of cohesion at the mission outset, day 23, and essentially maintained this position for the duration of the mission (Figure 3-19).

3.4.2.5 Sleep Questionnaire

The sleep questionnaires, which were responded to daily, were analyzed from the aspect of sleep duration. These responses are presented for each

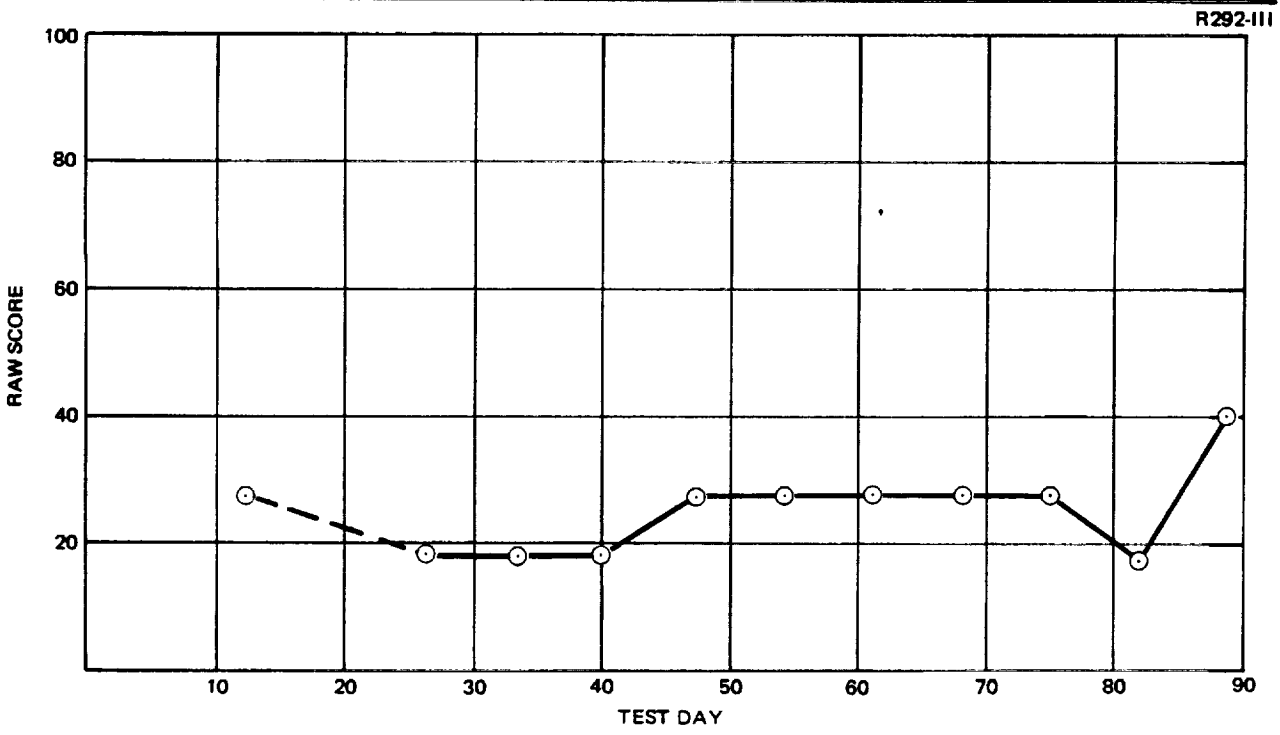


Figure 3-18. Subjective Stress Scale Results for Crewman 4

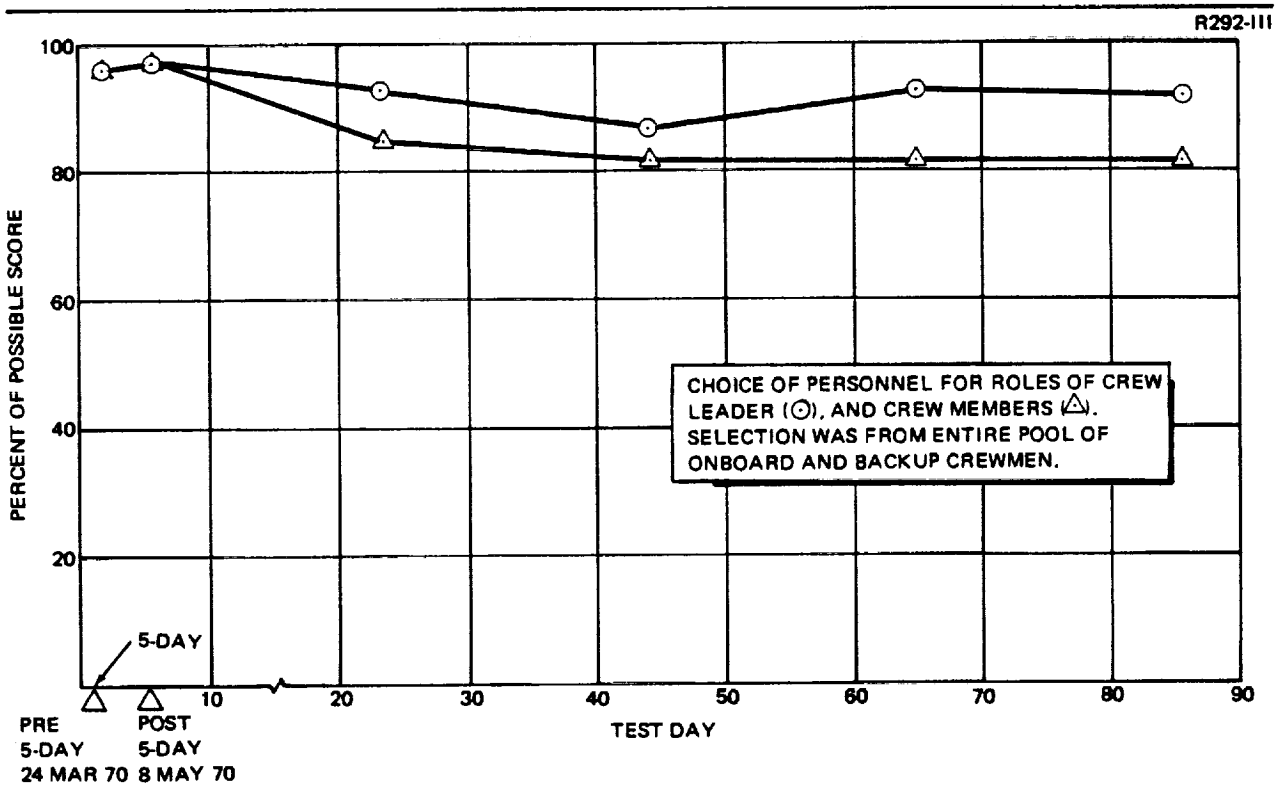


Figure 3-19. Sociometry Results

crewman in Figure 3-20 through 3-23. Review of these data leads to several observations: (1) a considerable variability existed in sleep duration reports for all men throughout the test; (2) there appeared to be a gradual overall increase in total sleep time during the first 30 days of the test; and (3) the two crewmen having the altered diurnal cycle (crewman 3 and 4) appeared to present a greater lag in this gradual increase, starting from a generally lower initial level, than the two crewmen whose cycle was not changed. In evaluating these impressions, Figure 3-24 and Table 3-15 were developed. These appear to confirm the observations.

3.4.2.6 Isolation Symptomatology Questionnaire

The Isolation Symptomatology Questionnaire (ISQ) was scored on four scales: (1) positive contemplation, (2) tedium, (3) unreality, and (4) anxiety. Responses were obtained four times during the test from each crewman.

Crewman 1's test results show no significant changes with the exception of a minor increase in unreality on day 37 (Figure 3-25). Anxiety was very low level as was positive contemplation (M = 22). Tedium (M = 34) was consistently higher than positive contemplation.

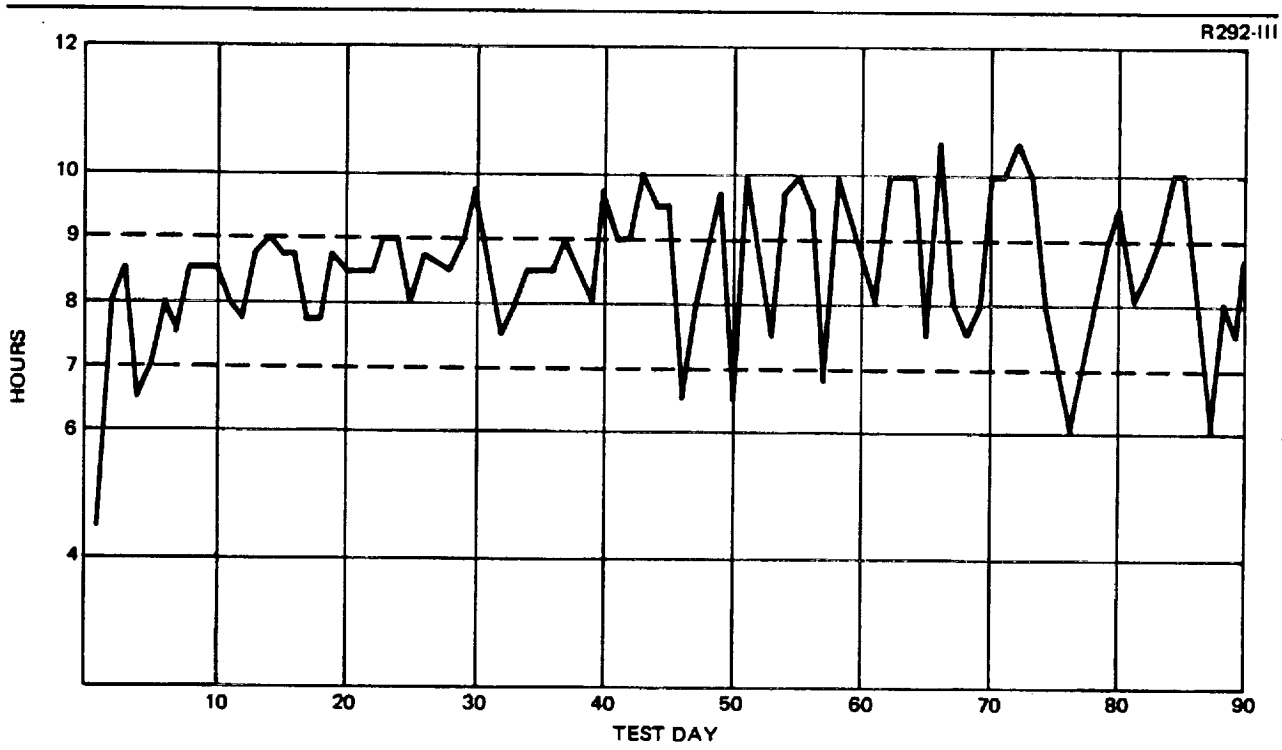


Figure 3-20. Sleep Durations for Crewman 1

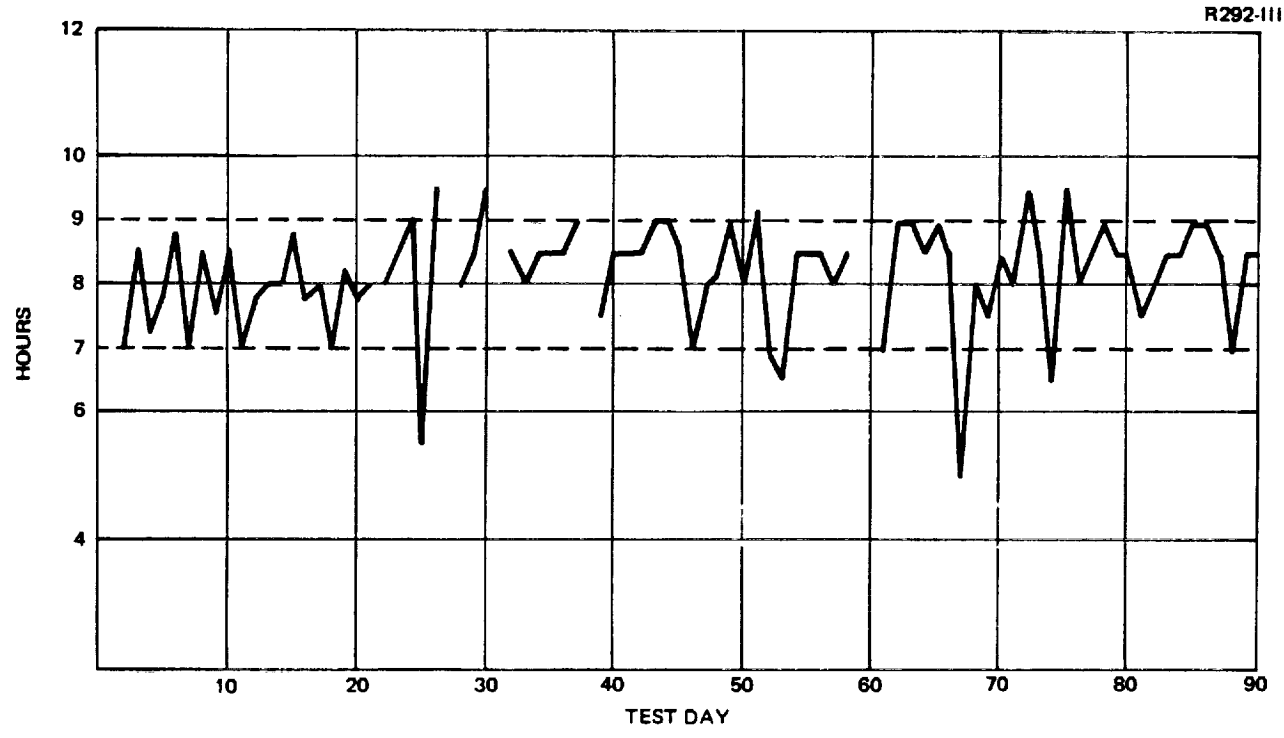


Figure 3-21. Sleep Durations for Crewman 2

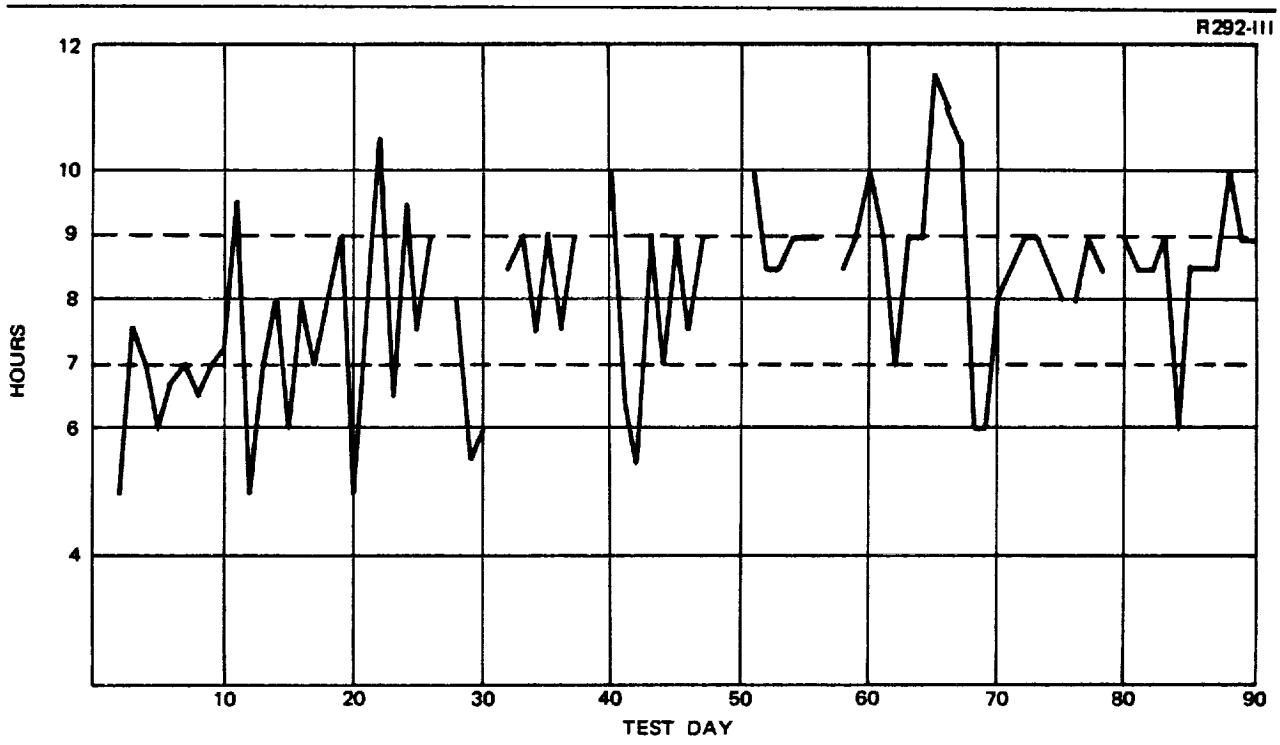


Figure 3-22. Sleep Durations for Crewman 3

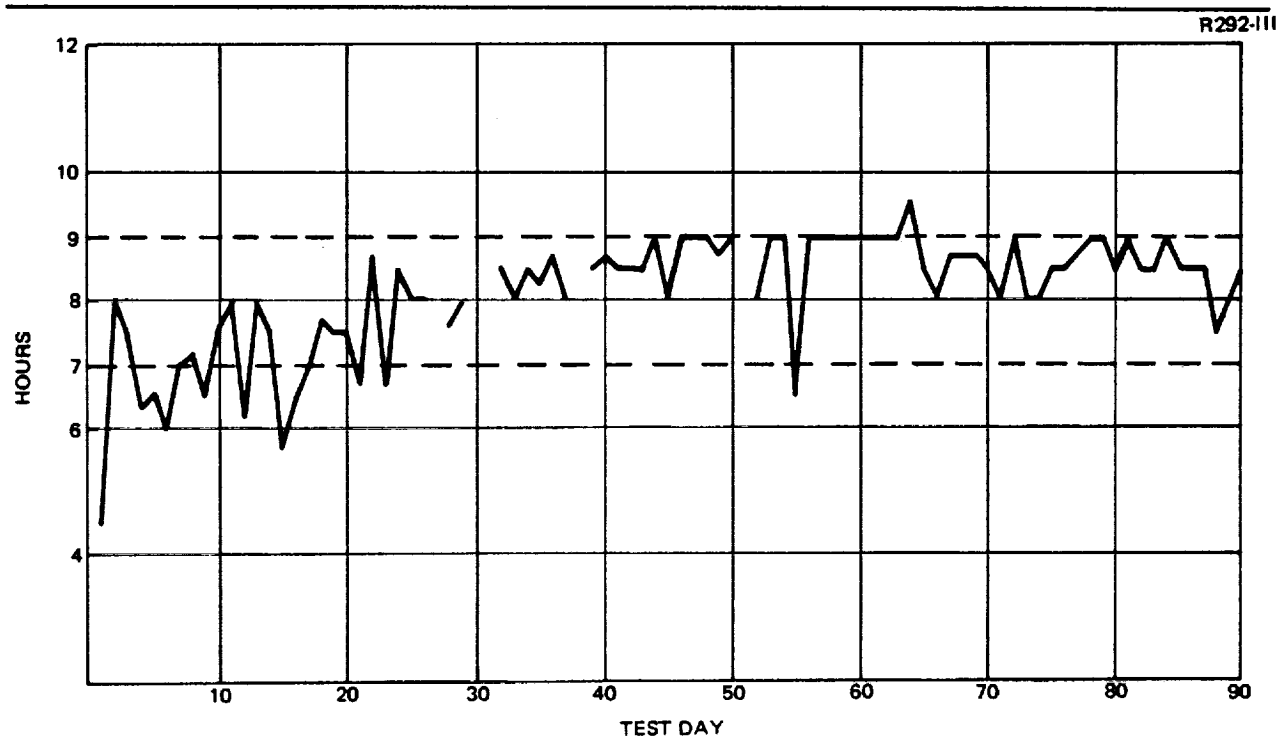


Figure 3-23. Sleep Durations for Crewman 4

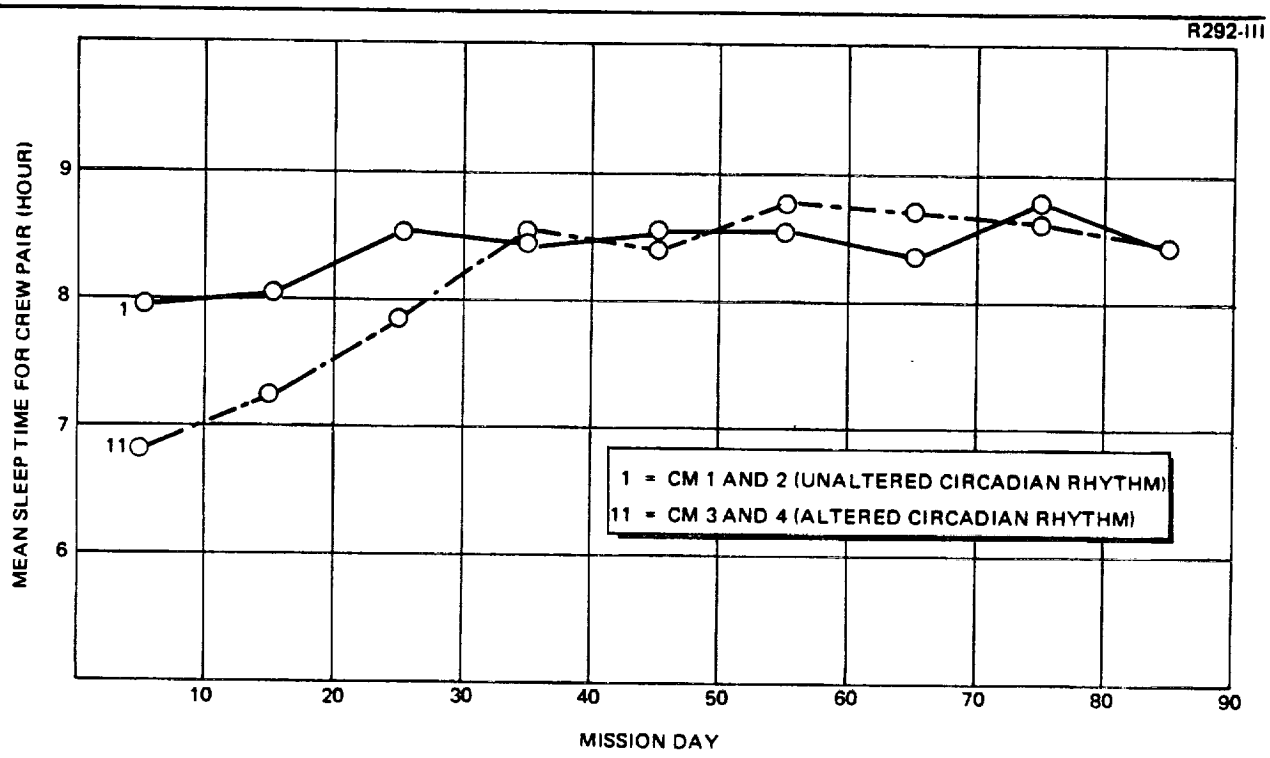


Figure 3-24. Sleep Questionnaire Responses. Smoothed Curve Based on 10-Day Segments

Table 3-15

MEAN SLEEP DURATION AND SIGMA VALUES

10-Day Segments

Crewmen	Days 1-10 M	Days 1-10 σ	Days 12-20 M	Days 12-20 σ	Days 21-30 M	Days 21-30 σ
1 and 2	7.93	0.66	8.03	0.56	8.53	0.96
3 and 4	6.82	0.71	7.22	1.18	7.86	1.29
	Days 31-40		**Days 41-50**		**Days 51-60**	
	M	σ	M	σ	M	σ
1 and 2	8.42	0.57	8.53	0.98	8.57	1.17
3 and 4	8.52	0.64	8.41	1.07	8.77	0.77
	Days 61-70		**Days 71-80**		**Days 81-90**	
	M	σ	M	σ	M	σ
1 and 2	8.35	1.38	8.79	1.31	8.42	1.04
3 and 4	8.69	1.38	8.62	0.38	8.45	0.78

NOTE: Crewmen 3 and 4 were on inverted sleep cycle.

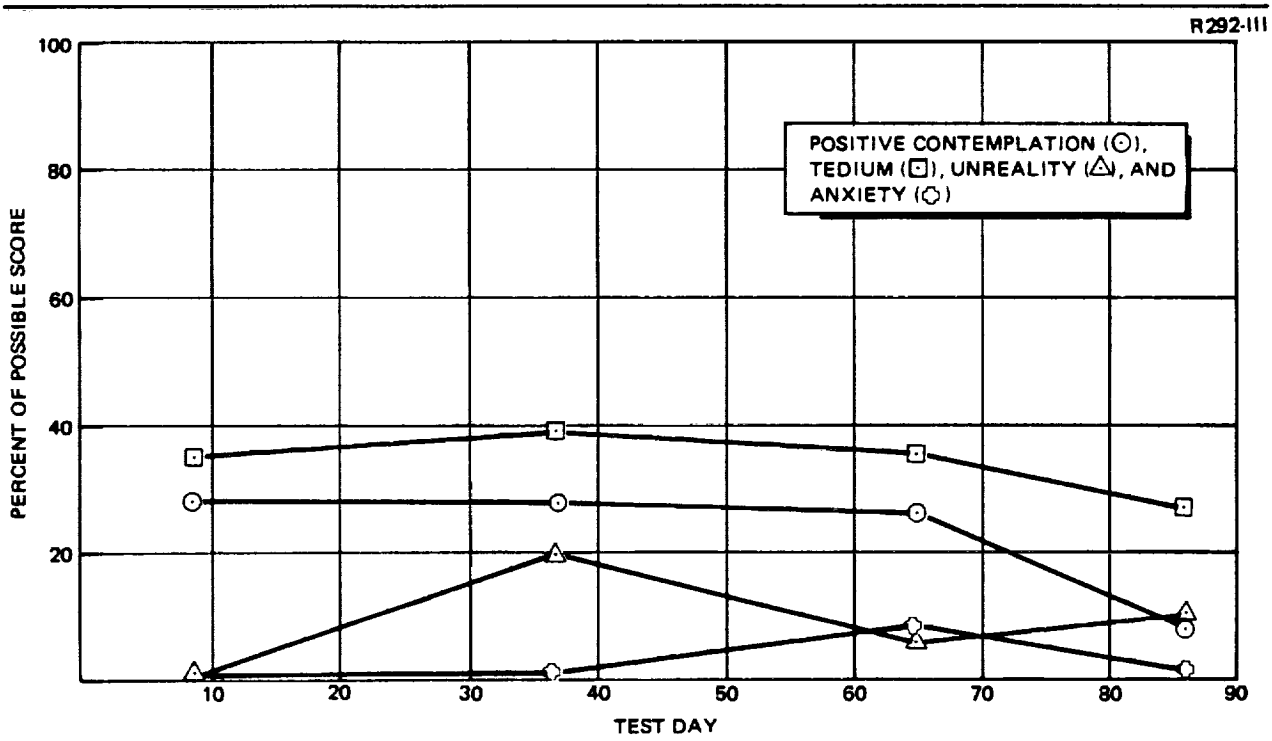


Figure 3-25. Isolation Symptomatology Questionnaire Results for Crewman 1

Positive contemplation for crewman 2 showed a moderate peak on day 37 followed by a general decrease (Figure 3-26). Tedium, unreality, and anxiety were all low level with no significant variations.

Crewman 3 began with a fairly high score on positive contemplation that decreased slightly on day 37 and then manifested a marked rise on day 65 which held throughout the run (Figure 3-27). Tedium, unreality, and anxiety, which were generally quite low, dropped on day 37 with unreality remaining very low level throughout. Anxiety and tedium increased to baseline on day 65 and fell again to approximately day 37 levels on day 86.

Crewman 4 had a moderate beginning positive contemplation score that decreased slightly until the final administration on day 86 (Figure 3-28). Tedium reached a high on day 65 and decreased to a mid-level on day 86. Unreality decreased monotonically from the first test administration. Anxiety was low level and showed no significant changes.

3.4.2.7 Group Confinement Inventory

The Group Confinement Inventory (GCI) was dichotomized into positive and negative categories, i.e., those items dealing with desirable and undesirable reactions to confinement.

Crewman 1 shows very high scores on the positive scale and very low scores on the negative scale (Figure 3-29). No significant fluctuations were evident.

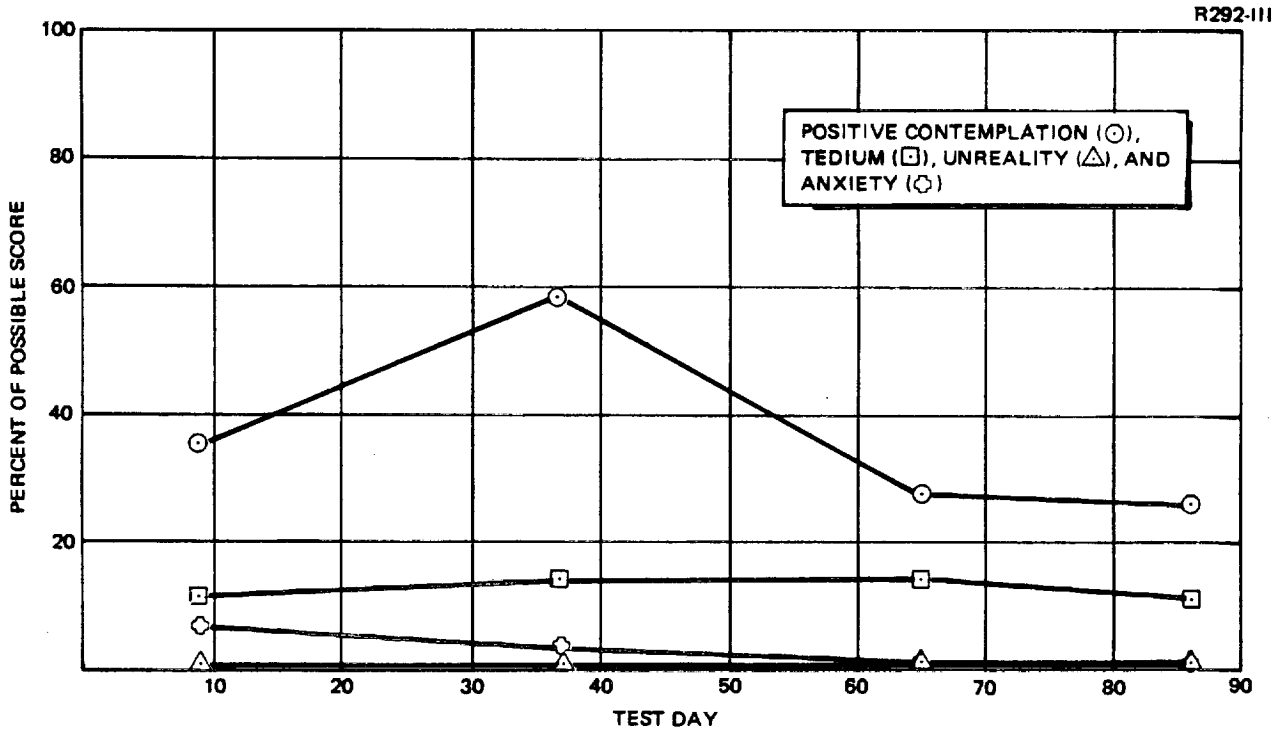


Figure 3-26. Isolation Symptomatology Questionnaire Results for Crewman 2

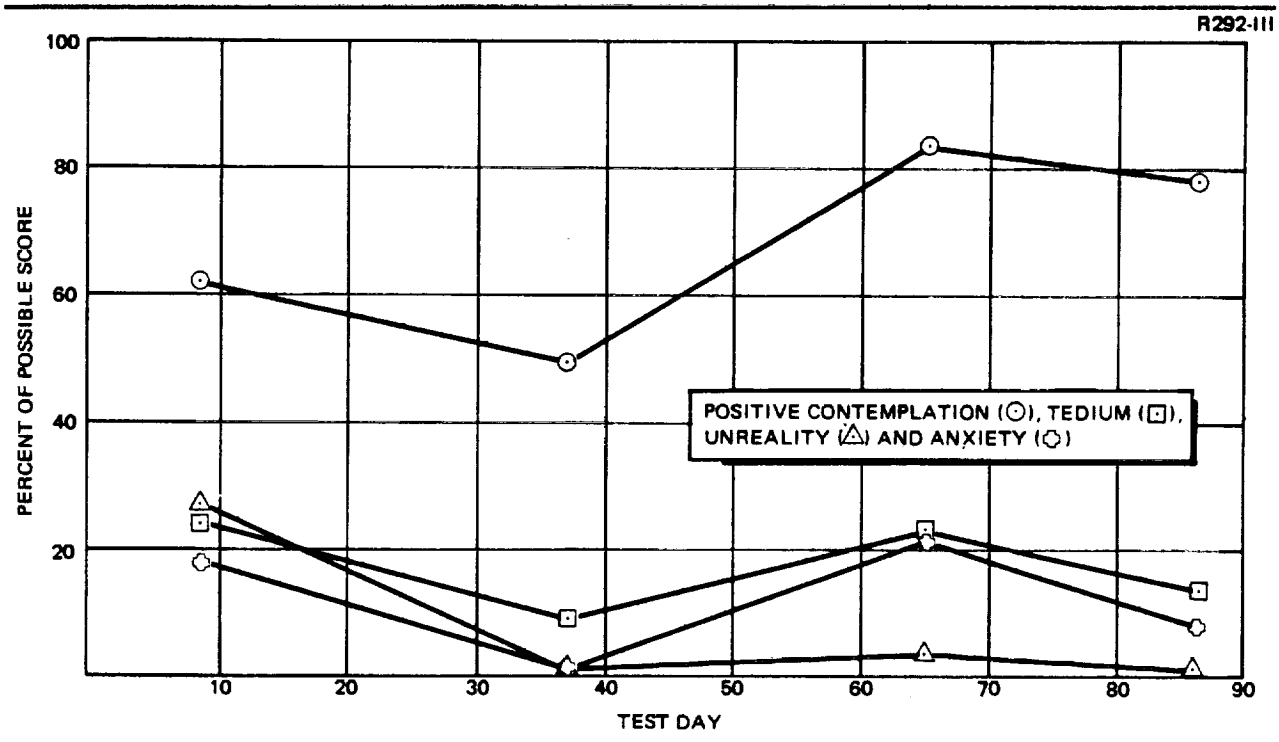


Figure 3-27. Isolation Symptomatology Questionnaire Results for Crewman 3

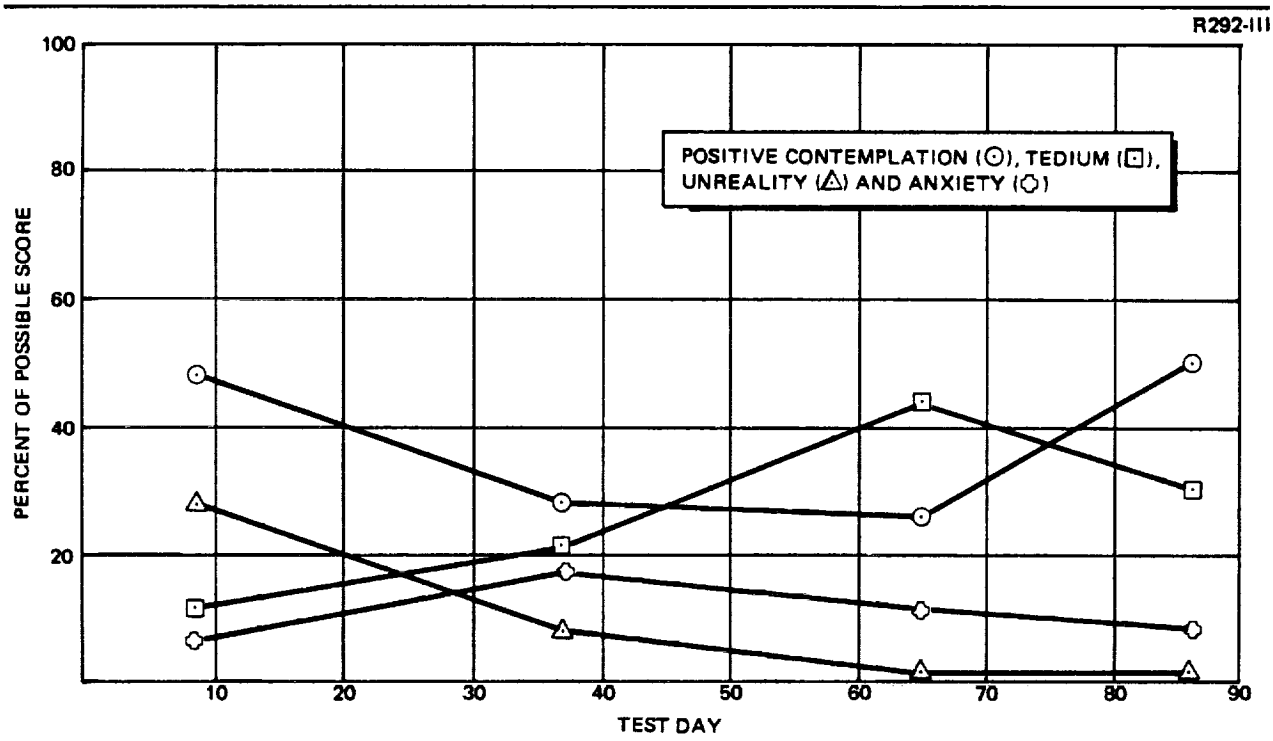


Figure 3-28. Isolation Symptomatology Questionnaire Results for Crewman 4

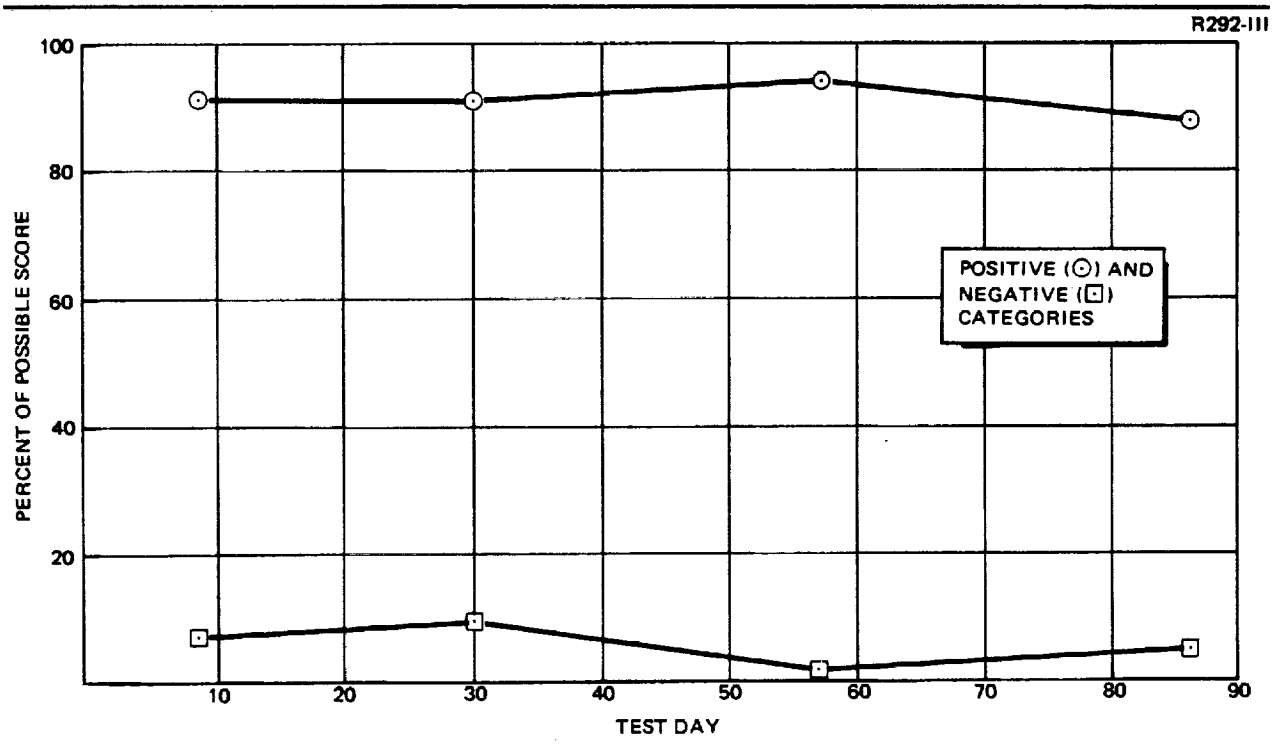


Figure 3-29. Group Confinement Inventory Results for Crewman 1

Crewman 2 evidences a moderate decline on the positive scale through day 57 with a slight rise occurring on day 86 (Figure 3-30). The negative scale was moderately low with no significant changes.

Crewman 3's data reflects crewman 2's except the decrease in the positive scale is more marked as is the subsequent increase (Figure 3-31). The negative scale shows a slight increase through day 57 followed by a slight decrease on day 86.

The data for crewman 4 are also similar to that of crewman 2 in that a moderate decline in the positive scale occurs through day 57 and a slight rise occurred on day 86 (Figure 3-32). The negative scale, however, shows a moderate increase on day 30 and remains at this level throughout.

3.4.2.8 Primary Affect Scale

Crewman 1's results on the primary affect scale shows obvious decreases in the arousal (activity) and happiness scales (Figure 3-33). On day 52, a spike to almost baseline levels occurred in both scales followed by a subsequent decline to earlier lows. The last administration shows a moderate increase in both scales. The other three scales of the PAS, namely anger, fear, and depression, showed no significant changes over the mission duration.

For crewman 2, a similar decrease in the happiness scale was seen but without the day 52 spike (Figure 3-34). Also arousal showed only a minor decrement over time and did not display an increase at the final administration.

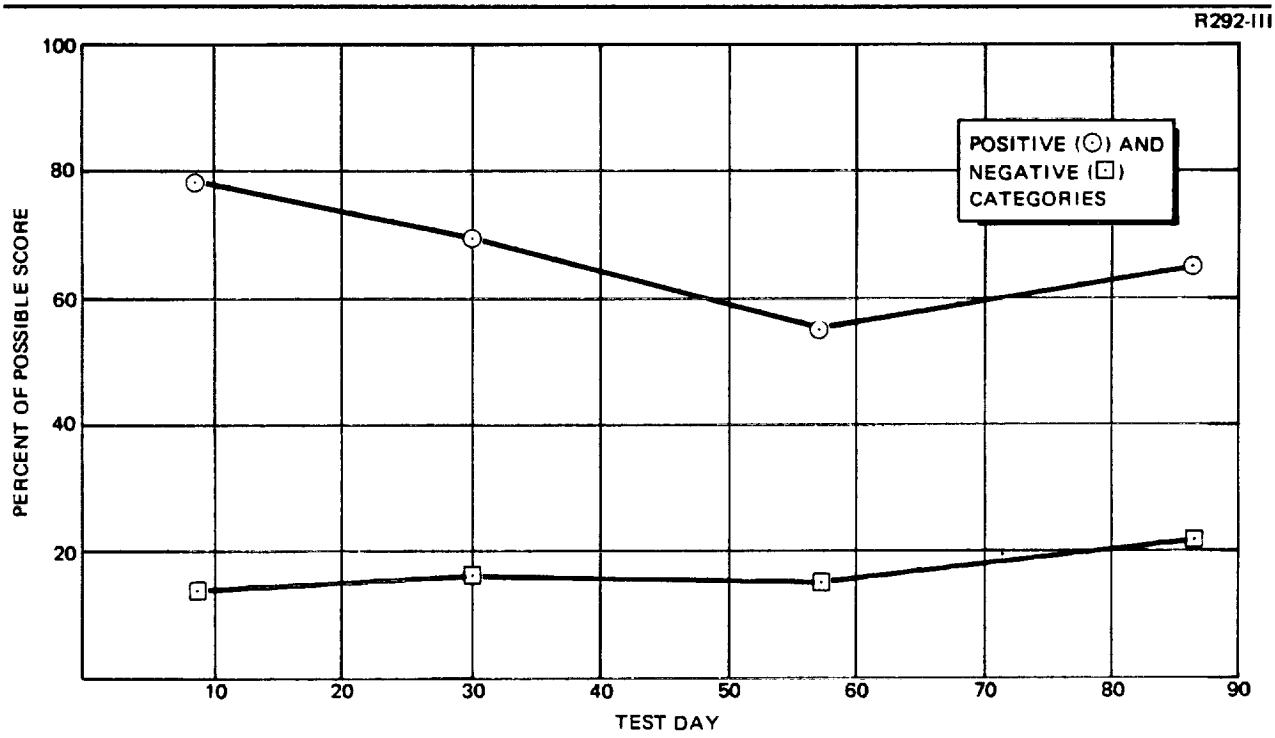


Figure 3-30. Group Confinement Inventory Results for Crewman 2

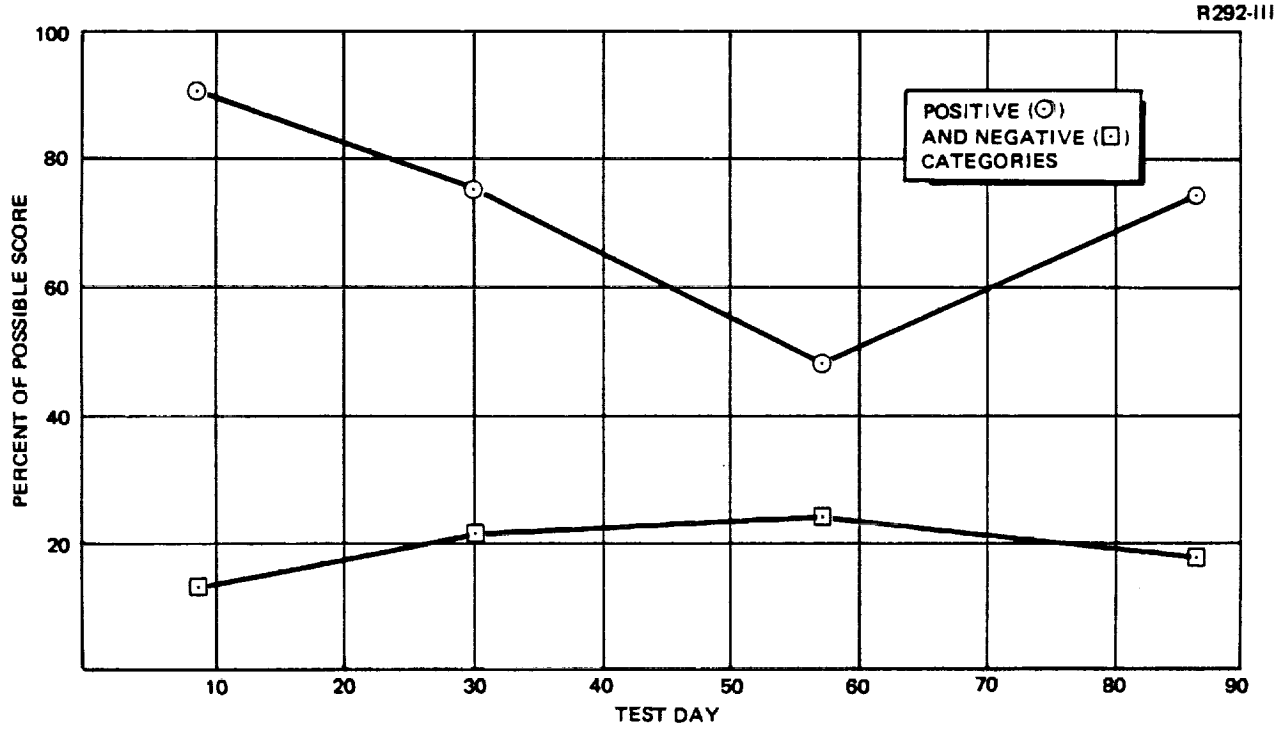


Figure 3-31. Group Confinement Inventory Results for Crewman 3

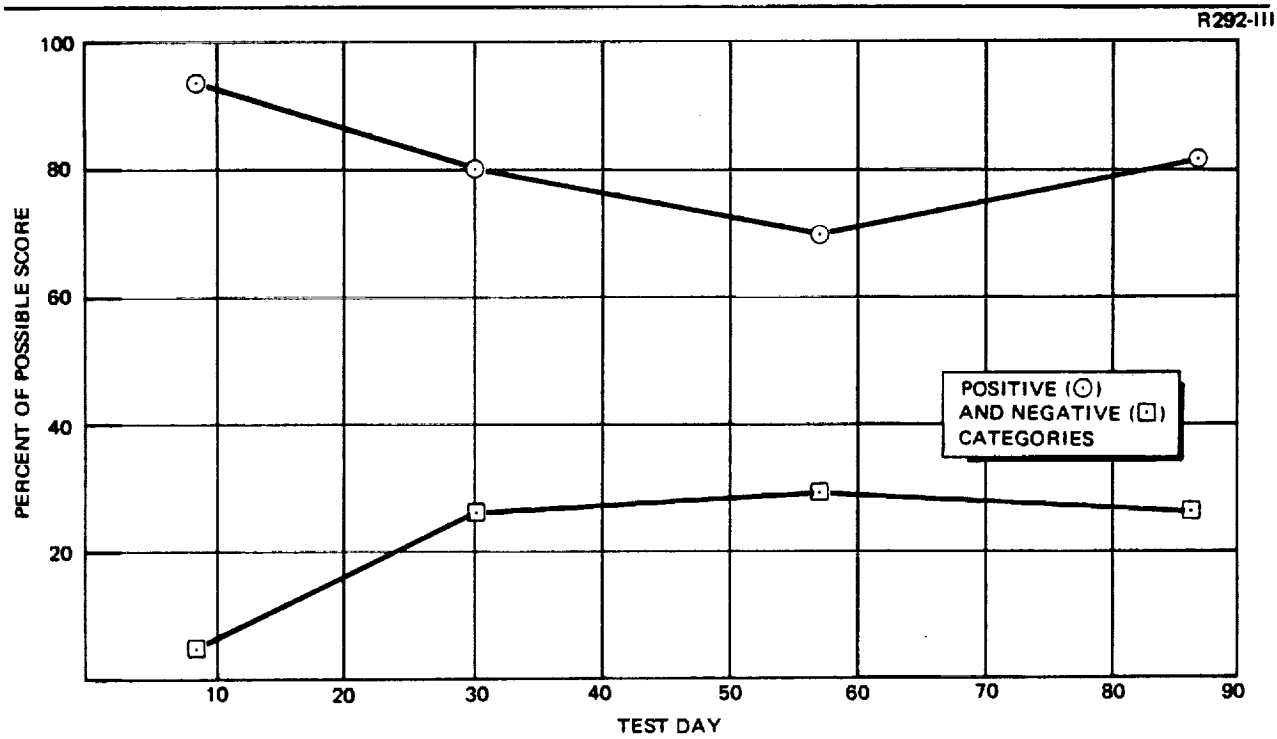


Figure 3-32. Group Confinement Inventory Results for Crewman 4

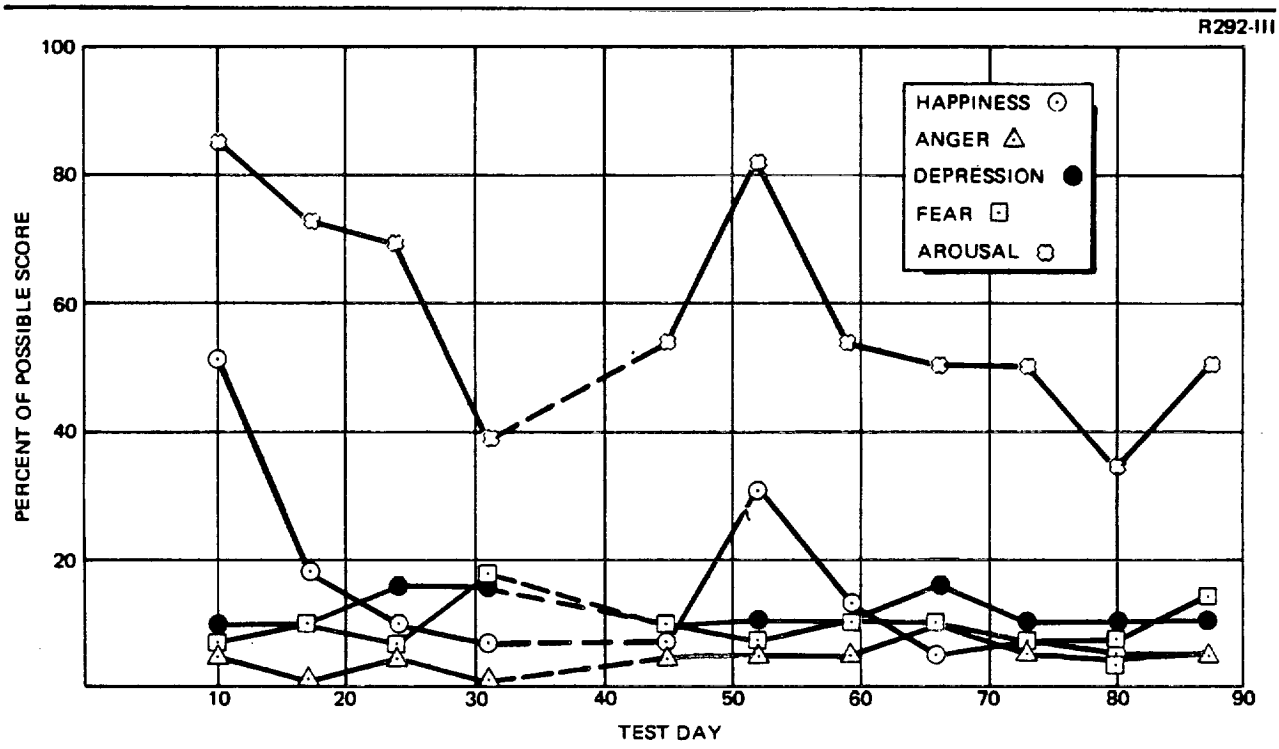


Figure 3-33. Primary Affect Scale Results for Crewman 1

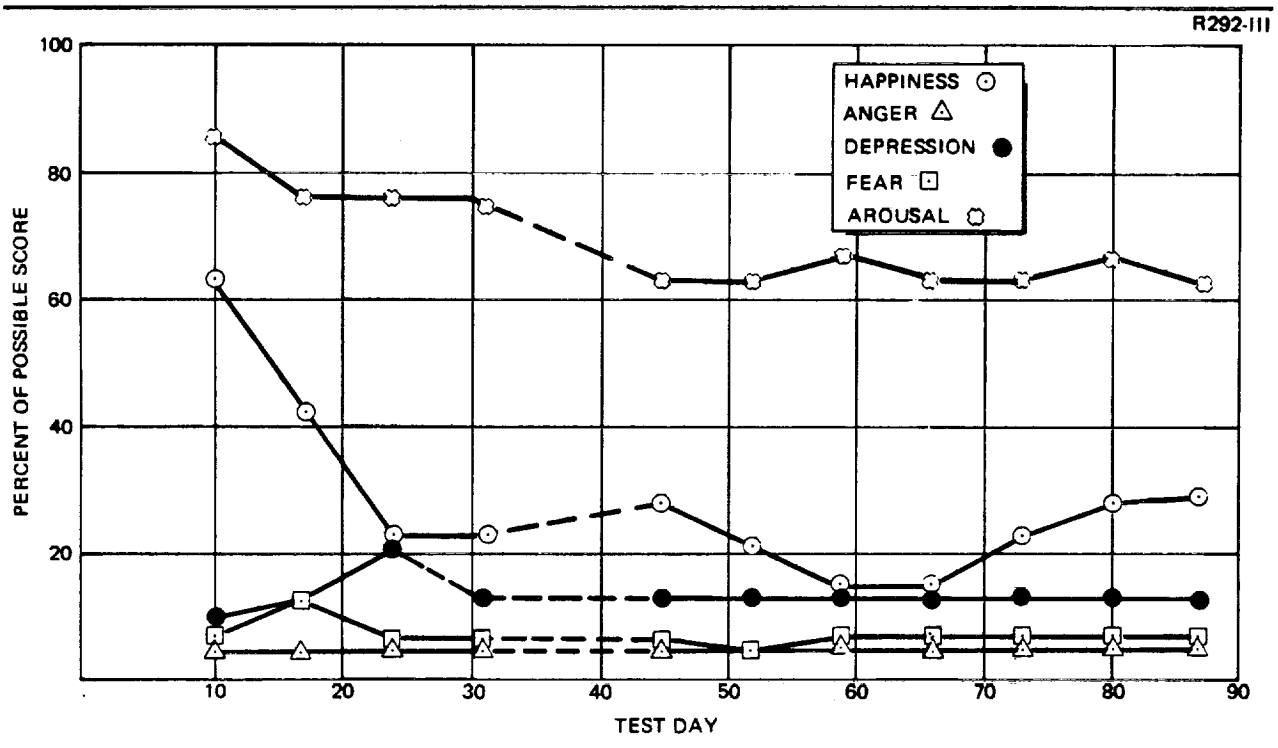


Figure 3-34. Primary Affect Scale Results for Crewman 2

Happiness scores became positively monotonic on day 73, but never reached baseline. The anger, fear, and depression scales showed no significant changes.

Happiness and arousal scores for crewman 3 began with a much lower baseline than the preceding two crewmen (Figure 3-35). It then proceeds with a moderate increase followed by a slight decrease. A marked peak occurred on day 52 on the happiness scale coincidental with a smaller increase in arousal. The day 52 happiness peak is followed by an extremely severe drop on day 59 with subsequent scores showing return to baseline and a moderate increase. Arousal apparently plateaued on day 59 and remained constant throughout the remainder of the mission. The anger, fear, and depression scales showed no significant changes.

For crewman 4, the happiness scale scores reflected little variation with a slight peaking on day 32 followed by a low on day 45 (Figure 3-36). Arousal began falling off on day 32 and did not show any increase until day 66. On days 66 and 73, the anger scale reflected increasing anger, associated with a high for the depression scale on day 73. A return to baseline occurred on day 80 with the final day 87 administration maintaining this level.

3.4.2.9 Personal Space Measure

This test required each crewman to periodically indicate, by drawing a circle around three-view diagrams of a human figure, how closely he could be approached by others without discomfort. No significant indications resulted from this test although crewman 4 consistently drew smaller circles than the other three crewmen.

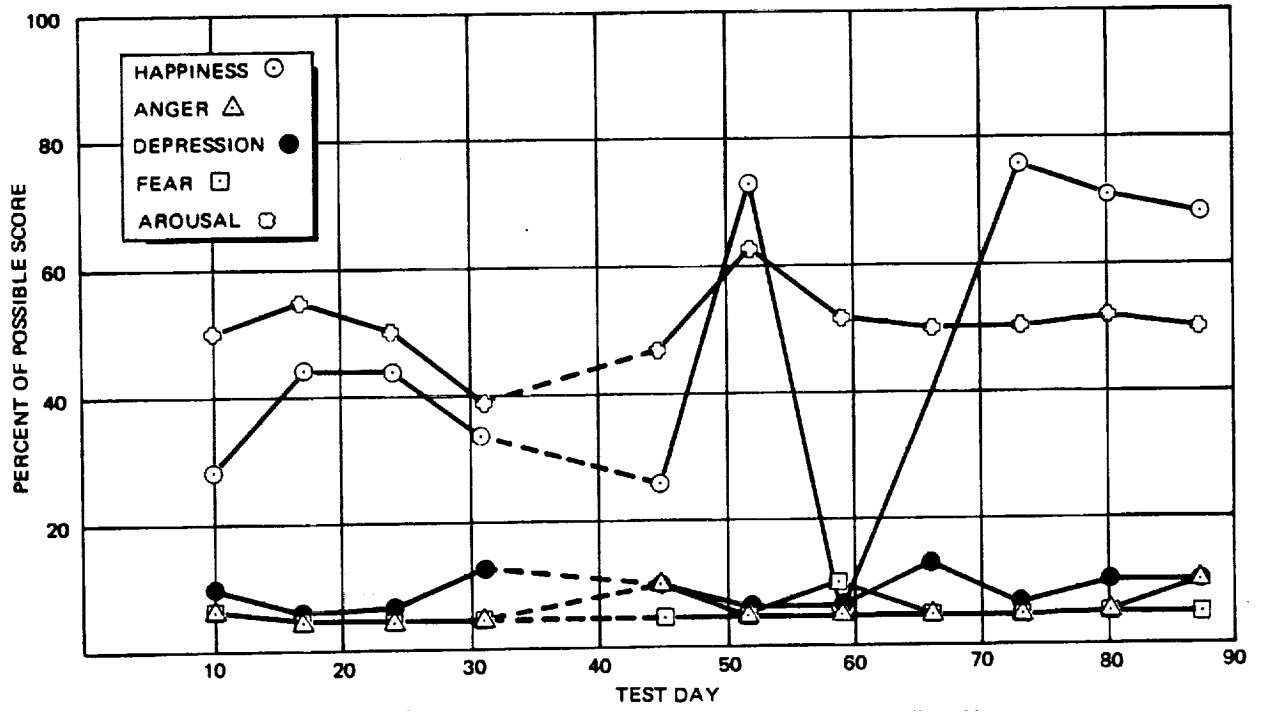


Figure 3-35. Primary Affect Scale Results for Crewman 3

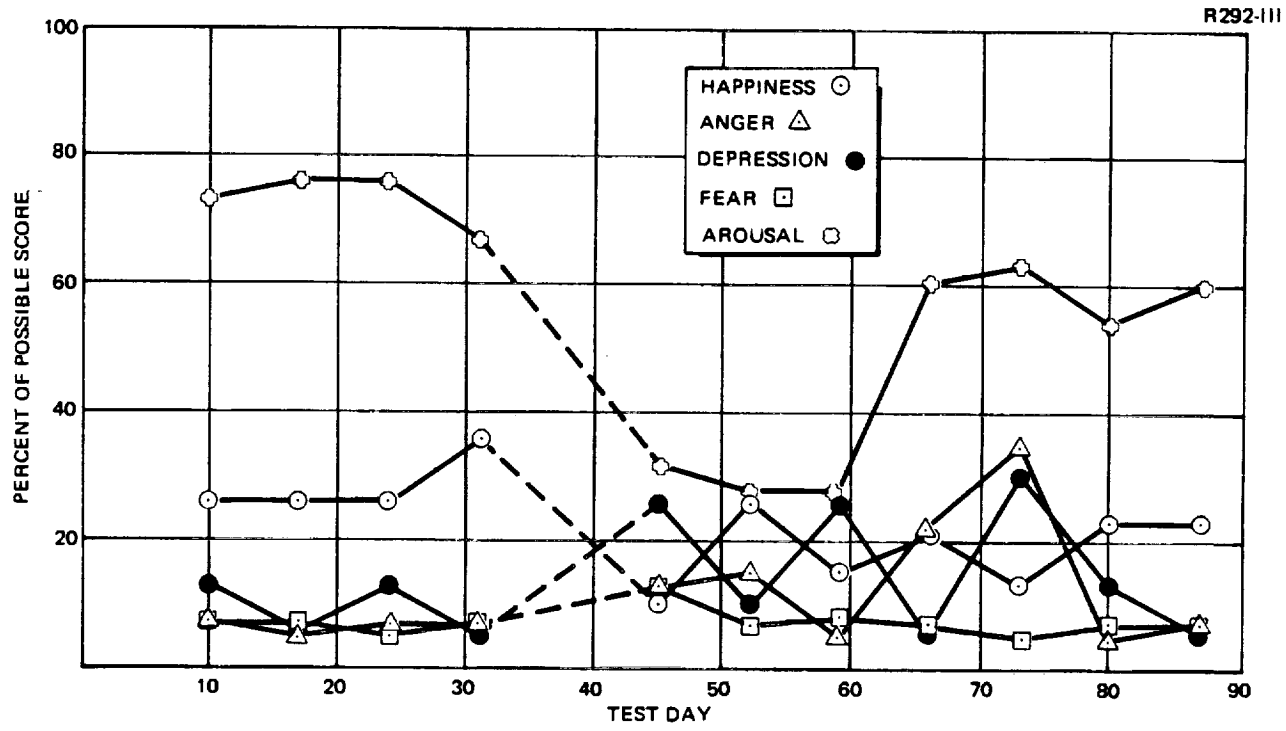


Figure 3-36. Primary Affect Scale Results for Crewman 4

3.4.2.10 Psychomotor Test Devices

As mentioned, the psychomotor tests performed by the crewmen included the LRC Complex Coordinator, the Response Analysis Tester (RATER), and the Critical Task Tester.

Operation of the RATER is described in the CR111882, Section 12.2. However, the results from this device were somewhat erratic, and over 30 days in the middle of the test are missing because of a malfunction of the device, so that useful data were not obtained.

Operation of the Critical Task Tester, also known as the human describing function experiment, is also explained in CR111882, Section 12.3. This device was used throughout the test, and raw data obtained was transmitted directly to the experiment principal investigator at NASA-Ames. The results of the use of the device are included in Section 3.10 of this report. The crewmen accepted the tests as a required task, but were not enthusiastic about their application.

As previously mentioned in Section 3.3.2.3, the crewmen did appear to enjoy use of the LRC-Complex Coordinator. This device, which is described in CR111882 (Section 10.4), was used extensively before test start to achieve apparently asymptotic performance. During the test, it was used three times each day. Each use required 100 trials and needed between 2 and 4 minutes of actual test time. Each trial was set up by a randomly programmed cam-switch which repeated after each 50 trials. In spite of the numerous

repetitions of the sequence, the crewmen were not consciously aware of remembering more than the first few combinations of the programmed sequence. However, a general continuous improvement in their time requirements continued throughout the test period with the exception of several days following day 55 when a spring broke on a foot pedal. This improvement appeared to be unrelated to other factors that might influence performance, such as subjective mood, state of well being, or physical parameters such as temperature or relative humidity. Strict correlations have not as yet been conducted, however, and the raw data has been transmitted to the principal investigator at NASA-LRC, who will perform more rigorous correlation studies.

Figures 3-37, 3-38, 3-39 and 3-40 show mean daily scores for each crewman over the 90-day test duration. The mean of the last three pretest trials is also shown.

3.4.3 Discussion

The decreases seen in the PAS arousal and happiness results for crewman 1 indicate increasing lethargy and decreasing pleasure with the mission. From about the second week on, crewman 1 saw the 90-day test as uninteresting. Day 52 or thereabouts, however, was a relatively significant period for him. A hostility scale indicates increased negativity toward outside personnel while the PAS reflects increased happiness and arousal. The first point may be partially explained by the occurrence of a disagreement between crewman 1 and the outside staff over task completion on day 49. (All psychological tests

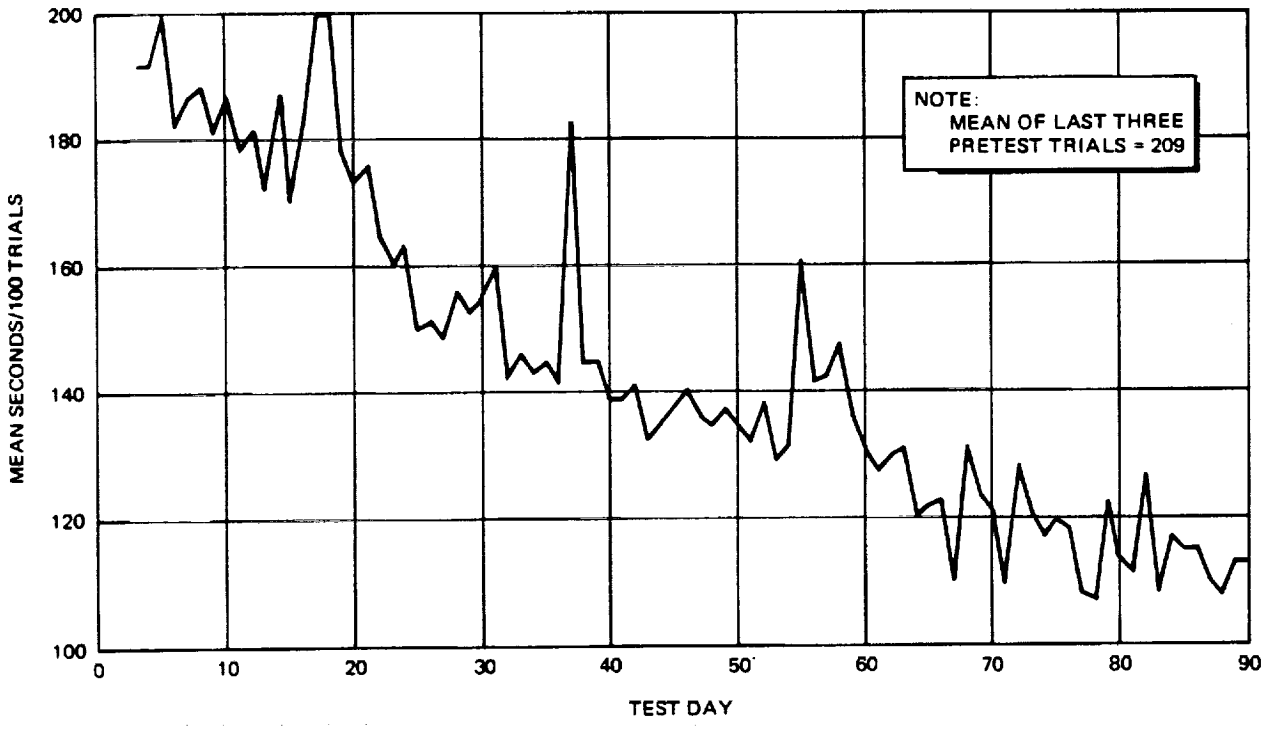


Figure 3-37. LRC-CC Daily Scores for Crewman 1

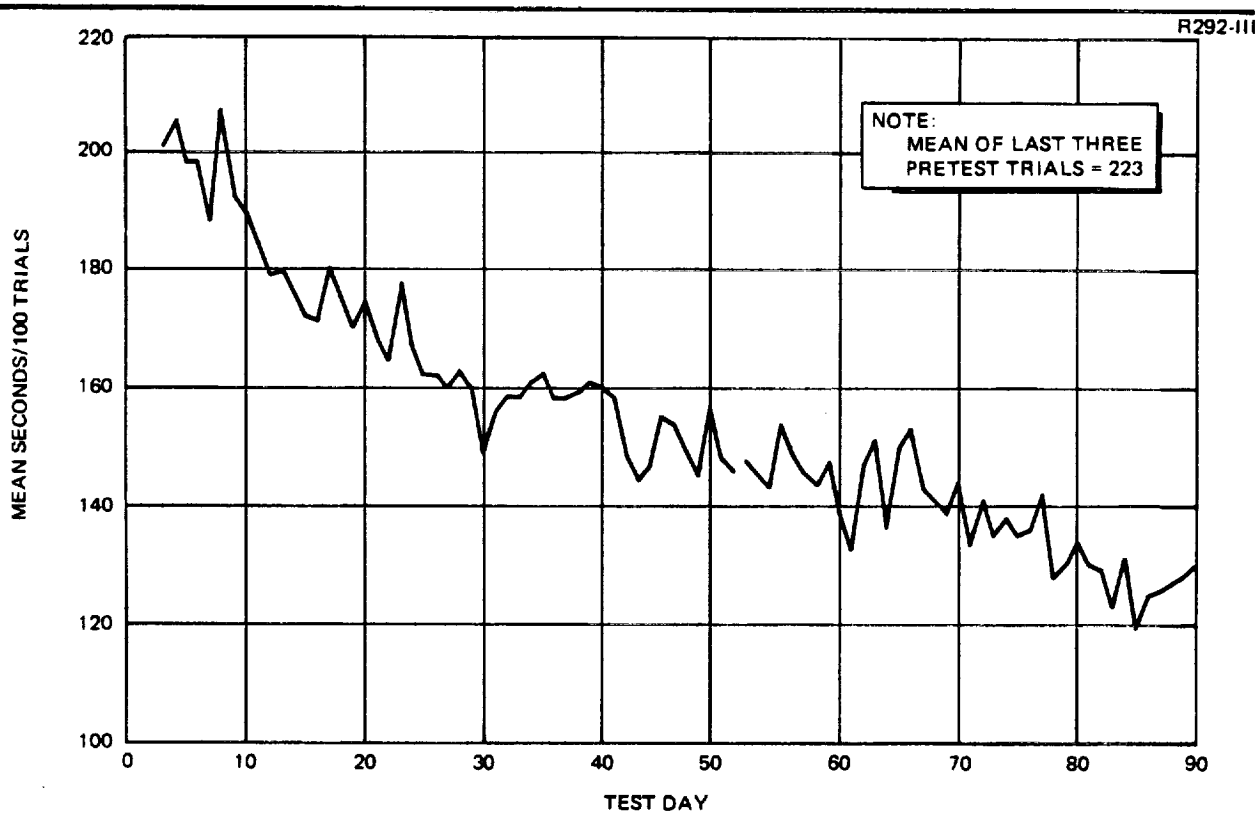


Figure 3-38. LRC-CC Daily Scores for Crewman 2

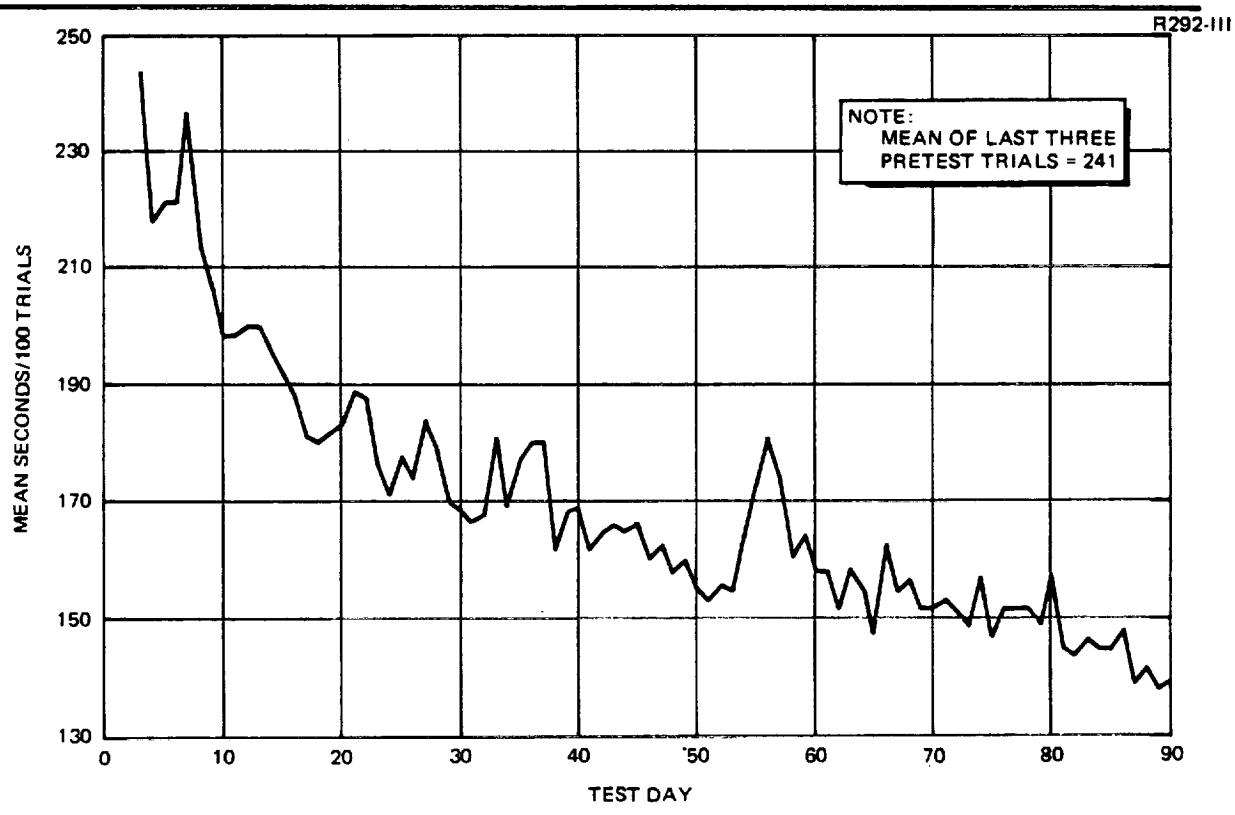


Figure 3-39. LRC-CC Daily Scores for Crewman 3

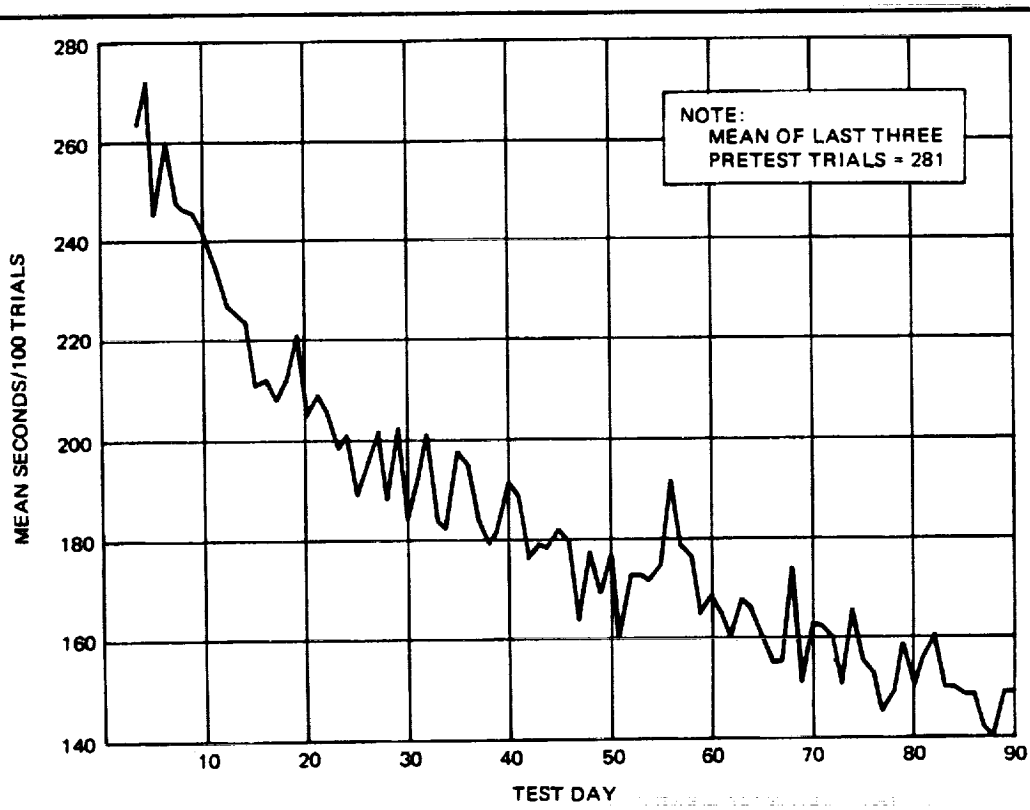


Figure 3-40. LRC-CC Daily Scores for Crewman 4

have instructions that relate them to the preceding week. For example, on the PAS, the crewman is requested to select a phrase that best describes the way he felt during the past week.) It was a minor problem but of sufficient proportion to warrant crewman 1 entering an account of the situation in his diary. Relative to the PAS results, on day 52 crewman 1 had a phone conversation, performed extensive exercise beyond that scheduled, and participated in still photography with the other crew members. Support for this explanation is also given when the complete inversion of the ISQ tedium scale over the positive contemplation scale is noted. Crewman 1 apparently suffered from boredom and inactivity a great deal of the mission, but the period around day 52 was not one of those times.

The extremely high and low scores for the positive and negative categories of the GCI seem to indicate that crewman 1 denied the existence of negative feelings toward his fellow crewmen. This finding is consistent with comments made in a debriefing session to the effect that it was not fair to rate fellow crewmen negatively.

With respect to the apparent increase in the unreality scale of the ISQ, it should be noted that this scale includes a gastrointestinal symptom scale. At this time crewman 1 was suffering real, but minor, problems in this area. Thus the resultant elevation in his score.

Subjective stress and hostility scale results for crewman 1 show fluctuations and levels independent of one another so are evidently not measuring related phenomena. Stress was recorded at very low levels whereas both hostility scales showed significant changes. Two scales (hostility toward fellow crewmen and toward outside personnel) begin with similar curves, gradually increasing in level, and then fall off markedly. It is difficult to know why the falloff occurred. It may reflect an initial adaptation syndrome or a reaction to high workloads. Three of the four crewmen show similar results.

Crewman 2's PAS results indicate that he began the mission with a high degree of optimism that gradually declined to a fairly low level. The PAS arousal scale drops somewhat, but not as severely. The results are apparently valid as observational records indicate that crewman 2 exhibited little change in physical activity throughout the mission. Furthermore, no inversion of the ISQ tedium scale with the positive contemplation scale occurred as it did with crewman 1. The decline in happiness or, more generally, positive affect is also seen in the ISQ positive contemplation scale and the positive category of the GCI. A low period for crewman 2 occurred during the third quarter of the test. The emotional lift at completing half of the run was over and was followed with the awareness that half of the run was still left and it was not a short time. Progressively the happiness scores increase again probably reflecting joy at the diminishing time of confinement. Tending toward corroboration, a slight increase may also be noted in the positive category of the GCI on day 86.

The lack of any changes in the Subjective Stress Scale results for crewman 2 may indicate uniformity of stress throughout the run, which is doubtful, or lack of interest and impatience with the stress test and deliberate response falsification, which is more likely. This latter point was reinforced by debriefing comments.

A similar lack of wide variations is seen in both hostility scale results with one exception. In hostility toward outside personnel, crewman 2 shows a high level spike on day 31. None of the associated tests reflect this increase nor do any of the observational notes. Evidently some singular unrecorded event or comment was the cause. It also may have been an error on the computer keyboard. The high score recorded requires the entry of a 10, whereas to record a more consistent score of 60 takes a 1.

Similarly inexplicable is the noted increase in the ISQ positive contemplation scale on day 37. Results for the other crewmen indicate a trend for the positive contemplation scale and the PAS happiness scale to support one another. Such was not true in this case.

Crewman 3, who was on the inverted sleep cycle with crewman 4, shows a reverse from crewmen 1 and 2 on the PAS happiness scale. He begins low, increases, and then decreases. Crewmen 1 and 2 begin high and continuously decrease. Since the PAS arousal scale also follows a similar pattern for crewman 3, it may be that the inverted sleep and activity schedule was affecting the results. Crewman 4's results support this as will be discussed later. The week preceding day 52 must have been a good one for crewman 3. The PAS happiness and arousal scales show increases which are supported by a marked decline in both hostility scales. Diary comments during the previous

week revealed: a phone call to his parents, pleasure at the visit of two NASA astronauts, and apprisal of a news release about the mission. Also, accomplishment of 50 percent of the 90-day duration occurred. Unfortunately crewman 3 did not fare so well during the succeeding week as indicated by the day 59 decline. The PAS happiness scale drops to the lowest possible score and hostility toward fellow crewmen increases markedly. Analysis of operational and anecdotal records indicates that crewman 3 was upset at what he considered to be negligence by another crewman in maintaining the operational status of an onboard system. The subsequent increases in the PAS happiness scale can generally be attributed to approaching the successful end of the run.

Over all, crewman 3 had very low hostility and stress scores. Comments by the outside staff members strongly support the low results for outside-directed hostility. Support for the low inside directed hostility is also found, but not so strongly, in debriefing comments and his diary.

As mentioned earlier, crewman 4 shows the same reversal as crewman 3 in his PAS happiness scale results. He begins at a low level, increases slightly and then decreases to generally the same level as the rest of the crew. His arousal data decline follows the same curve as the other crewmen and can be attributed to the same cause, i.e., inactivity and boredom. The subsequent increase and plateau of arousal beginning around day 66 is apparently real, but cannot be supported by other usually supportive data such as the happiness and tedium scales.

The ISQ positive contemplation scale shows the same decreases as the PAS happiness scale, as might be expected. The reason that no increase is seen in the early stages of the ISQ scale is probably due to the spacing of the administrations. By the time of the second administration of the ISQ, the happiness scale indicates the same downward trend as the positive contemplation scale. Crewman 4 shows an inversion of the tedium and positive contemplation scales as did crewman 1, but for one day only. This occurred during the third quarter of the run along with a fairly high PAS depression score. Comparing these results with other crewmen indicates that crewman 4 was experiencing a mildly negative reaction to confinement during the latter portion of the 90-day test.

Of significance is the marked decline in hostility by crewman 4 toward fellow crew members that was evidenced around day 65. During the week preceding this test administration, crewman 4 as crew commander, made a formal statement to the Program Manager concerning what he and the rest of the crew believed to be ill-considered demands on their time. Adjustments were made on the outside because of this. This exercise of the commander's role was probably a satisfying experience for crewman 4. On the day following, outside TV newscasters interviewed and made films of the crew in various pseudo-operational activities. After the news production was completed, the entire crew sat around and pleasantly discussed the morning's activities for a few hours. The above are coincidental events and may help explain an otherwise enigmatic data point.

Crewman 4 shows a few moderate peaks in his outside directed hostility results. On day 39, prior to the high noted on day 45, the crew had been reprimanded for an impromptu system modification. An entry in crewman 4's

diary indicates that he believed the reprimand was justified, but thought it was handled poorly. This may have been reflected in the score. The peak on day 59 may have been brought about by an increased sensitivity about the psychological aspects of the run. Again relying on diary entries, crewman 4 appears to have become quite resentful about the NIPA program (Section 3.9) and inopportune comments made by an outside staff member implying a lack of individuality among the crew. Resolution of the problem seems to have occurred the following week as no significant deviations are shown on the curve.

Stress for crewman 4 was relatively low level throughout the run with a slight peak occurring at the end.

Sleep and sociometric data are best discussed as combined group functions. With respect to the sleep results it would be expected that the crew pair on the inverted circadian rhythm would show adaptation to pretest sleep durations by approximately the second week. This did not occur. Self reported sleep duration times indicate complete adaptation did not occur until around the fifth or sixth week. Another measure typically used to show adaptation is oral temperature. Data from this measure indicate adaptation occurred around the fourth week (Section 4.5.2). The disparity between the two measures may, in part, be a function of the error inherent in the self-report technique used in the sleep questionnaire. Regardless of the origin of the disparity, however, it still appears that adaptation to a changed diurnal cycle required longer than the literature would predict.

The sociometric data indicate a minor loss of crew integrity over the entire mission. This was mainly the result of an apparently irreconcilable incompatibility that existed between two of the crewmen. It was not a major difficulty that in any way affected their performance, but was mutually annoying. Actually it appeared to the outside staff that a close knit group was never formed. The crew functioned more as professionally motivated individuals who happened to be in the same place and tolerated the inconveniences while occasionally making use of the others.

The LRC-CC results display a classical learning curve function. Days 55 to 57 are exceptions and are the consequence of a broken pedal spring. The pedal was repaired but required a higher operating force. Adaptation evidently occurred by day 58 and the scores continued their downward trend.

3.4.4 Conclusions

Negative reactions to confinement appeared infrequently during the test. Beginning to appear after 2 weeks, they became a definable pattern after approximately 60 days had been completed. Seen by outside observers as increased sleep time, decreased mission task activity, unusual inactivity, and startling few interpersonal interactions, this behavior pattern was manifested in test results as slumps in positive affect scores and increases in tedium and scores associated with negative affect. This episode persisted for almost a week with no indication of a potential reversal. Program management discussions with crew members resulted in its being labeled as a "morale decline." At the recommendation of program management, an "encounter session" (round-table discussion) was undertaken onboard at the instigation of

the crew commander on day 69. The discussion revealed that numerous minor irritations had accumulated among crew members which had previously not been voiced. Surprise was a common response to complaints aired during that session. This was accompanied by resolutions to alter behavior to suit the needs of those offended. Behavioral and biochemical data support the contention that an improvement in morale began almost immediately thereafter, which carried through for the remainder of the test duration.

Reported intracrew hostility was generally quite low, but situations did occur and for the most part are reflected in the data. When situations did develop they were typically the result of a crewman becoming angry at another crewman for some type of operational omission rather than the result of an interpersonal disagreement. Occasionally life styles did clash but the crewmen always put professionalism before this sort of problem preferring to repress hostilities than to deal with them openly. As mentioned in diaries and debriefings, mission completion was the goal and no individual wanted to interfere with the goal.

During the test, sociological observations revealed little group cohesiveness. Social-emotional penetrations among crew members were essentially absent, thus eliminating the possibility of the establishment and maintenance of close, warm, human relationships. The crew can be characterized as close-working, professionally motivated, impersonal, and noninteractive in spite of the attempts made through cohesion training (Section 3.1.2) to foster the development of a group. The 90-day test can only be characterized as an emotionally sterile experience, as a consequence of the absence of warm interpersonal relationships.

Such a condition served as the basis for a negative or neutral crew reaction to confinement. The overall low-level scores in the negative test categories and the stress scale indicate that the test was not perceived as stressful by the crew. Whereas the mission may not have been severely stressful, neither was it a particularly happy or pleasurable experience for the crewmen.

Certain behavioral tests (ISQ and GCI) may be insensitive to the low levels of stress inherent in the SSS. Unless additional information comes to light which denies this conclusion, these tests are prime candidates for elimination from future batteries.

The suggestion that crewmen may have consciously biased behavioral test scores on at least the hostility scale (corroborated by post-test debriefings) indicates that the validity of some of these devices for assessing affect states of individual crewmen is highly suspect. This conclusion points out the desirability of increased effort to develop valid techniques for the measurement of affect states. Other tests, however, such as the PAS showed a great deal of similarity in findings to other studies, Project RIM in particular (Reference 3-14). The arousal and happiness curves, which show a least-squares correlation of 0.85 ($p < 0.01$), are quite similar in shape and magnitude.

The crew believed the primary cause of boredom was the inadequacy of the work program. This inadequacy resulted in an overall use of crewmen for approximately 1,200 man-hours of work out of a total available time of 4,700 man-hours. This is an approximate 14-percent utilization of the crew for mission-related tasks. As time progressed during the test and as subsystem difficulties were resolved, free time available to crewmen increased and work-related activities decreased. Hopefully, this is unlike what would be expected on an actual mission in terms of utilization of time by crewmen over the mission duration. Almost without exception, all crewmen felt that more could have been accomplished in terms of work performance onboard had there been more to accomplish. As with most group confinement studies, inactivity, or time not devoted to productive mission-related work, may be considered anathema. This is a primary problem to overcome in successfully scheduling activities of crewmen for long-duration confinement situations.

During debriefings, the crew expressed a desire for more responsibility in running the mission. This is particularly true in regard to the role of the Crew Commander. The role of the Crew Commander apparently was not satisfactorily defined before the mission. Consequently, the Crew Commander was uncertain about his responsibilities and authority. This uncertainty affected his satisfaction in job performance to no small extent.

Unfortunately, the minimal behavioral effects noted during this 90-day test do not provide sufficient information to permit extrapolation to missions of greater duration. Similarly, information based upon a group of four provides little data for the prediction of behavior of groups consisting of more than four crewmen.

3.5 MANNED MISSION ACTIVITY ANALYSIS

The objectives of the mission activity analysis (MAA) experiment on the 90-day test were to generate manual and computer schedules of planned crew activities for the purposes of:

A. Exercising and evaluating the planning and scheduling capabilities of the LRC Space Station Mathematical Model (SSMM).

B. Evaluating the applicability of the operational schedules by a comparison of actual crew performance with manual and computer-generated crew activity schedules.

The experiment objectives were successfully accomplished. Both the SSMM-produced crew activity schedules and the MDAC manual schedules were operationally acceptable. The MAA experiment crew descriptions and scheduling activity acted as a forcing function for the early identification and resolution of problem areas and operational constraints. The MAA crew activity schedules were utilized successfully as an aid to the management of crew activities and materially contributed to the successful operations conducted during the test.

3.5.1 Mathematical Model Description

The LRC SSMM is an integrated set of 11 computer programs which provides the capability for in-depth mission and program planning (Figure 3-41 and References 3-15, 3-16, and 3-17). The many interrelated space vehicle elements, such as crew skills, human factors, vehicle capabilities, experiment programs and station operations and logistics, are considered in their proper perspective and the interacting effects of these variables are analyzed with respect to their effectiveness on the total mission.

The SSMM is responsive to requirements for detailed mission plans, evaluations of accomplishments, and resource use. To validate the techniques used and the results obtained, it is necessary to obtain real inputs and to employ these as a basis of comparison between computer outputs and activity data representative of realistic missions. The 90-day test provided a unique opportunity to test and evaluate the use of schedules to help allocate the manpower resource within the framework of a well-defined system and an established program of activities. It also provided a realistic data base for comparison of manual and computer planning methods and for the evaluation of the effectiveness of the SSSM.

The mission activity analysis experiment made use of the SSMM to schedule activities onboard the SSS. The emphasis in this experiment was in the use of the planning model to set up the initial schedule for 90 days and the one-day model to support scheduling efforts for day-to-day activities. Limited time and resources precluded the use and evaluation of the other models in this experiment.

A brief description of the two models used and evaluated on the manned mission activity analysis experiment are given here.

The planning model provides the capability for a wide range of studies involving the determination of resource requirements, crew scheduling analyses, and accomplishment rates of planned onboard activities. The principal operations of this program are the calculation of expendable usage, determination of a satisfactory logistic profile, development of the station-keeping task and experiment schedules, mission cost calculations, and a summary of mission resource utilizations.

The model develops a mission operational plan analogous to one which would be made before performing an actual mission. The planning model is a deterministic model in which the entire mission is viewed as a single problem. Initially, the station expendable requirements are determined based on an input crew profile. Next, any required logistics payloads are determined. The scheduling routine is then employed to schedule the operations required to maintain the station, and to schedule the experiment program. Finally, the evaluation routine provides a summary of mission requirements and the effectiveness with which the available resources were used.

The one-day model (ODM) provides the capability to timeline the mission on an event-by-event basis. A set of basic descriptors for all events which occur on the day being scheduled are input to the ODM. These descriptors quantify the resource requirements for event accomplishment.

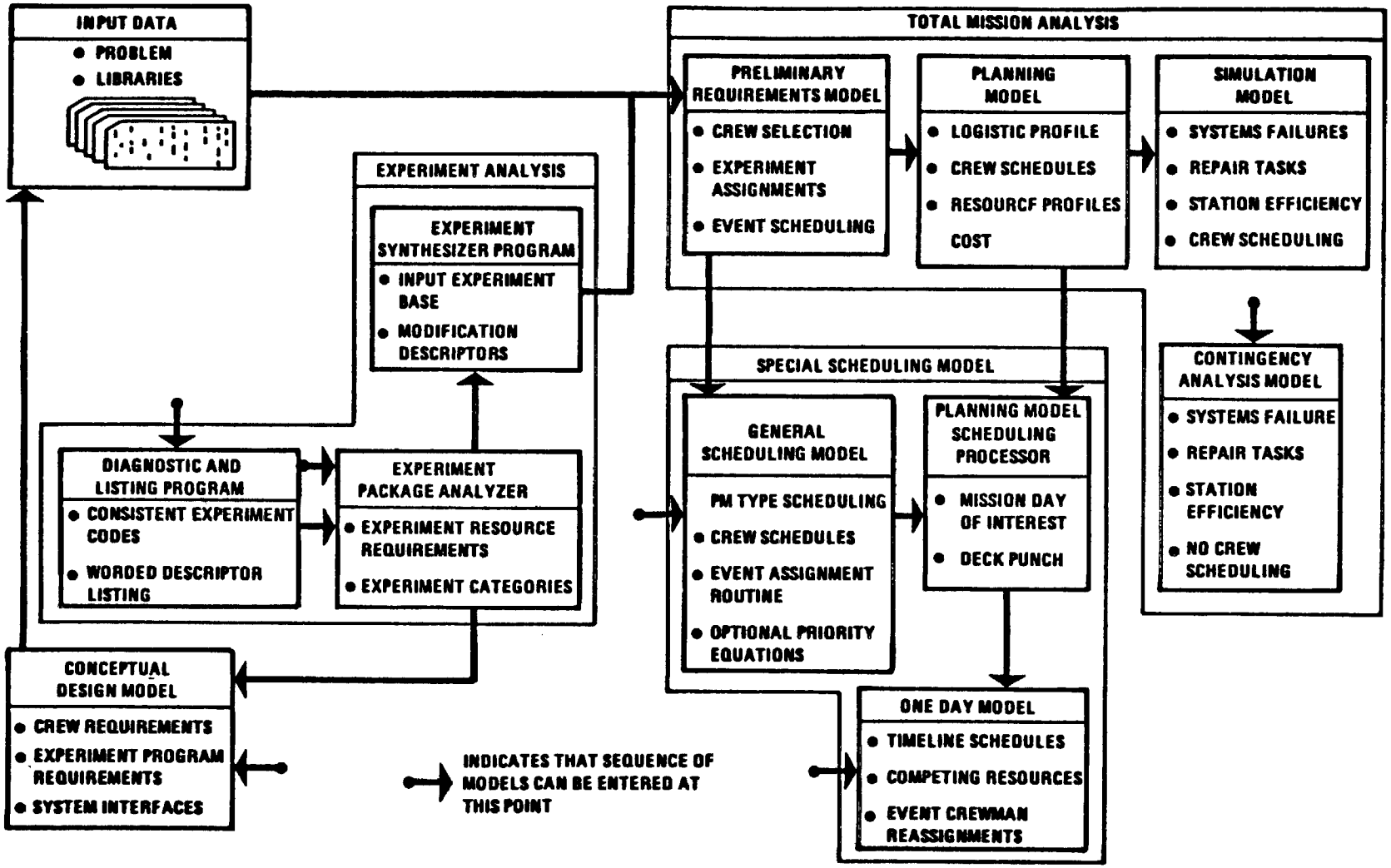


Figure 3-41. Model Concept and Utilization Sequence

The ODM is organized into three basic sections; the first section contains:

A. The input routine which is responsible for reading the parameters which define the systems crew and required activities.

B. The priority routine which determines the order in which events are to be considered for scheduling.

C. The orbital mechanics routine which determines the scheduling opportunities for the fixed time/position events if any, which are either earth target or celestial target constrained.

The second section contains:

A. The search routine which determines the set of sequential time points (beginning at time t_o) at which an attempt will be made to schedule an event.

B. The resource compatibility routine which determines if sufficient resources are available at any time points where an attempt is made to schedule an event.

C. The bookkeeping routine which maintains a current timeline record of the resources used and those which remain available for scheduling.

The third section consists of the output routine. There are three basic types of output from the ODM:

A. Timeline profiles for each event, each crewman, and each resource.

B. A set of scheduling diagnostics indicating why the unscheduled events were not scheduled.

C. A set of accounting and resource utilization printouts.

With this varied set of capabilities, it is possible to perform studies involving different work-sleep cycles, equipment sharing, time-position event scheduling, skill proficiency effects, scheduling rate conflicts, effects of team tasks, data dumps, EVA, and crew mobility rates.

Basically the ODM can be used in two major application areas. The first of these is to aid in prerun task analysis mission planning. The ODM can pinpoint problem areas which may occur at the daily level of crew and station activity. In this capacity, the ODM is allowed to schedule with very few constraints and the result will point out operational problem areas, show possible resource conflicts, and point up design difficulties.

The second application area for which the ODM is useful lies in its capability to aid in scheduling activities which are to be conducted to support an actual mission. In this capacity the model works out daily schedules taking into account the necessary operational constraints and resource limitations of the mission. At this point the station design is set, the resources limited, and schedules must take these and other operational constraints into account.

3.5.2 Pretest Documentation

Mission activity analysis was accomplished through mutually supporting, but independent efforts: MDAC employed manual planning and scheduling techniques and NASA-LRC utilized the SSMM. The more significant areas required for the accomplishment of this effort are discussed below. It is considered of some importance that they be presented in sequence to provide a better understanding of the statement "mutually supporting but independent efforts" (Figure 3-42).

3.5.2.1 Crew Skill Matrix

LRC designed the data submittal format for the crew skill and crew event matrices to insure that all essential data items were provided for adequate exercise of the planning and scheduling capability of the SSMM. The formats were coordinated with MDAC to insure that they would allow the inclusion of all test and operational constraints and provide an easily understood and usable method of presenting the data.

The crew skill matrix (Table 3-16) was a combination of requirements as stated by MDAC and LRC personnel. The matrix described in general terms the skills required by the individual crewmen for the purpose of providing basic data for crew assignments of events. This information was used in the planning model in the generation of the mission event profile. The original crew skill matrix design was essentially the same as that presented in

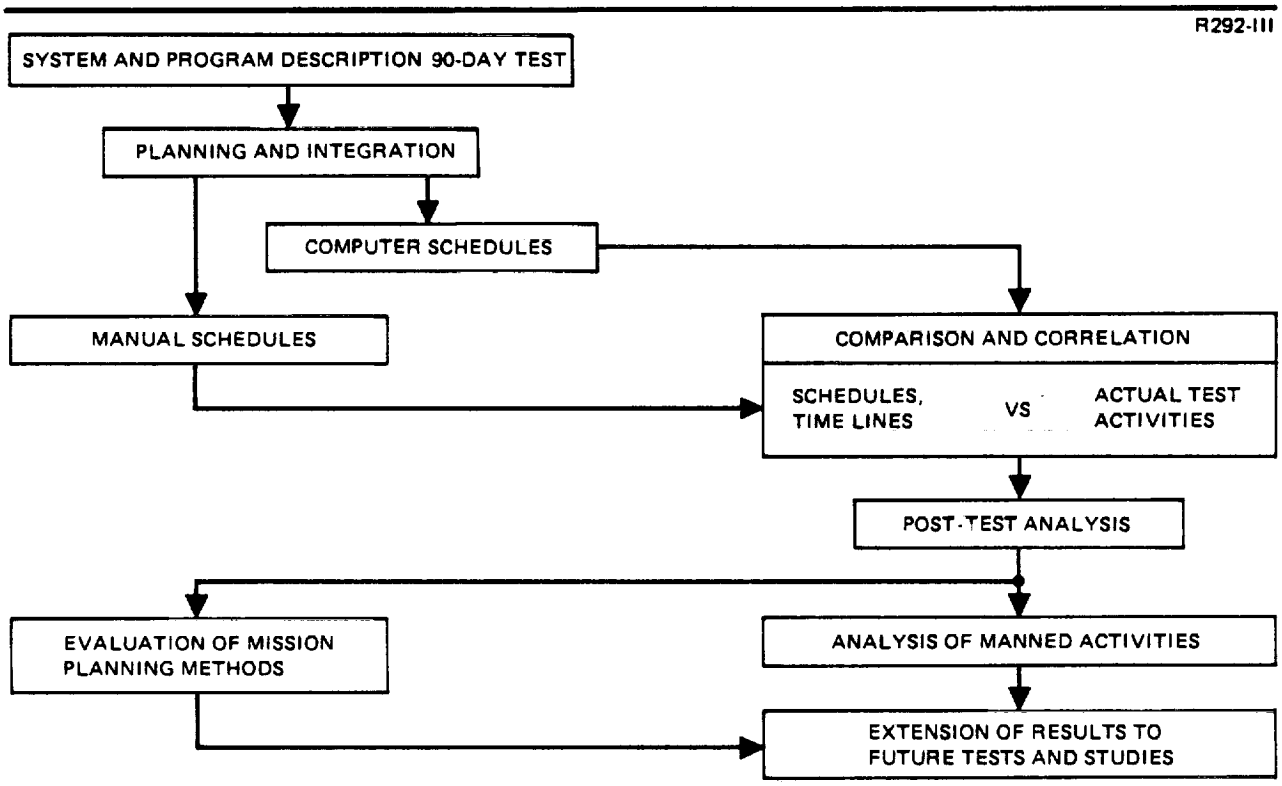


Figure 3-42. Mission Activity Analysis Overview

Table 3-16

CREW SKILL MATRIX

Skill	Crewman 1	2	3	4
1. Mechanics	2	2	1	1
2. Electrical/electronics	2	1	2	1
3. Microbiology	1	1	2	2
4. Biochemistry	1	1	2	2
5. Medical treatment	2	2	2	2
6. Photography	1	1	1	1
7. Utility	1	1	1	1
8. Special, requires crewman 1	1	0	0	0
9. Special, requires crewman 2	0	1	0	0
10. Special, requires crewman 3	0	0	1	0
11. Special, requires crewman 4	0	0	0	1

1 - Primary skill, 2 - Secondary skill, 0 - No skill

Table 3-16. However, as training progressed, and more became known about the individual skills of the specific crewmen, it was necessary to make some changes in the definition of primary skills and secondary skills for individual crewmen. As an example, subsequent to the 5-day test, final selection of the crew for the 90-day test was made and crew identification numbers were assigned. With this designation of crewmen, it became necessary to realign primary and secondary skills because of crewman 1's (CM1) background and affinity for the biochemical and clinical biology tasks. Crewman 2's capabilities in these areas, as demonstrated during training, indicated that he should also be designated as having primary skills in this area. Crewmen 3 and crewmen 4 both demonstrated mechanical aptitude in training and they were, therefore, designated as having primary skills in the areas of mechanics. For the same reason, crewman 4 was designated a primary in the area of electrical and electronics skills.

Once these selections were made and the crew skill matrix agreed to in final form, it became a prime document for assignment of tasks in the various disciplines designated. Both manual and computer schedules had this matrix as a standard item for scheduling purposes.

Skills 8, 9, 10 and 11, which were designated special, were primarily used for computer purposes for areas such as blood samples, body wash, exercise, etc., which required that each individual crewman participate in the specified event.

The zero designation indicates that the specified crewman has no skill in the designated skill area.

3.5.2.2 Crew Events Matrix

The data submittal format for the crew events matrix was designed by LRC to ensure that all essential data items were provided for adequate exercise of the planning and scheduling capability of the SSMM. The formats were coordinated with MDAC to ensure the inclusion of all test and operational constraints and provide an easily understood and usable method of presenting the data (Table 3-17 and 3-18).

The formatting of the crew event data was accomplished by MDAC personnel using traditional methods commonly used during the initial planning stage of any program; that is, by utilizing system and experiment descriptions and by interviewing engineers and experimenters. The review of system and engineering descriptions had been initiated prior to the implementation of the mission analysis activities experiment and, therefore, the majority of the initial effort was spent in the interviewing of principal engineers and experimenters to obtain information on those activities in which the crew (onboard) would participate during the 90-day test. Each individual area, such as biomedical and manned systems, was completed before contacting the principal investigators in the next general area. As might be expected, during this initial phase of data collections, the individual principal investigators and experimenters had not given sufficient detailed thought to the description and procedures required by the onboard crew for the successful completion of particular events. Interviews with individual experimenters took as long as 4 hours to obtain the information necessary to adequately complete the crew events matrix in each of the areas. As each interview progressed, the principal investigators and experimenters became aware of the necessity for exchange of information and realized the importance of defining requirements for events. In addition to providing information to be used purely for scheduling, this part of the MAA experiment effort proved doubly valuable in that it forced each individual to recognize that this was an integrated test, that individual requests had to receive priorities and that it would be necessary to resolve conflicts in the constraints defined. In some instances, stated requirements had to be modified for the test to operate as a total systems evaluation rather than an application of individual events in specified areas. Insufficient time exists, in the initial phase of any program, for individuals to do other than confine their mode of thinking to their particular specialty. An integrated systems test dictates that integration aspects be emphasized early in the program to insure that individuals do not lose sight of the overall test objectives.

At the time of this initial effort, the final selection of all systems and experiments had not been made. Therefore, the first crew event matrix described approximately 50 events, some of them incompletely, and all with conservative time estimates. There were three major revisions to the crew event matrix

Table 3-17. CREW EVENT MATRIX (1 of 7)

No.	Event	Frequency	Skill	Crew Time	Equipment	Pre-Event Restrictions	Post-Event Restrictions	Power	Work Area	Remarks
M1	Aerosol Particle Analysis	1/day (See Remarks)	Any	5 min for two filters	Four samplers				1	Change filter in two samplers each day. Change filter in four samplers once per week. Filters passed out.
M2	Bacteria Sample Count	24 and 48 hr after bacteria sample tests	3	24-hr check (10 min) 48-hr check (5 min/ sample)					2	Every day (starting on Day 4) at approximately the same time. Time varies per water sample matrix.
R3	Bacterial Sensor Experiment	Every other day Start on Day 3.	3	30 min	Microbial monitor				1,2	Schedule in conjunction with water samples and tests. Must use same sample for both events.
R4	Bed Linen Change	Every 14 days Start on Day 12	Crewman*	10 min					4	Schedule during 4-up period.
M5	Biomedical Checks	1/day/crewman	Crewman*	15 min for two crewmen		M43 Sleep			2	Two-man event. Schedule immediately after sleep event. Body weight prior to first voiding.
M6	Blood Samples	1/wk/crewman on pass-out day	Crewman*	10 min for two crewmen		Crewmen 1 and 2 prior to breakfast Crewmen 3 and 4 prior to dinner			2	Two-man event. Schedule before M33 nose and throat swabs. Medical director request.
M7	Blood Tests	1/wk/crewman on pass-out day	4	10 min for four samples			Schedule maximum of 60 min after blood samples		2	Medical director request.
R8	Body Hygiene–Shave	1/day/crewman	Crewman*	10 min	Electric razor, wash water system			326 w 14 w dc	3	Crew request: schedule prior to breakfast.
R9	Body Hygiene–Wash	1/day/crewman	Crewman*	30 min	Wash water system	Schedule after exercise		326 w 14 w dc	3	Crew request: schedule after exercise.
R10	Breakfast	1/day/crewman	Crewman*	60 min	Microwave oven, potable water dispenser, wash water system			2.2 kw 63 w dc 326 w 14 w dc	2,3	Time for one crewman may be decreased by 20 min if two crewmen are scheduled to eat at same time.
R11	Cabin Cleaning	2/week	Any	30 min					1,2,3,4	Crewmen rotate duty at their discretion. Schedule during 4-up period.
M12	Commode Liner Change	Once on Day 47	1	180 min					3	Two-man event.
M13	Deleted (Data Management)									
M14	Descriptive Sentence Test	1/2 wk/crewman, Start on Day 6	Crewman*	5 min	TSCL				1	Mission analysis monitor gives go-ahead to crewman, times for 3 min, gives stop signal. Same as M21.
R15	Diary	1/day/crewman	Crewman*	15 min					2,4	

*Each crewman individually

Table 3-17. CREW EVENT MATRIX (2 of 7)

No.	Event	Frequency	Skill	Crew Time	Equipment	Pre-Event Restrictions	Post-Event Restrictions	Power	Work Area	Remarks
R16	Dinner	1/day/crewman	Crewman*	80 min	Microwave oven, potable water dispenser, wash water system			2.2 kw 63 w dc 326 w 14 w dc	2,3	Time for one crewman may be decreased by 30 min if two crewmen are scheduled to eat at same time.
M17	Deleted (Electrolysis Maintenance)									
M18	Exercise	1/day/crewman except Sat and Sun	Crewman*	45 min/crewman Thursday: 90 min/ two crewmen	MRM Bike blower			165 w	1	Two-man event on Thursday. Crew request: schedule prior to body hygiene–wash. Schedule minimum 1 hr after meal.
M19	Food Consumption Data	1/day/crewman	Crewman*	15 min	TSCL	(See Remarks)			1	Crewmen 1 and 2 after dinner and prior to 2400. Crewmen 3 and 4 after breakfast and prior to 2400.
R20	Glycerol-Based Drink	4/day/crewman for 5 days, 2 times during test, near midpoints of first and last 30 days	Crewman*		TSCL				1	Schedule in conjunction with meals and snacks. Questionnaire data included in Event M19. Crewmen 1 and 2 last drink min 8 hr prior to pass-out. Crewmen 3 and 4 last drink lunch prior to pass-out.
M21	Group Confinement Inventory	1/4 wk/crewman	Crewman*	20 min	TSCL				1	Schedule 2000 to 0600 or 1500 Sat to 0600 Mon. Operational requirement for TSCL.
M22	Habitability Evaluation	1/2 wk/crewman, start on Day 7	Crewman*	25 min	TSCL				1	Same as M21.
M23	Hostility Scale	1/wk/crewman start on Day 10	Crewman*	5 min	TSCL				1	Same as M21.
R24	Human Describing Function	1/day/crewman Sat: 3/crewmen Sun: none	Crewman*	15 min/day/crewman Sat: 10 min/ 3/day/crewman	Critical task tester, communication system				2	Schedule within ± 1 hr of same time each day. Requires 10 min equipment warmup. Per experiment protocol.
M25	Ion Exchange Element Recharge	1/test on Day 58	1	60 min					1	Two-man event. Will recharge when required, probably in last third of test.
M26	Isolation Symptomatology	1/4 wk/crewman, start second wk	Crewman*	60 min	TSCL				1	Same as M21.
R27	Laundry	1/2 wk/crewman, start on Day 12	Crewman*	30 min wash, 10 min dry, 10 min cleanup and storage	Wash water system, dryer, communication system	Communication monitor OK prior to event		3 kw	3	Sequence: 30-min wash cycle (crewman time required). 90-min dry cycle 10 min to load and unload (crewman time required). 90-min dry cycle 10 min for cleanup and storage (crewman time required).

*Each crewman individually

Table 3-17. CREW EVENT MATRIX (3 of 7)

No.	Event	Frequency	Skill	Crew Time	Equipment	Pre-Event Restrictions	Post-Event Restrictions	Power	Work Area	Remarks
R28	Lighting	1/wk (See Remarks)	Any	10 min	Light meter				1,2,3,4	First month: 1/wk. Second month: after any light change. Third month: 1/wk.
M29	LRC Psychomotor Test	3/day/crewman; early, middle, and late shift	Crewman*	10 min	Psychomotor tester, communication system	Communication monitor OK prior to event			1	Schedule ± 30 min same time each day per experiment protocol.
R30	Lunch	1/day/crewman	Crewman*	70 min	Microwave oven, potable water dispenser, wash water system			2.2 kw 330 w 63 w dc 326 w 14 w dc	2,3	Time for one crewman may be decreased by 20 min if two crewmen are scheduled at same time. Crewman 1 performs daily radiation survey of microwave oven.
M31	Mass Balance Data Collection and Reporting	1/day	Any	15 min	CLSM, TSCL, communication system				1	Schedule between 2000 and 0600 to assure TSCL availability.
M32	Medical Interview	1/day/crewman	Crewman*	10 min/crewman	Communication system				1	Schedule between 0900 and 1600. Operational requirement.
M33	Nose and Throat Swabs	1/wk/crewman	Crewman*	10 min/2 crewmen		Prior to throat wash sample			2	Two-man event. Schedule on Tues prior to pass-out.
M34	Personal Space Measure	1/crewman on Days 4, 25, 46 and 67	Crewman*	5 min	TSCL				1	Same as M21.
R35	Photography	1/4 days	Any						1,2,3,4	At crew discretion.
M36	Primary Affect Scale	1/wk/crewman start on Day 10	Crewman*	5 min	TSCL				1	Same as M21.
R37	Psycho-Acoustics	1/mo	Any	20 min					1,2,3,4	
M38	Psychologist Interview (if required)	1/mo/crewman	Crewman*	45 min	Communication system				1	Scheduled crewman* only in area 1.
R39	Response Analysis Tester (Rater)	1/2 days/crewman	Crewman*	15 min	Rater, communication system	Communication monitor OK prior to event			1	Crewmen 2 and 4 start on Day 5. Crewmen 1 and 3 start on Day 4.
R40	Recreation (free time)	Daily/crewman	Crewman*	(See Remarks)					2,4	Schedule continuous free time period daily of approximately 3 hr if possible. Crew request: 30 min free time after dinner. Scheduled events have priority over free time periods.
M41	Safety Inspection	1/day	Crewman 4	10 min					1,2,3,4	Responsibility of crew commander.

*Each crewman individually.

Table 3-17. CREW EVENT MATRIX (4 of 7)

No.	Event	Frequency	Skill	Crew Time	Equipment	Pre-Event Restrictions	Post-Event Restrictions	Power	Work Area	Remarks
M42	Sample Pass-Out	1/wk	Any	15 min		Event 50 immediately prior to pass-out			2	Tues: 0810 ± 15 min
M43	Sleep	Daily/crewman	Crewman*	480 min			Event 5, biomedical checks		4	Schedule crewmen 1 and 2 for same sleep period. Schedule crewmen 3 and 4 for other sleep period.
M44	Sleep Log	1/day/crewman	Crewman*	5 min	TSCL				1	Same as M21.
R45	Snack	1/day/crewman							2	Not scheduled event. Crew option during free time.
M46	Sociometric Questionnaire	1/3 wk/crewman, start third wk	Crewman*	5 min	TSCL				1	Same as M21.
M47	Station Atmosphere Samples	1/2 wk	3	(See Remarks)	Vacuum pumps			440 w	1,2	Schedule day before pass-out. Require 20 to 24 hr sample culture time prior to pass-out. Crew event initiation time: 15 min. Sampler's run time: 60 min. Crew event termination time: 15 min
M48	Station Surface Swabs	1/wk	Any	5 min			Pass-Out		2,3	Schedule on pass-out day prior to pass-out.
M49	Switch Water Tanks	1/2 days, start on Day 5	Any	10 min		Communication monitor OK prior to event			1	In conjunction with M56, VD-VF liquid transfer
M50	Throat Wash Samples	1/2 wk/crewman	Crewman*	5 min		Prior to eating or drinking	Pass-out		2	Schedule event for all crewmen immediately prior to pass-out on Tues. Medical requirement.
M51	TV Camera Maintenance	1/wk or as required	Any	5 min/camera		Communication monitor OK prior to each camera maintenance			1,2	5 cameras.
M52	Deleted (Urinalysis)									
M53	Deleted (Urine Sample for Urinalysis)									
M54	Urine Sample for Pass-Out	1/wk/crewman	Crewman*	5 min/crewman		Prior to blood sample			3	Schedule on day of pass-out.
R55	Visual Acuity Tester	1/wk/crewman	Crewman*	30 min	Visual acuity tester			100 w	2	Schedule at same time each day ± 1 hr. Schedule between 0800 and 1700.
M56	VD-VF Liquid Transfer	1/day, start on Day 3	Any	20 min					1	Schedule daily with water tests, M62.
M57	VD-VF Boiler Replacement	1/test on Day 44	Any	(See Remarks)					1	Best estimate for replacement day. Could be ± 5 days. Two-man event, 4 hr. One man monitor event for 5 min at 30-min intervals for 4 hr.

*Each crewman individually

Table 3-17. CREW EVENT MATRIX (5 of 7)

No.	Event	Frequency	Skill	Crew Time	Equipment	Pre-Event Restrictions	Post-Event Restrictions	Power	Area	Remarks
M58	VD-VF Boiler Startup	2/test on Days 2 and 44	Any	(See Remarks)					1	Same as M57 for times and constraints.
M59	Wash Water Filter Change	1/test on Day 71	1	30 min					3	Day 71 selection for schedule use only. Exact day of change cannot be predicted.
R60	Waste Management–Defecate			10 min	Waste management system. Wash water system.			748 w 280 w dc 416 w 400 Hz 326 w 14 w dc	3	At crew discretion.
R61	Waste Management–Urinate			5 min	Waste management system. Wash water system.			660 w	3	At crew discretion.
M62	Water Samples and Tests	Daily, start on Day 3	3	(See Remarks)					1,2,3	**See Table 3-20**
M63	Alpha Air Monitor Filter Change	Daily, start on Day 1	Any	5 min					1	Schedule at same time each day ± 60 min. Medical director requirement.
M64	Pencil Dosimeters Read and Charge	Daily, start on Day 1	Crewman*	2 min to charge 2 min to read					2	Read: Pre-sleep free-time period. Charge as required after reading.
M65	Film Badges, Film Change	1/wk/crewman start on Day 3	Crewman*	(See Remarks)					2	Schedule prior to pass-out.
M66	Ingress Chamber	Once	All	10 min/4 crewmen			All startup events		4	Includes airlock procedures.
M67	Communication System Check	Once	Any	10 min	Communication System	Ingress chamber			1,2,3,4	Initial communication check.
M68	Thermal Control Startup	Once	1	10 min					1	Two-man event.
M69	Humidity Control Startup	Once	Any	5 min					1	
M70	Wash Water Startup	Once	Any	5 min					3	
M71	Potable Water Startup	Once	Any	5 min					3	
M72	Waste Management Startup	Once	Any	5 min					3	
M73	Mass Spectrometer Startup	Once	Crewman 1	(See Remarks)					1	Crew time 15 min, stabilization 90 min, crew time 45 min, stabilization 15 min, crew time 50 min. (Start during hour 1).

*Each crewman individually

Table 3-17. CREW EVENT MATRIX (6 of 7)

No.	Event	Frequency	Skill	Crew Time	Equipment	Pre-Event Restrictions	Post-Event Restrictions	Power	Work Area	Remarks
M74	Two-Gas Control Startup	Once	Crewman 1	25 min (See Remarks)					1	Perform during hours 3 and 4 in conjunction with mass spectrometer sequence. Mass spectrometer 45 min, CO_2 15 min, mass spectrometer 50 min, CO_2 10 min.
M75	Sabatier/Toxin Burner Startup	Once	Crewman 2	(See Remarks)					1	Perform part 1 startup in hours 3 and 4. Perform part 2 startup after electrolysis startup, 30 min.
M76	Electrolysis Startup	Once	Crewman 2	60 min		After Part 1 Sabatier	Part 2 Sabatier		1	
M77	CO_2 Concentrator Startup	Once	Crewman 1	30 min					1	Perform during hour 7.
M78	Shutdown Procedures	Once	All	20 min					1,3	
M79	Egress Chamber	Once	All	10 min		Shutdown Procedures			4	
R80	Monitor Instruments	1/day for crewmen 1 and 2, 1/day for crewmen 3 and 4	Any	15 min					1,2,3	
M81	Subjective Stress Scale	1/wk/crewman	Crewman*	5min/crewman					1	
M82	Tritium Drink	1/run/crewman	Crewman*	5 min/crewman					2	Schedule at approximately Day 58, prior to first voiding. Urine sample for pass-out first voiding of day.
M83	Mass Spectrometer Verification	1/day for 14 days	Crewman 1	5 min, 30-min wait, 5 min					1	Schedule between 0900 and 1600. Requires intercom communication only. Frequency of event after Day 14 depends on unit stability.
R84	Pico Projector	(See Remarks)								Crew discretion during free time.
M85	EEG	Days 1 through 9 Days 42 through 46 Days 85 through 89		(See Remarks)			Sleep		4	Will be done on two crewmen. Crewman selection on 5 June, Crewman 1 and 3 selected. Two-man event to apply sensors and remove. (50 min to apply and calibrate, 10 min to remove).
R86	Behavioral Acoustics	1/wk/crewman Start on Day 8	Crewman*	30 min/crewman					4	If possible, schedule all crewmen sequentially to facilitate work outside principal investigator, 0800 to 1700.

*Each crewman individually

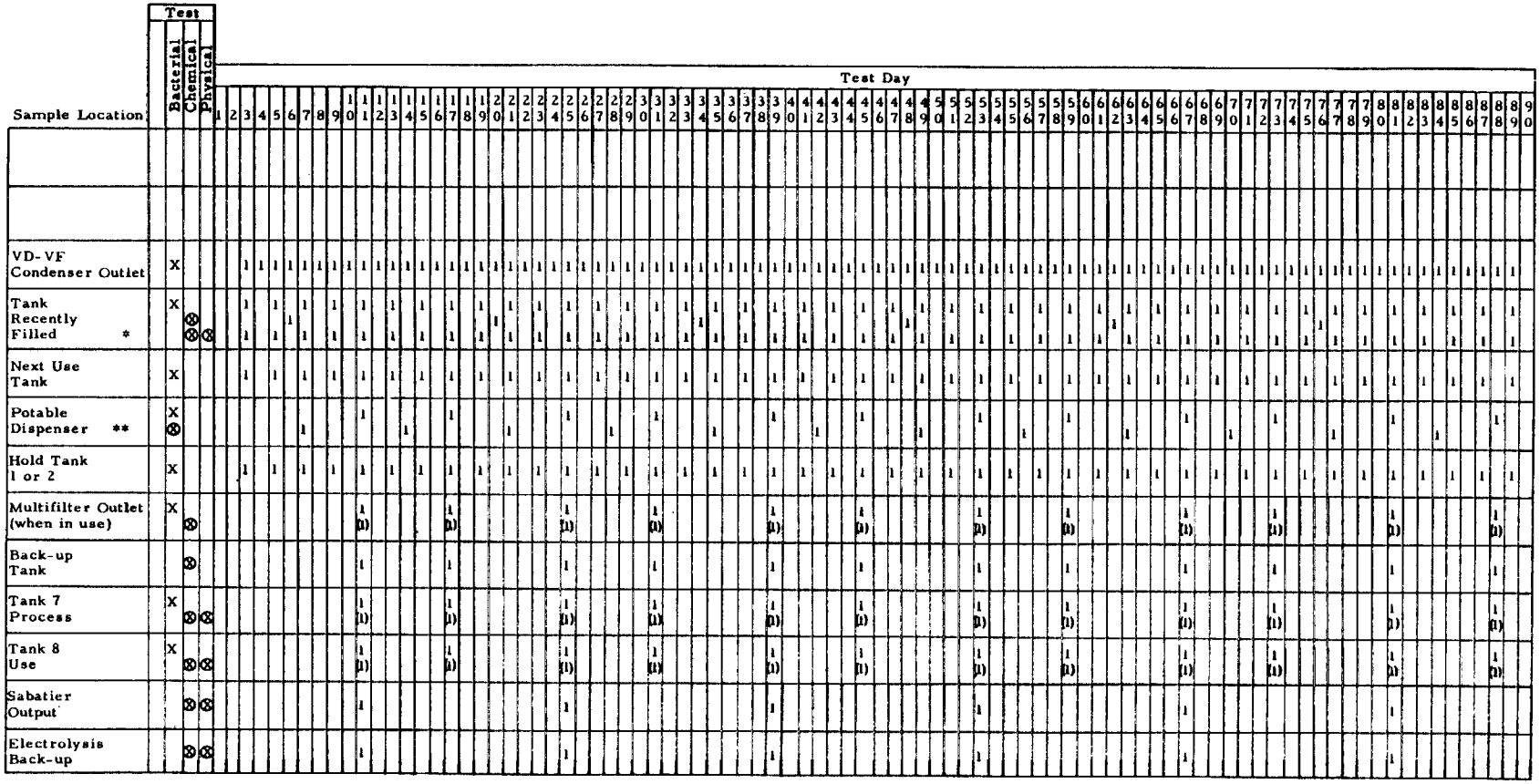
Table 3-17. CREW EVENT MATRIX (7 of 7)

No.	Event	Frequency	Skill	Crew Time	Equipment	Pre-Event Restrictions	Post-Event Restrictions	Power	Work Area	Remarks
M87	EKG	1/wk/crewman	Crewman*	10 min/crewman		No food for 2 hr prior to event			4	Two-man event. Outside staff support required. 10 min to apply, 5 min to remove sensors.
R88	Time Perception Experiment	Deleted 6/12/70								
R89	Flicker Fusion Experiment	Deleted 6/12/70								
R90	Energy Cost Experiment	Deleted 6/12/70								
R91	Mass Balance Experiment	Deleted 6/12/70								
R92	Spirometer	1/wk/crewman	Crewman*	5 min/crewman		None	None		2	Schedule between 0800 and 1700.
M93	Garbage Can Check	1/wk on Sun	Any	10 min						Pass out any bulging cans.
M94	Alveolar Air Sampling	See Remarks	Any	5 min/crewman		Prior to pass-out				Second pass-out: Crewmen 1 and 2 Third pass-out: Crewmen 3 and 4 Sixth pass-out: Crewmen 1 and 2 Seventh pass-out: Crewmen 3 and 4 Eighth pass-out: Crewmen 1 and 2 (baseline) Eleventh pass-out: Crewmen 1 and 2 Twelfth pass-out: Crewmen 3 and 4
R95	Adjective Checklist	Days 1, 2, 3, 4, 5, 15, 29, 43, 57, 71, 85	Crewman*	2 min/crewman					1	Schedule ± 30: Crewmen 3 and 4, 0300, 1200, 2100. Crewmen 1 and 2, 0800, 1400, 2200.
M96	Solid Amine Startup	1/test on Day 1	Any						1	

*Each crewman individually

Table 3-18

WATER SAMPLE MATRIX



⊗ Overboard Samples

*⊗ Overboard Sample Passed Out Through Sample Tube, All Others Pass-Through Airlock

(1) Same Sample-Dual Purpose

X Onboard Samples

** NOTE: Schedule Tuesday AM Prior to Pass-out

Samples: Overboard 122
Bacteria 192
Total Samples 314

Times: 3 Min. Draw Water Sample.
7 Min. Bacterial Test.
5 Min. Draw Water Sample and Pass-out Through Sample Tube.

to reflect the inclusion of refined data and to add new events as they were defined. The first revision was accomplished approximately 2 weeks before the 5-day manned test and incorporated principally the addition of procedures for equipment startup events. The times estimates for crew performance of each of the specified events were conservative and in some cases were amended as a result of information received during the training of the crewmen. The use of preliminary schedules based on this events matrix during the 5-day manned test proved the applicability of the methods that had been employed in the preparation of schedules. It also served to confirm certain event time estimates and provided the basis for revision to others. A detailed crew debriefing, an analysis of the log maintained during the 5-day test, and a review of selected portions of a time-lapse video tape, resulted in the second major revision to the crew event matrix.

During the time between the 5-day test and the start of the 90-day test, each crew event was arranged in alphabetical order on the crew events matrix and numbered sequentially. Each number was prefixed with either an "R" for recommended task or an "M" for mandatory task. This designation facilitated the evaluation of the performance of mandatory events for which the crew was to receive incentive pay.

The crew events matrix, after this revision, contained 95 events which had been described in detail or identified as probable candidates for performance during the 90-day test. During the week before the 90-day test was started, a complete review was held with the Test Engineering Director, the Medical Director, and the Behavioral Director in which the crew events matrix was reviewed to ensure that it described those events which would be active during the test. The number of events on the final events matrix was 87.

The importance of the crew events matrix to both the SSMM crew activity scheduling and the manual crew activity scheduling cannot be overemphasized. It was the common data base used by both LRC and MDAC for computerized and manual planning and provided a valuable comparison point for final evaluation. Although it was designed to provide the input required for the computer program, it also served, from an operational standpoint, to define each event in which the crew would participate, required the performance of a partial task analysis, and forced the early definition of constraints. Those constraints that would be applicable to the crew because of limitations in the ability of the outside staff to support onboard crew activities were of particular importance. An example of this was the requirement on certain events for nonsimultaneous performance by crew members because outside support would not allow operation of certain pieces of equipment at the same time. The LRC Complex Coordinator, the Ames Research Center (ARC) RATER, and the ARC Critical Task Tester, in which one outside crew member was required to operate all three pieces of equipment, were in this category. Some events required two men to perform the required tasks. An example of this was the biomedical tasks required on a daily basis by each crewman. Other events required that they be performed at specified times. An example of this was cabin cleaning as the noise from the vacuum cleaner was such that it had to be scheduled during periods when all four crewmen were up to preclude interfering with crewmen's sleep. An example of time critical events which required rigid sequencing is the passout operation and associated events, which were

scheduled Tuesday mornings. The blood samples had to be scheduled so that they could be passed out within 30 minutes after collection. Nose and throat swabs had to be scheduled before throat wash samples. The collection of station surface, nose, and throat swabs needed to be scheduled immediately prior to passout to ensure that the cotton swabs did not dry out before their availability for culturing by the microbiologist.

3.5.2.3 Mission Event Profile

The mission event profile (MEP) (Table 3-19) was the initial planning schedule determined by the Planning Model of the SSMM computer Program. This profile was a schedule of the crew activities for the entire 90 days organized on a day-by-day basis and indicated which events were to be active on each mission day. The input data required for this program were: the crew skill matrix, the crew events matrix, and the designation of the work/rest cycle to be employed during the 90-day test. The selection of a two up/two down cycle was based on considerations of safety and provided the best monitoring of advanced subsystem operation. The work/rest cycle closely approximates a work/rest cycle that was originally specified in the Space Station study being conducted by the MDAC for Marshall Space Flight Center. This sleep cycle provided coverage during the entire 24 hours for equipment operation and also provided for a maximum time up for all four crewmen during the normal plant work cycle to insure maximum interaction between onboard crew members and outside staff.

The use of the computer to generate the MEP provided a basis on which to evaluate the LRC model capability for long-term scheduling. It also eliminated the need to spend the extensive time required to manually generate the MEP. This profile was updated by MDAC as events were added to or deleted from the crew events matrix and it was the key document, when supplemented by details in the crew events matrix, used in crew activity scheduling.

3.5.2.4 Crew Activity Schedules

Crew activity schedules, consisting of 270 pages of 8-hour mission segments, were formulated on an independent basis by LRC and MDAC using the following items as standards: (1) mission event profile, (2) crew events matrix, (3) mission rules, (4) crew operating ground rules, and (5) work/rest cycles for each crewman.

The mission rules referred to above are contained in Section 3 of CR111882 and cover normal and contingency operating procedures for both the crew and the outside staff. The crew operating ground rules were formulated to establish guidelines for crew members and outside staff personnel during the 90-day test and as guidelines for use by computer programmers during interpretation of input data supplied by the crew events matrix. These rules are stated in Appendix D.

The manual formulation and subsequent revision of schedules was a difficult and time-consuming task. Each of the three major updates of the crew events matrix contained numerous changes which necessitated a major update of the

Table 3-19 (page 1 of 6)

MISSION EVENT PROFILE

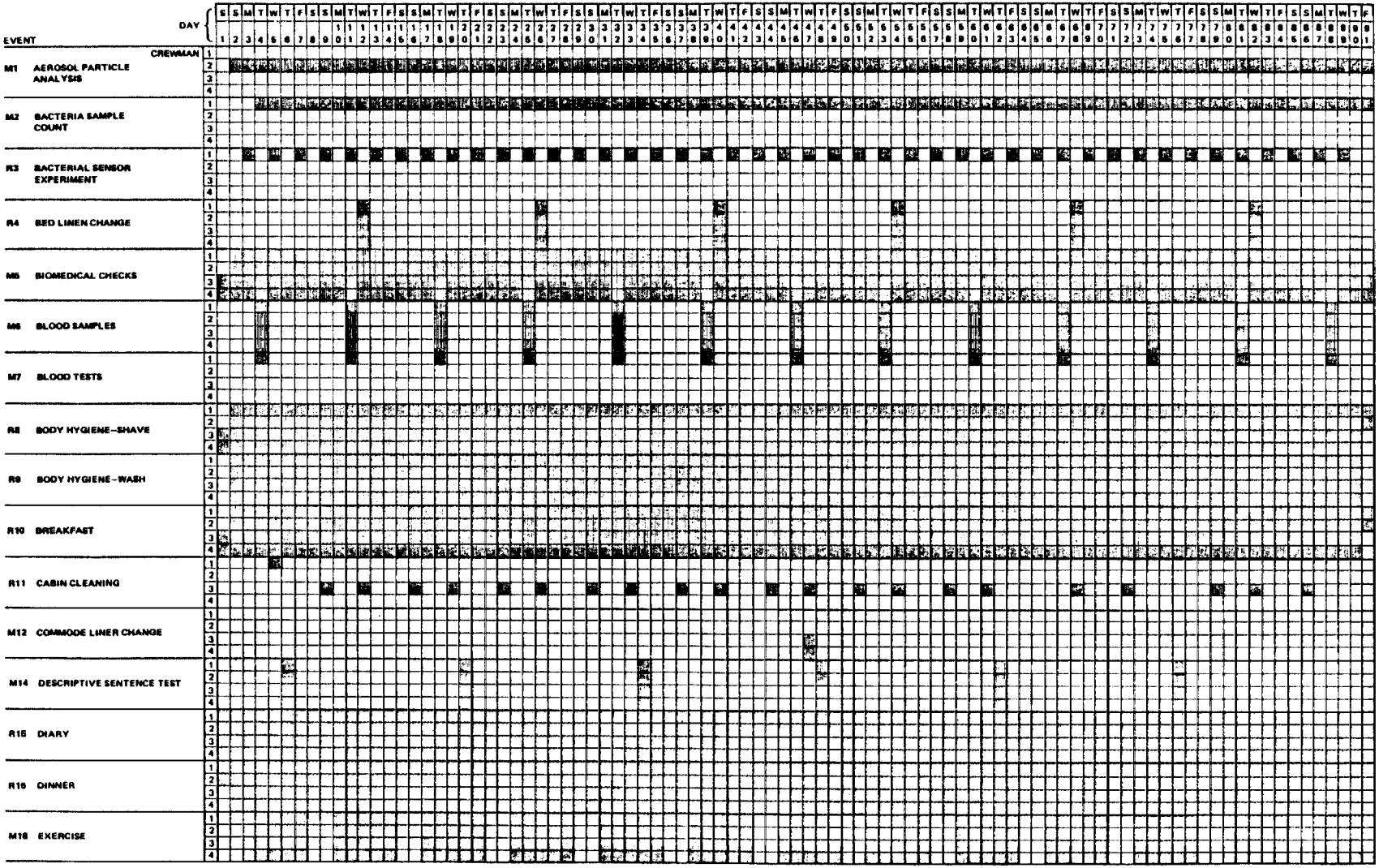


Table 3-19 (page 2 of 6)

MISSION EVENT PROFILE

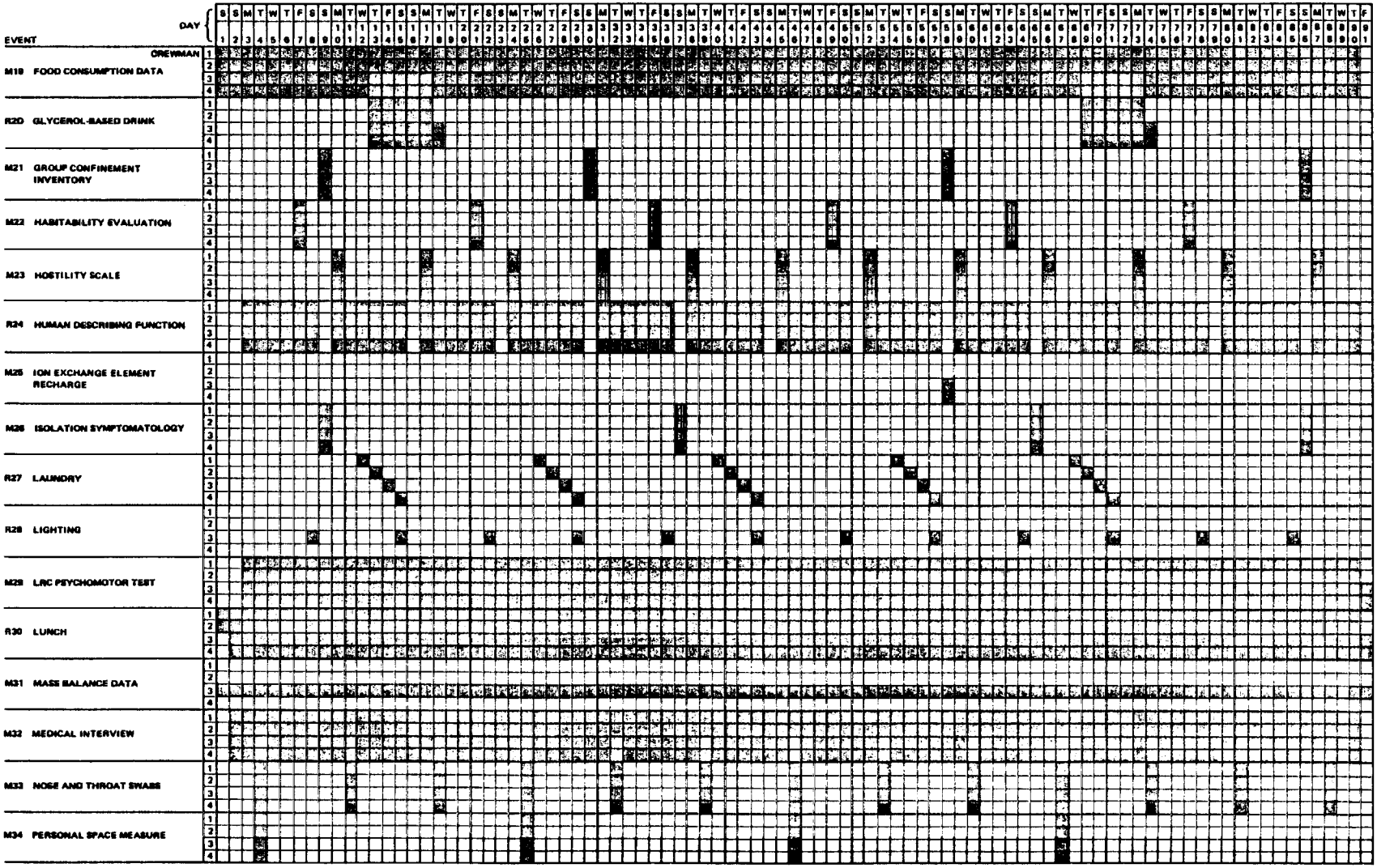


Table 3-19 (page 3 of 6)

MISSION EVENT PROFILE

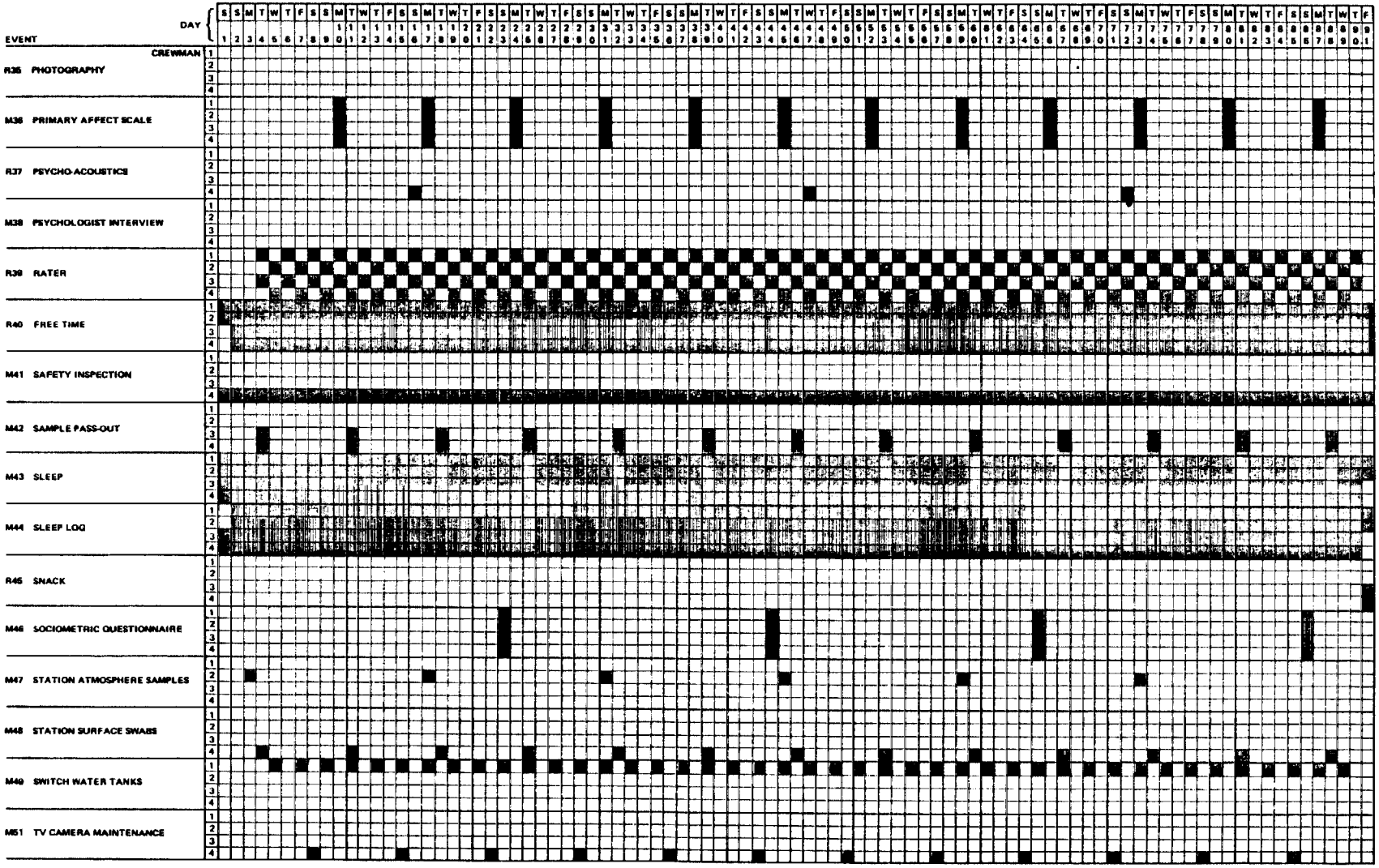


Table 3-19 (page 4 of 6)

MISSION EVENT PROFILE

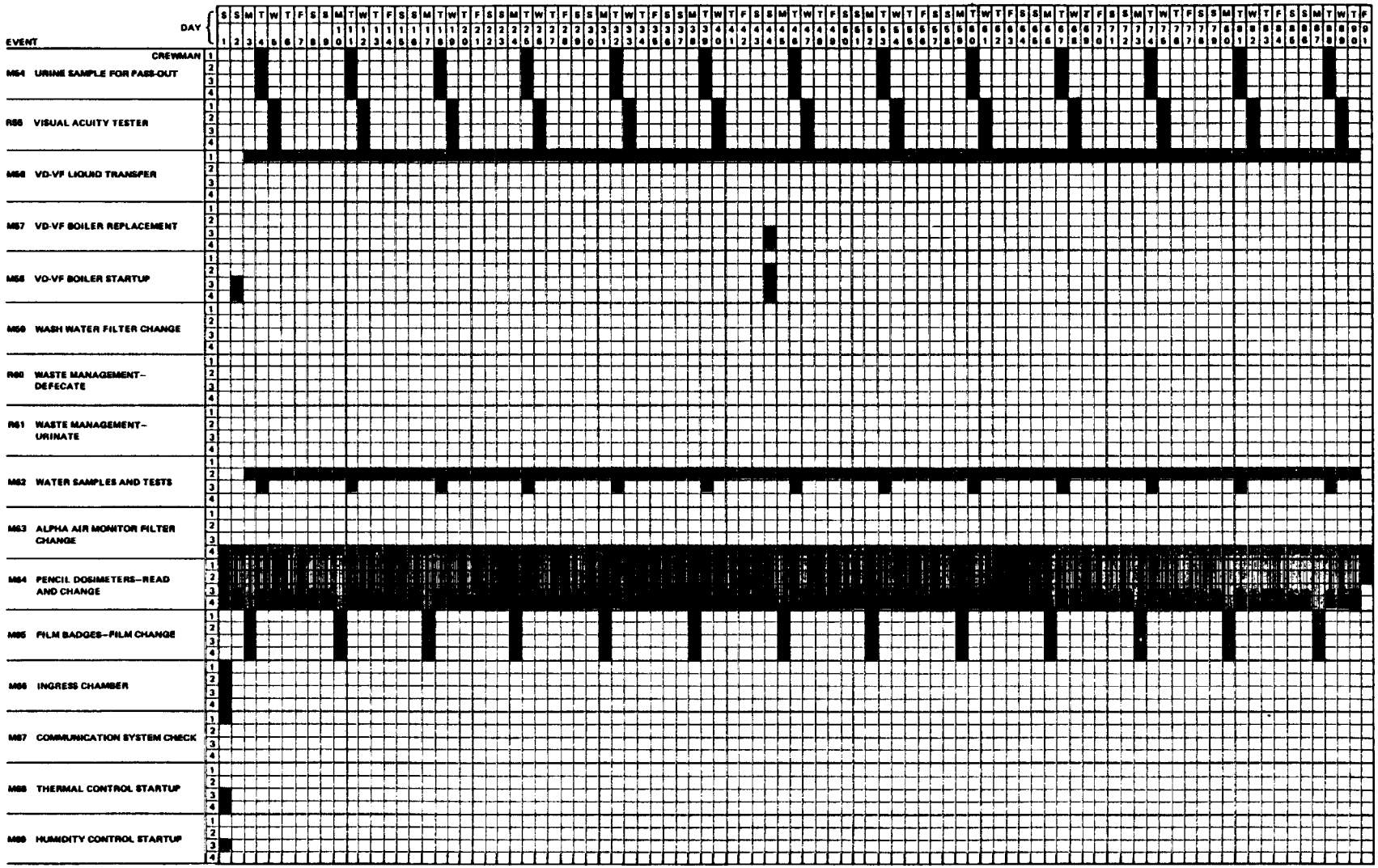


Table 3-19 (page 5 of 6)

MISSION EVENT PROFILE

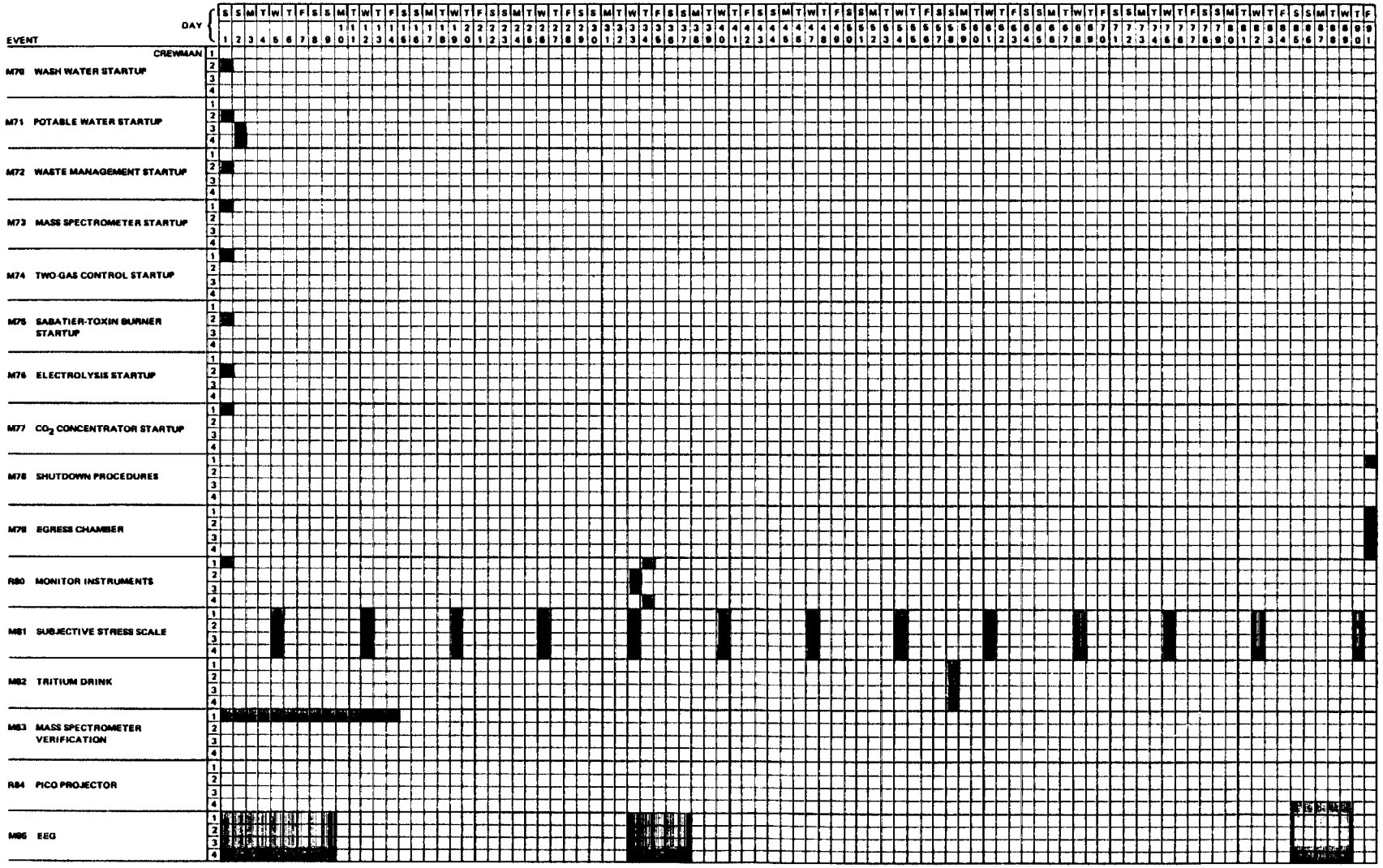
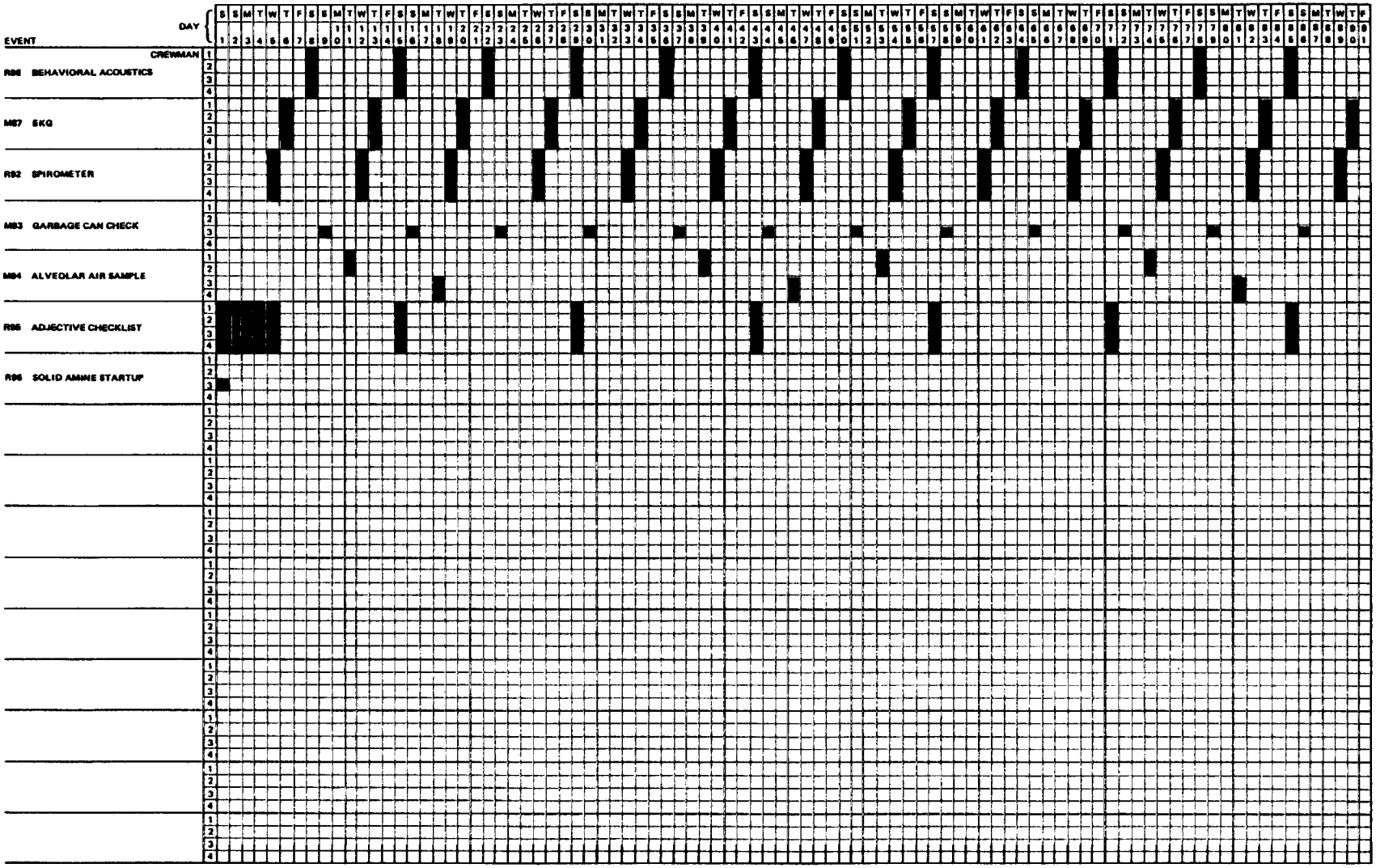


Table 3-19 (page 6 of 6)

MISSION EVENT PROFILE



mission event profile and a complete revision of the crew activity schedule. The effort required in this activity indicated the necessity for better planning and scheduling aids to reduce the large manpower requirements for manual methods and decrease turnaround time for rescheduling efforts.

The SSMM formulation of crew activity schedules at LRC essentially paralleled the manual effort. The initial task consisted of interpreting the crew skill and crew events matrix data and describing this information as well as a system description in formats amenable to computer operations. Subsequently, (1) all equipment was designated as to area locations in the simulator, power levels were designated, and all equipment was referenced to specific events; (2) crew skills and crew skill levels were referenced for each event; (3) each event was annotated as to duration and activity cycle, event transit times were defined and predecessor and successor information was defined; and (4) procedures were designated for coping with constraints, such as fixed time events, repeat events, event predecessor-successors, and common equipment. The next task consisted of exercising the program to produce the mission event profile and crew activity schedules.

Computer schedules were periodically updated to evaluate the SSMM capability for rapid generation of new schedules. Before test start, these iterations were based on the use of updated events information obtained from revisions of the crew events matrix. During the test they were based on interviews with the Crew Commander and analysis of daily monitor logs. Crew activity schedules for days 31 to 50 were provided to MDAC by LRC.

Comparison of man-hour efforts required to change and reissue activity schedule by manual and computer methods showed that the computer iterations were several orders of magnitude faster than the same iterations done by the manual methods.

3.5.3 Crew and Observer Training

The mission analysis activity training was conducted in two parts: crew training and observer training.

Crew training consisted of a one-hour classroom briefing for all crew members covering the following items.

A. Introduction

   1. Manual planning methods used in past simulation tests and in the Mercury, Gemini, and Apollo missions.

   2. Requirements for space station and space base.

B. LRC Space Station Mission Simulation Mathematical Model

   1. Background and purpose of model.

   2. Brief description of model.

C. Mission Activity Analysis Experiment

1. Purpose
2. Descriptions of MDAC activities
3. Descriptions of LRC activities
4. Description and discussion of:
   a. Crew skill matrix
   b. Crew events matrix
   c. Mission event profile
   d. Crew activity schedules
5. Crew operating ground rules.

Subsequent to the final selection of crewmen to participate in the 90-day manned test, the four crewmen individually and as a group reviewed the crew activity schedules in detail. A very stringent training schedule precluded their participation in the formulation of the schedules, so this review provided their only real opportunity to affirm their understanding and approval of the schedule and to verify that crew preference constraints had been included in the schedule. Specifically, these crew preferences were that they desired a body wash after exercise, a shave prior to breakfast, no exercise until at least 1 hour after any scheduled meal, a 20-minute free-time period in conjunction with dinner, and the largest possible blocks of free time to insure they could work on personal projects.

Observer training for the four backup crewmen, who were to do all MAA data recording and monitoring, was accomplished by each crewman receiving individual instructions on the duties of the mission analysis monitor, instruction on the operation of the video time-lapse recorder as described in NASA CR111882, Section 12.1.3, and on-the-job training during the 5-day manned test and the first 15 days of the 90-day manned test. This method of instruction provided the best compatibility with crew training which continued up to the beginning of the test. A preferred method for future manned tests would add to the above a minimum of two hours of classroom instruction for all crew members and communications monitors on monitoring and logging requirements. This additional instruction is essential to assure the complete understanding and acceptance of the requirements to enhance working relations within the group of people and to insure uniformity in log entries.

3.5.4 Test Monitoring

Data for this experiment were collected for days 31 through 60 by the four backup crewmen who acted as mission analysis monitors. Continuous surveillance of the inside crew was maintained via closed-circuit television monitors (Figure 3-43). A log entry was made to record the start and stop time of each



- MISSION ANALYSIS MONITOR ON LEFT COMPLETING AN ENTRY INTO THE MISSION ANALYSIS/COMMUNICATIONS MONITOR LOG.
- COMMUNICATIONS MONITOR ON RIGHT BEFORE CONTROL CONSOLE
- THE TIME LAPSE VIDEO SYSTEM IS BEHIND THE COMMUNI-CATIONS CONSOLE WITH THE NUMBER TWO RECORDER IN OPERATION

Figure 3-43. Mission Analysis Monitoring

event and the time-lapse video system was used to record a picture every 3 seconds from one of five TV cameras located within the SSS. The mission analysis monitor was responsible for selecting the scene to be recorded on time lapse video.

The mission analysis monitor worked in cooperation with and was assisted by one communications monitor when time permitted. Written guidelines for the MAA monitors and communications monitors are contained in Tables 3-20 and Table 3-21.

Each mission analysis monitor worked an 8-hour shift for 15 days with 5 days off between shift changes. This duty cycle was acceptable with the exception of the length of the daily work shift. The monitors stated that after approximately 5 hours of duty they recognized a distinct reduction in their efficiency to observe, operate the time-lapse video, and log data. This was confirmed during review of the logs and time-lapse video tapes.

The logs show numerous instances were entries of event start and stop times were changed and a marked decrease in the number of remarks entered into the logs. The time-lapse video tapes show a decrease in switching to different cameras to record the start and stop of events. The most complete and apparently accurate observations and data logging occurred during periods when only two crewmen were on duty and the communications monitor could work in coordination with the mission analysis monitor. During periods when four crewmen were on duty, the communications monitor was usually too busy to assist in observing and logging data. The mission analysis monitor could not accurately observe and record all activities regardless of his diligence during these periods. Observations were further constrained by the following limitations and log entries were either not made on events or were based upon estimates by the monitors:

A. Crew privacy requirements excluded TV monitor coverage of the bunk and hygiene areas. This curtailed adequate observations of: (1) bed linen change, (2) body hygiene-wash, (3) body hygiene-shave, (4) commode maintenance or repair, (5) laundry, (6) wash water filter change, (7) waste management, and (8) hygiene area surface swabs.

B. TV monitor coverage of the biomedical and maintenance work counters was marginal in that no direct indication of exactly which events were being performed was possible. This precluded accurate observation of: (1) dosimeter read and charge, (2) film badge change, and (3) aerosol particle analysis events.

C. TV monitor coverage of the laboratory work counter was marginal when the crewman's body obscured his activities at the counter. This precluded positive identification of: (1) water samples/tests, (2) bacteria sample counts, and (3) bacterial sensor experiment events.

Table 3-20

GUIDELINES FOR MISSION ANALYSIS MONITOR DATA COLLECTION

1. Time Lapse Video Tape: Record as much manned activity as possible, endeavoring to record the beginning and end of events to insure accurate time checks during tape analysis. Do not stay with the entire duration of the event to the exclusion of taping other simultaneous events. Normally, one tape system will be used. During periods of high activity, use both tape systems to insure coverage of as many events as possible.

2. Indicate conformance to the crew activity schedule of mandatory and recommended events on the schedule itself. This should be done by placing a number next to the event that indicates the sequence in which the events were actually performed as opposed to the sequence in which they were scheduled to be performed.

3. Deviations from the activity schedule should be identified in the log by placing the event number and then the crewman's number in the ID column. In the Comments section describe the deviation and the consequences; e. g., slip in schedule, deletion of event, etc. Times for each event will be logged.

4. Deviations from scheduled man-loading on all events should be identified and described in the log in terms of conditions and reasons.

5. Unscheduled events should be video taped and described in the log.

6. At the end of each shift, complete a crew events schedule to reflect actual crew event performance.

7. All monitors will initial every entry made in the log.

D. Obtaining accurate total times for biomedical checks was virtually impossible in that crewmen would arise, weigh themselves, and then interrupt the sequence by either going to the waste management area, checking instrument readings, writing in logs, or just sitting and talking with other crew members. The only certain points in the sequence were the start time (time when crewmen awoke) and the stop time (the time when the crewman transmitted required data to the medical monitor).

E. It was impossible for the monitor to determine which onboard log was being used by the crewman and consequently the mission analysis entries for the diary event were his best guess. A review of the logs subsequent to the test revealed that some crewmen did not make entries in the crew diary on a daily basis nor was elapsed time information provided in their entries.

F. During the Tuesday passout, the sequence of events could not be adequately followed even with the cooperation of the communications monitor. Some event start and stop times were not logged and

Table 3-21

GUIDELINES FOR COMMUNICATIONS MONITOR DATA COLLECTION

1. Indicate conformance to the crew activity schedule of mandatory and recommended events on the schedule itself. This should be done by placing a number next to the event that indicates the sequence in which the events were actually performed as opposed to the sequence in which they were scheduled to be performed, which may be different.

2. Deviations from the activity schedule should be identified in the log by placing the event number and then the crewman's number in the ID column. In the comments section describe the deviations and the consequences; e. g., slip in schedule, deletion of a recommended event, etc.

3. Deviations from scheduled manloading on mandatory events should be identified and described in the log in terms of conditons and reasons.

4. Staff-crew communications should be described as follows:

   a. Start time

   b. Stop time

   c. Duration

   d. Subject

5. Unscheduled events should be described as follows:

   a. Time of occurrence as noted from Engineering Monitor.

   b. Time of occurrence as noted from crew.

   c. Description of event.

   d. Duration of correction, including only crew activity time.

   e. Type of outside support required; e. g., audio, video, etc.

   f. Consequences (effect on schedule, new operating mode, interrupted event, etc.)

6. Describe free-time activities.

7. At the end of each shift, summarize accomplishment of all mandatory events per individual crewman.

8. All communications monitors will initial every entry made in the log.

Table 3-21 (Continued)

9.	Scheduled crew events are classified as mandatory and recommended. Each event in the schedule will be identified with an M or R. A mandatory event has a pay incentive for its completion. A recommended event is merely scheduled and has no incentive. It is, of course, desired that the crew perform the recommended events whenever possible. Also each mandatory or recommended event has an event number associated with it. This number is to be used whenever a specific event is referred to in the log; e. g., item three in the guidelines.

occasionally an event was missed completely. Verification of performance of the events was confirmed by the use of a passout checklist to ensure that all samples required for passout were in fact contained in the pass-through port.

3.5.5 Data Analysis and Results

As stated in the crew operating ground rules, crewmen were instructed to use the crew activity schedules as a guideline rather than attempting rigorous adherence. Therefore the analysis relative to the schedules is not made to evaluate crew performance itself, but rather to determine the adequacy of the crew activity schedules when used for management of the crew time and to provide updated realistic times for specific events which are likely candidates for use in future tests or space missions.

Ten test days were selected for a detailed comparison of the manually and computer-generated crew activity schedules. Data resulting from a detailed analysis of the mission analysis monitor's log, supplemented by review of video time-lapse recordings, onboard diary entries, and Non-Interference Performance Assessment data (Section 3.9), was used to construct a graphic presentation of the actual crew performance in the crew activity schedule format. An "eyeball" comparison of the manual, computer, and actual crew performance schedules was used as a quick method of identifying areas or items for detailed analysis. Table 3-22 shows a typical example of the manually generated crew activity schedule for day 45. Table 3-23 shows the computer-generated schedule and Table 3-24 the actual schedule for the same day. In addition, the basic data were loaded for computer program manipulation to facilitate more detailed identification of specific areas, events, and to identify trends.

Figure 3-44 presents the average hours per crewman per day for scheduled time, free time, and unscheduled engineering time for the 10 days on which detailed data were analyzed. The three basic elements are defined below:

Scheduled Events include:	Baseline medical and man-systems events, station operations events, scheduled maintenance of SSS and experiment equipment, meals, sleep, experiment events and personal hygiene—shave and body wash only.

Table 3-22. MONDAY, DAY 45, MANUAL ACTIVITY SCHEDULE (1 of 3)

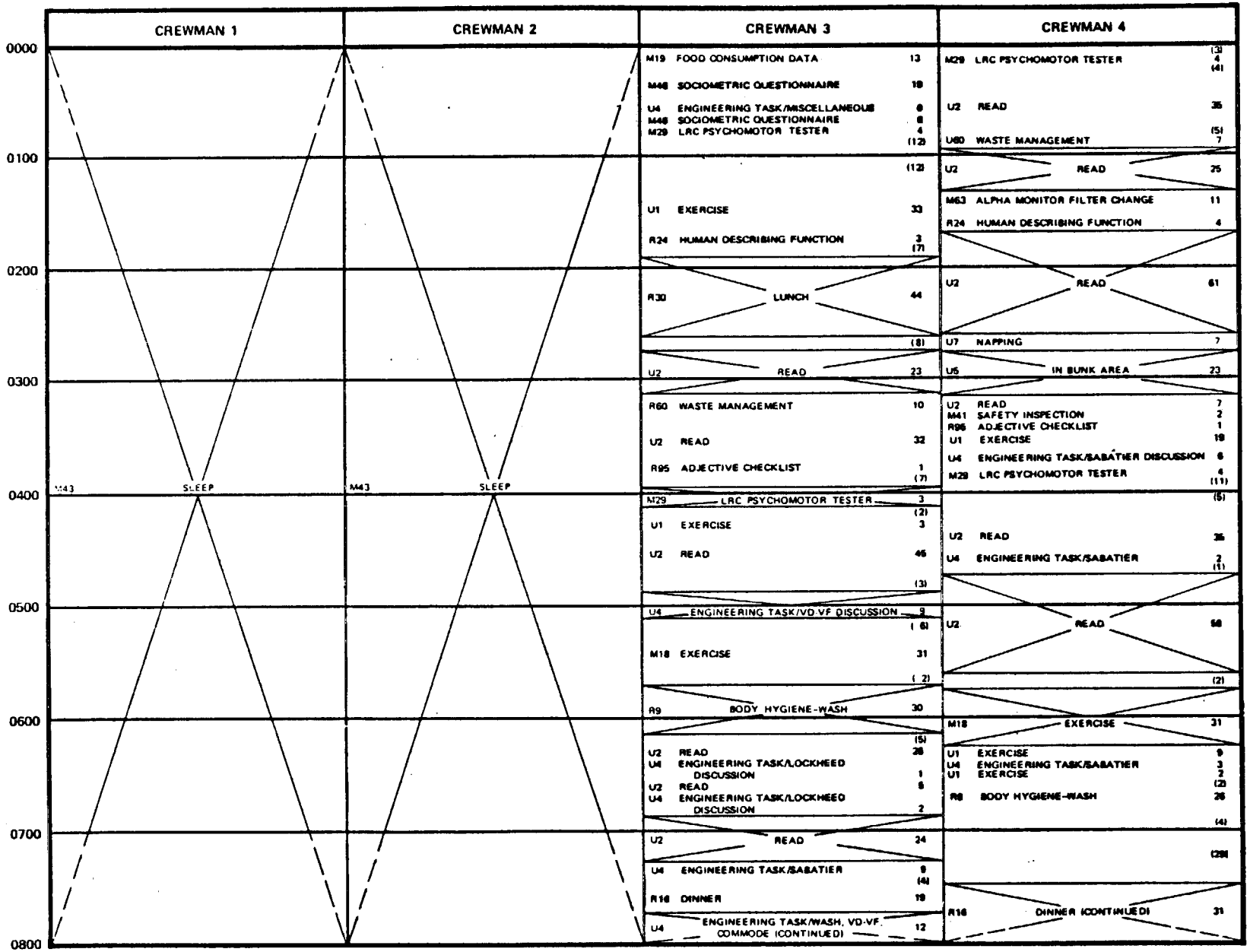


Table 3-22. MONDAY, DAY 45, MANUAL ACTIVITY SCHEDULE (2 of 3)

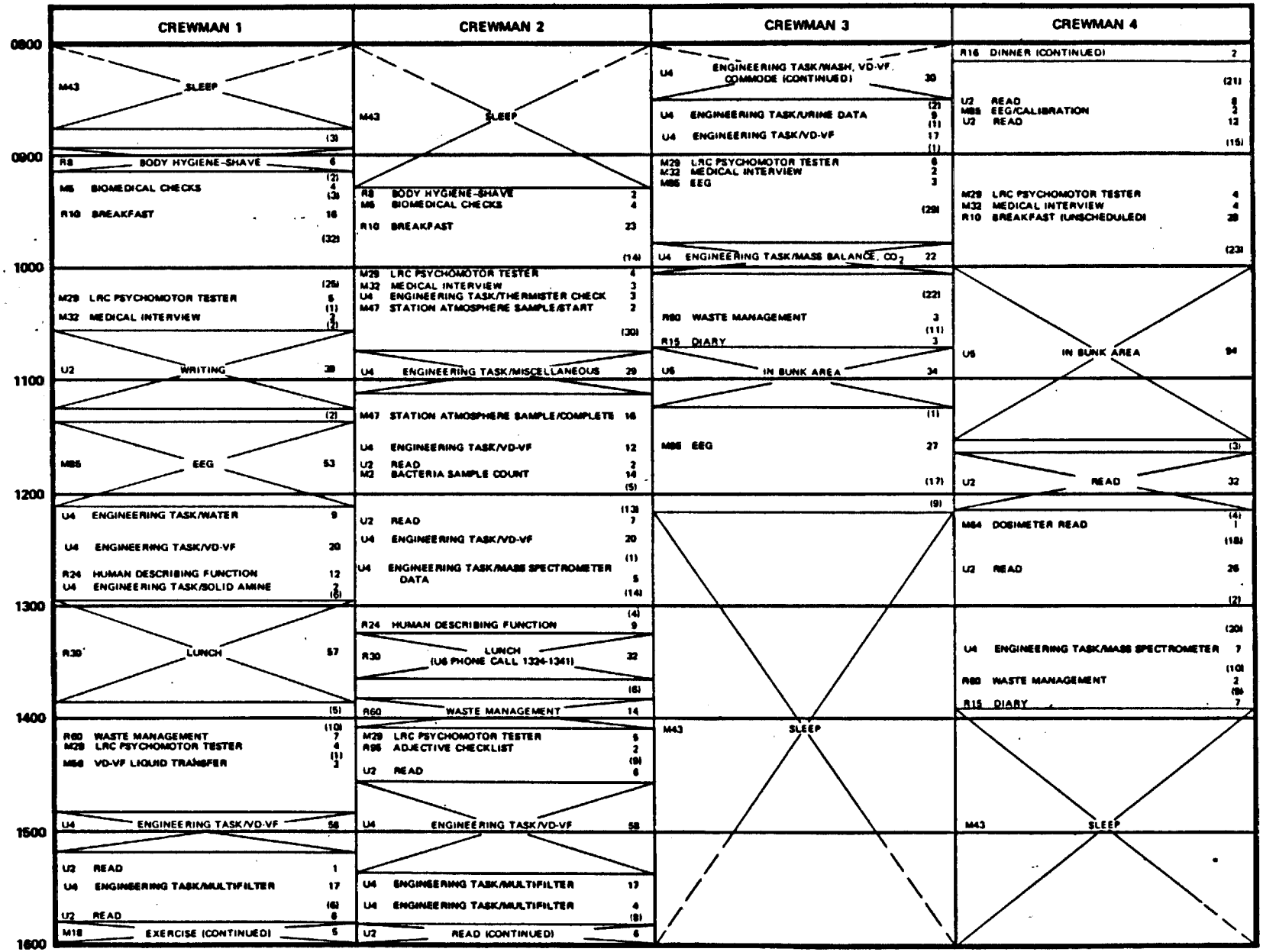


Table 3-22. MONDAY, DAY 45, MANUAL ACTIVITY SCHEDULE (3 of 3)

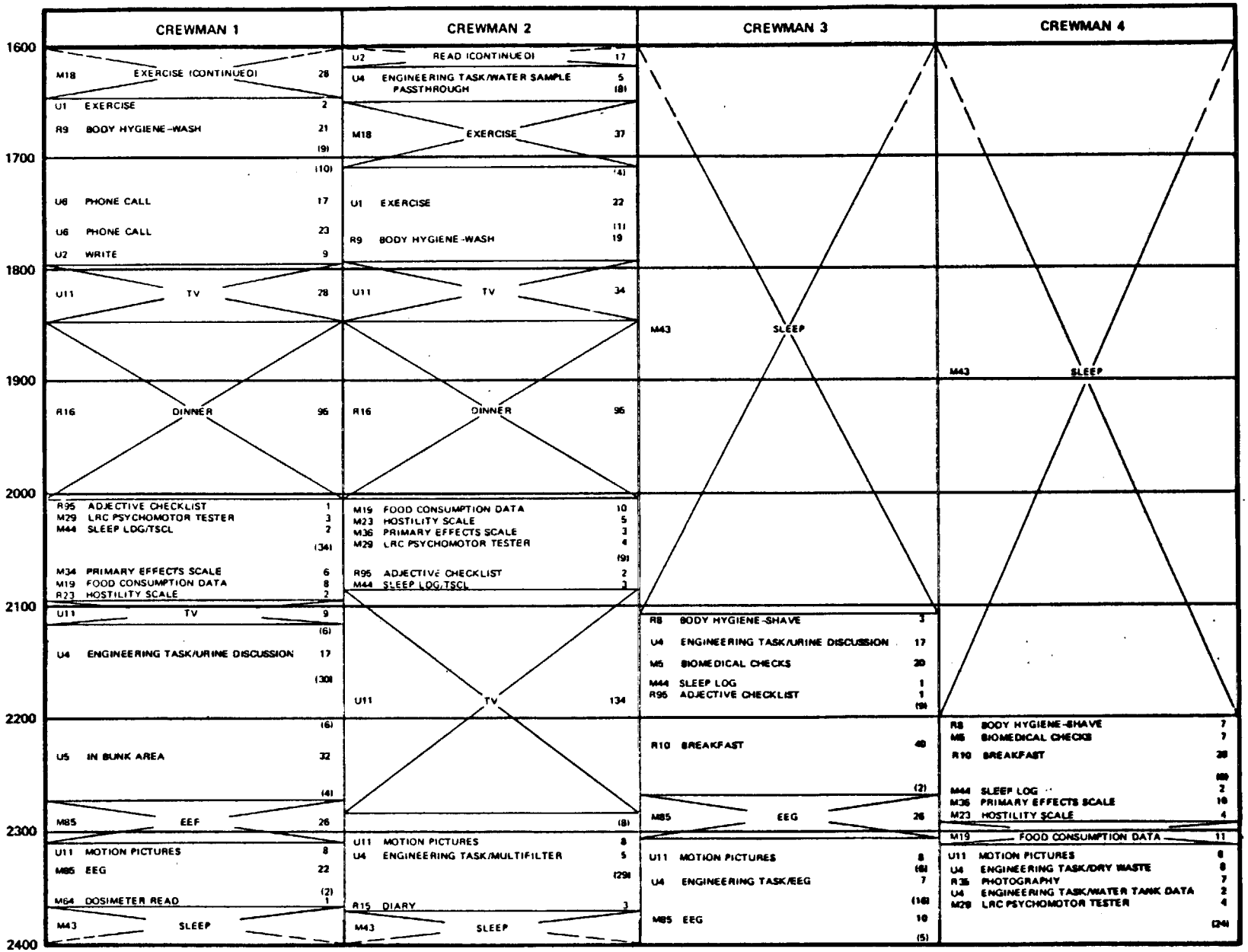


Table 3-23. MONDAY, DAY 45, COMPUTER ACTIVITY SCHEDULE (1 of 3)

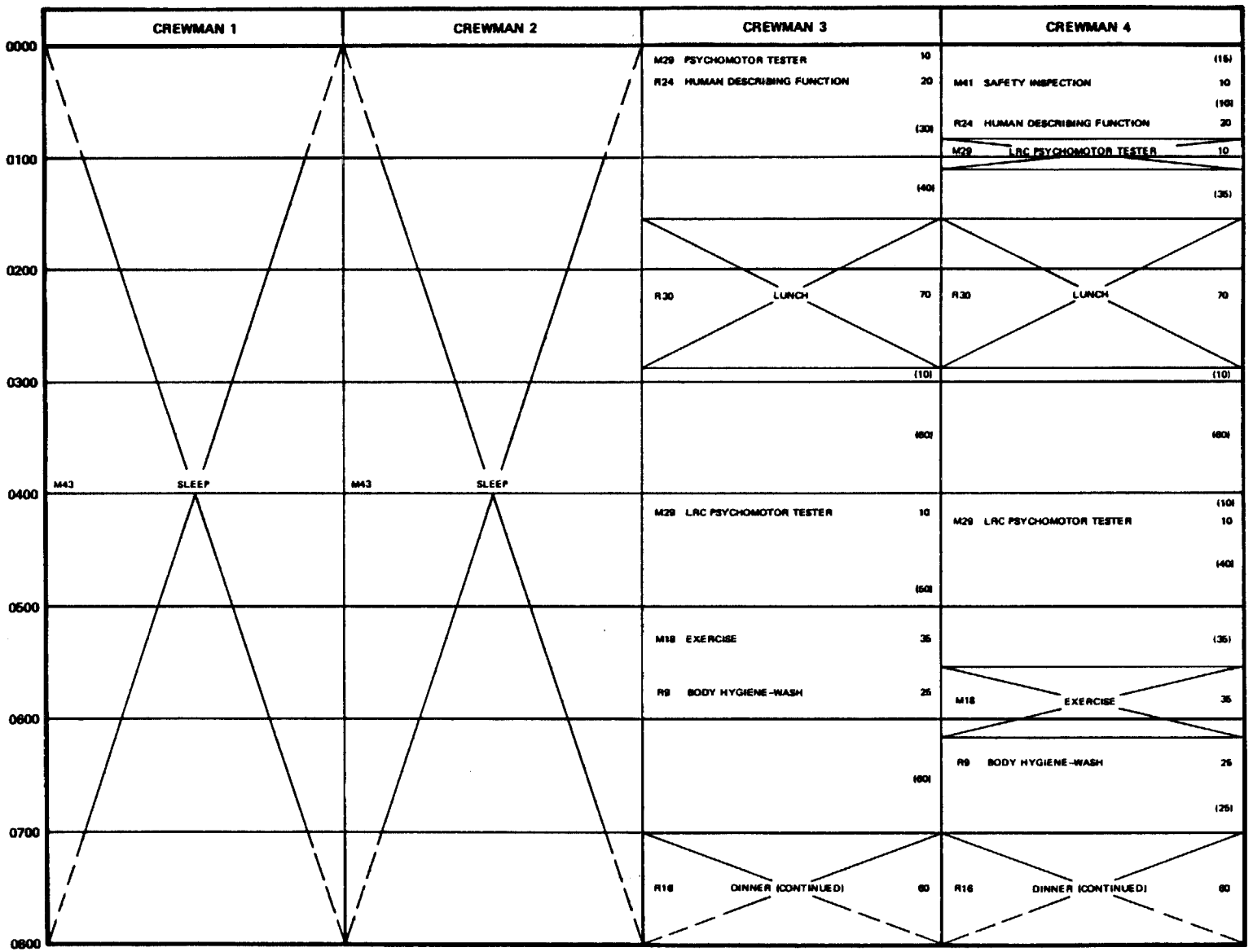


Table 3-23. MONDAY, DAY 45, COMPUTER ACTIVITY SCHEDULE (2 of 3)

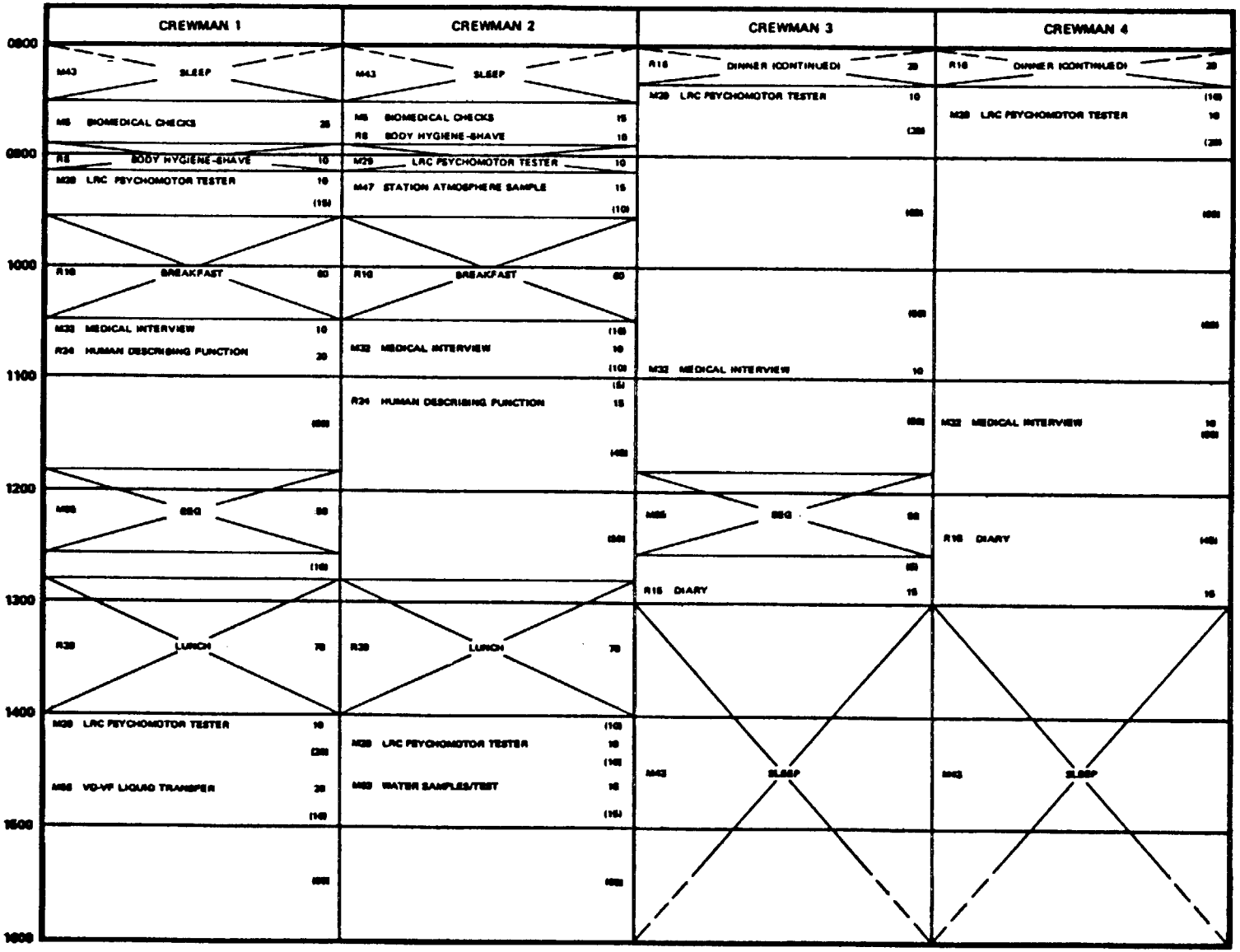


Table 3-23. MONDAY, DAY 45, COMPUTER ACTIVITY SCHEDULE (3 of 3)

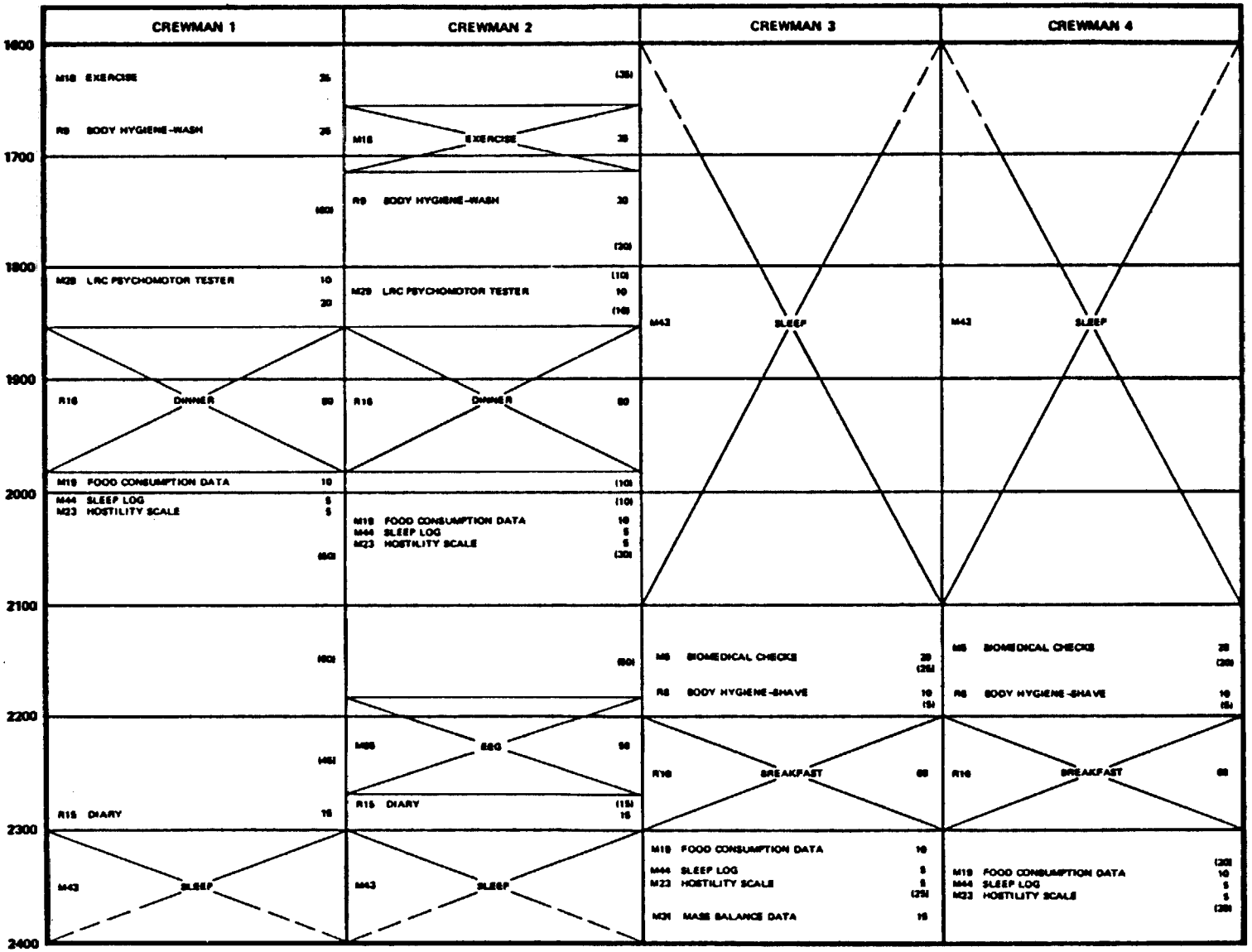
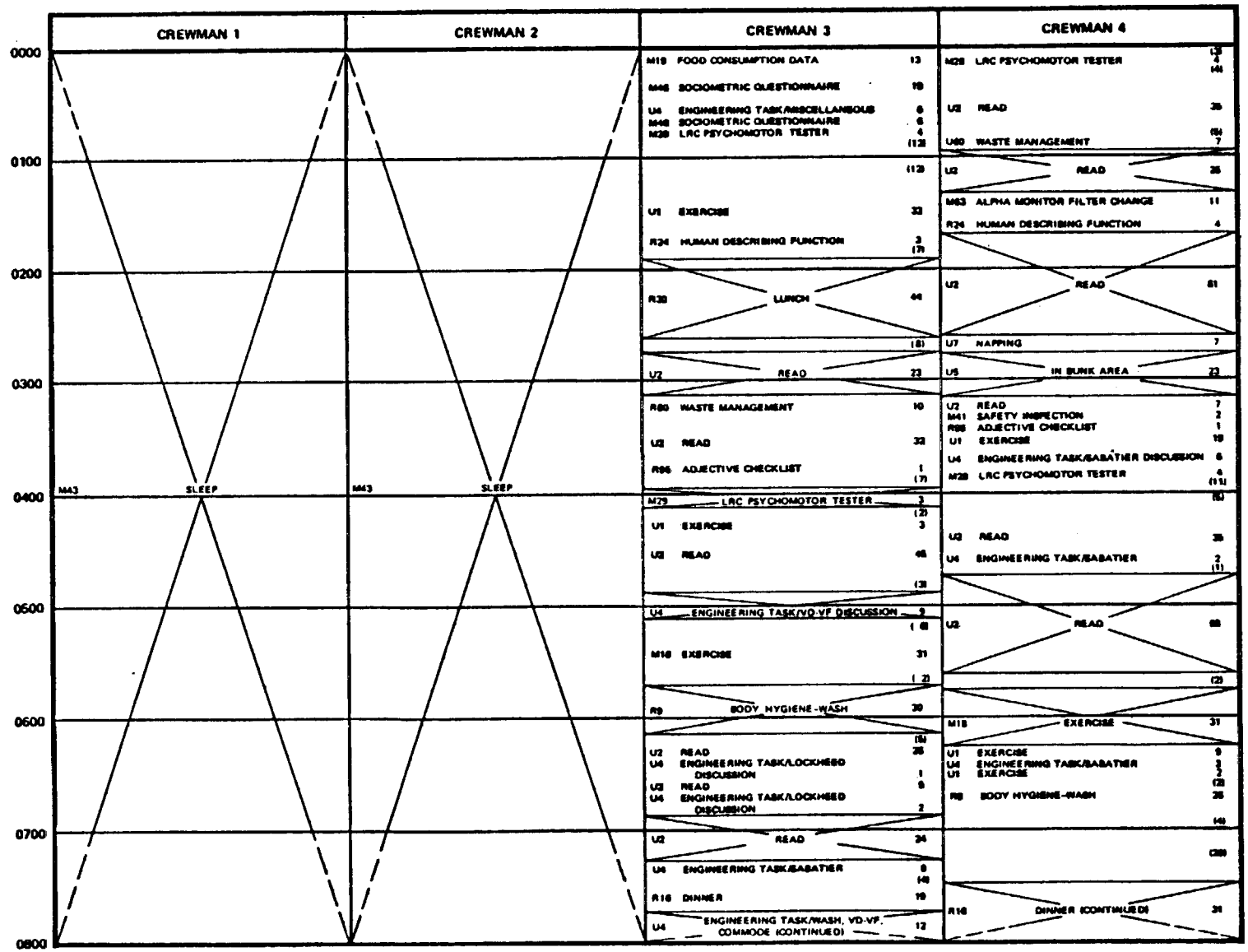
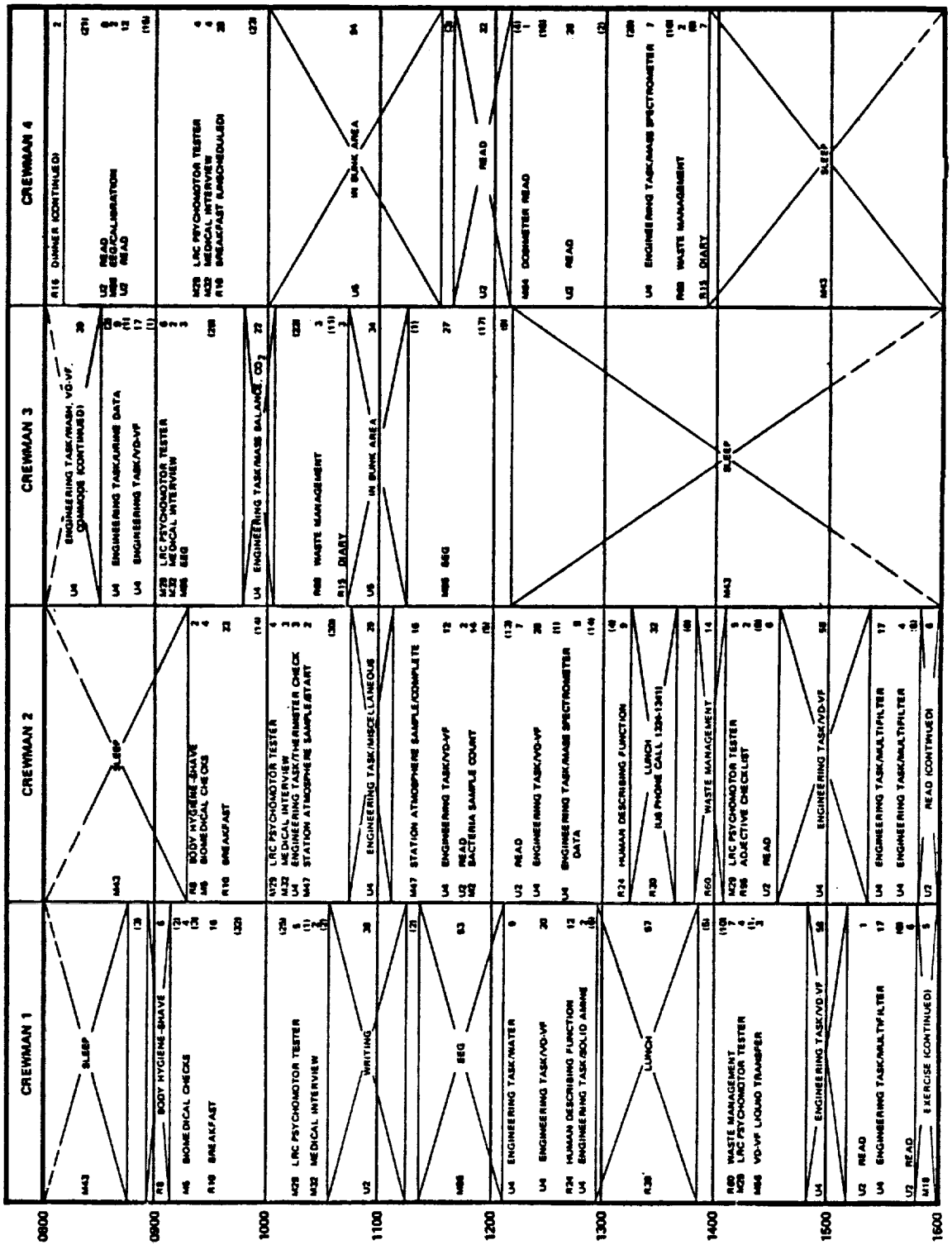


Table 3-24. MONDAY, DAY 45, ACTUAL CREW SCHEDULE (1 of 3)



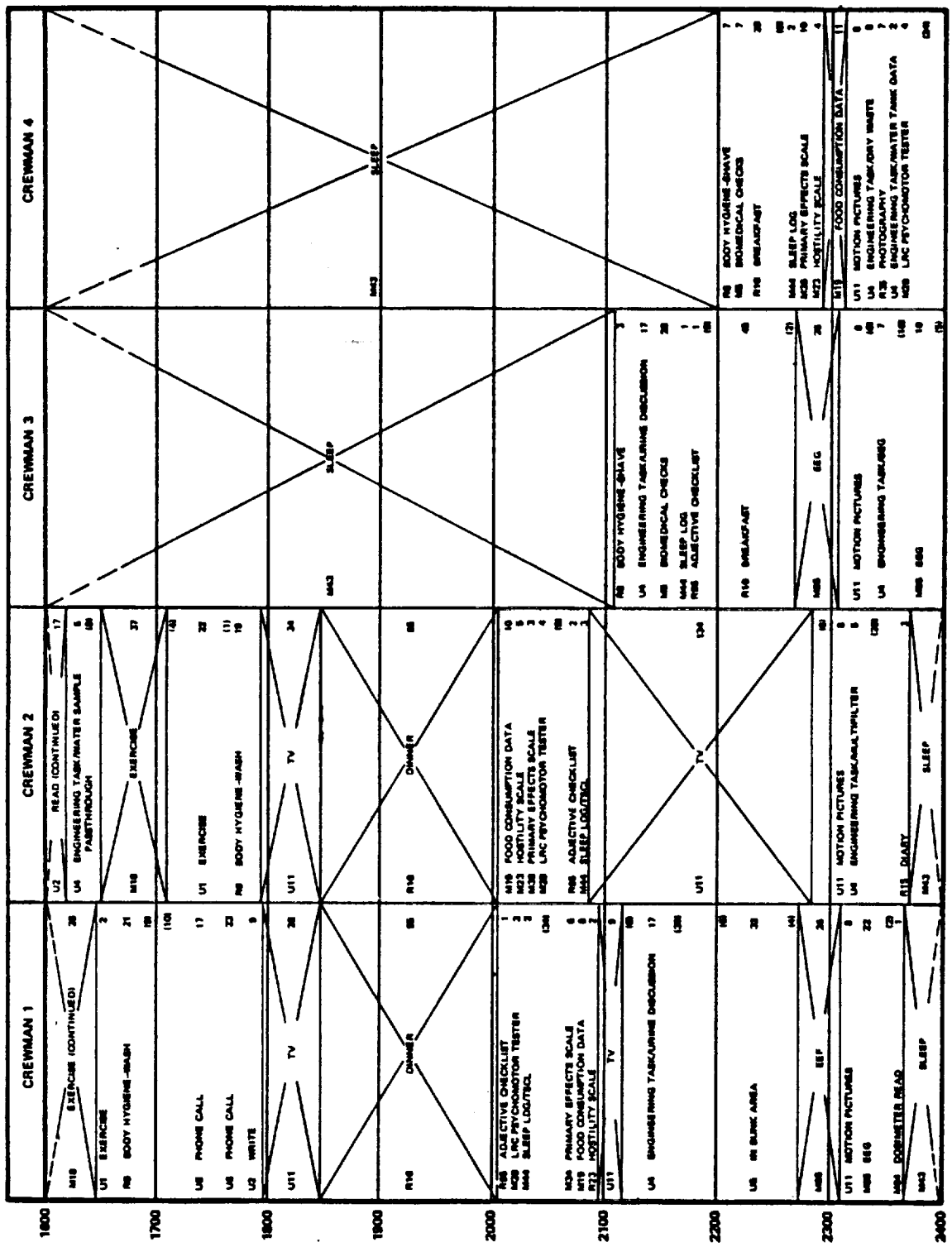
R292-III

Table 3-24. MONDAY, DAY 45, ACTUAL CREW SCHEDULE (2 of 3)



R292-III

Table 3-24. MONDAY, DAY 45, ACTUAL CREW SCHEDULE (3 of 3)



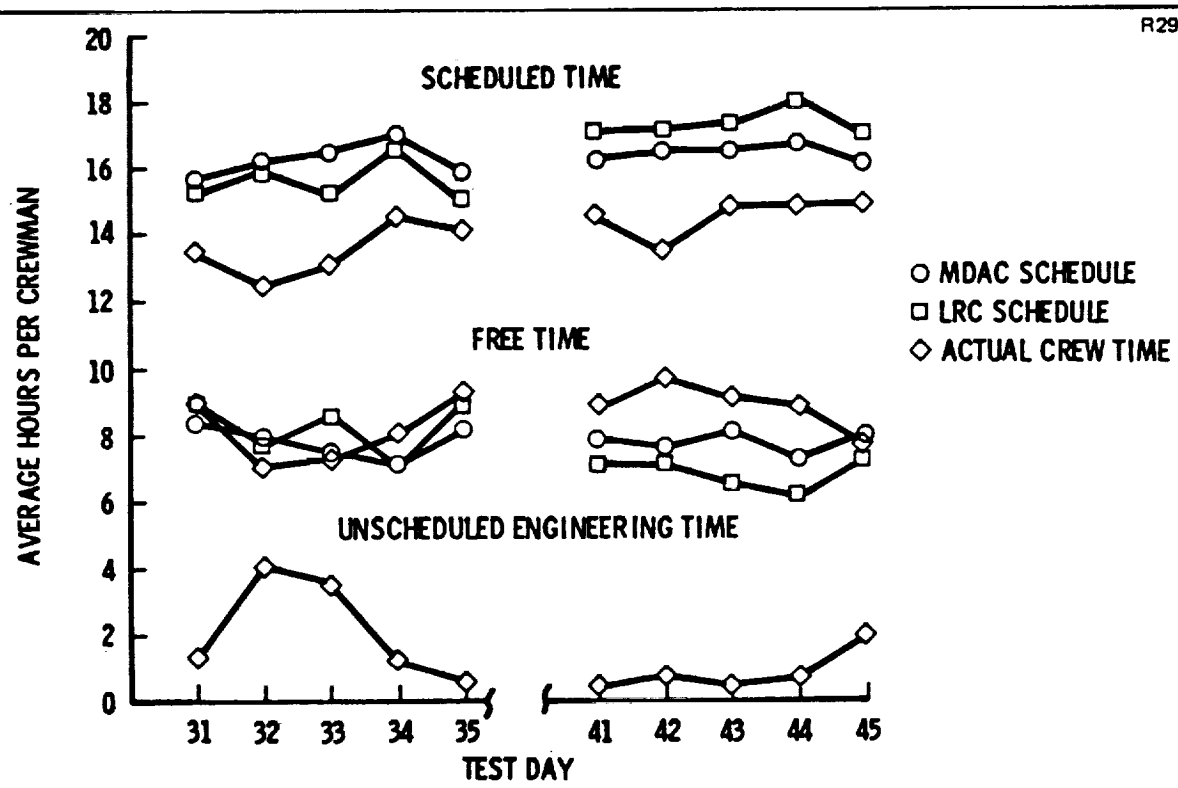


Figure 3-44. Crew Activity Schedule Comparison

Unscheduled Events include: Unscheduled maintenance and repair of SSS and experiment equipment, crew response to staff requests for monitor or adjustment of equipment, interviews and unscheduled medical events.

Free Time: In MDAC and computer schedules it is the time for recreation and all unscheduled events. In crew performance schedule it is only the time for recreation.

The differences between the activities scheduled and the actual work times are relatively small. The rationale followed in crew activity schedule planning was that the crew should use the allocated free time to perform unscheduled events. The graph shows that on each day the actual time spent on scheduled events was less than allocated and that the crew free time was more than planned. A cursory examination of the actual daily Crew Performance Schedules and the MDAC crew activity schedules shows that the crew chose to reduce the scheduled event times when possible to allow for necessary unscheduled engineering tasks and indicates that times for specific events should be further analyzed to determine a more realistic time allocation for use in the planning of future integrated tests.

For days 41 through 45, more scheduled time is shown for the LRC schedule than for the MDAC schedule. This is primarily due to an update of the computer generated schedule to more closely represent the actual increased sleep times of the crew. It reflects an increased allocation of 45 minutes per man per day.

Figure 3-45 presents a more detailed breakout of the types of activities the crew performed during the test. Table 3-25 presents the crew mean time for each type of event. Each area shown in Figure 3-45 is discussed in more detail in the following paragraphs.

The free time category includes the following activities: (1) unscheduled exercise, (2) in bunk area (other than scheduled sleep), (3) observing movies/slides/television, (4) napping, (5) personal phone calls, (6) playing games, (7) reading/resting, and (8) snacks. The mean times per crewman per day were 8 hours and 30 minutes. The amount of free time per day varied based on the crew's ability to decrease scheduled event times. This provided larger blocks of uninterrupted free time for personal activities. An example of this results from analysis of the crew activities on day 31. On that day, the crew spent 8 hours and 14 minutes less on scheduled events than planned (approximately 2 hours per man). Of this time 5 hours and 49 minutes were spent on performance of unscheduled events and the remainder on free time. The time used for unscheduled events and the increased free time period resulted from a reduction in duration of scheduled events rather than from a reduction of free time as originally envisioned by planners. This is due partly to the fact that the scheduled event times were conservative estimates and partly to the reduction of scheduled event times to allow for necessary unscheduled engineering tasks. Approximately 48 percent of the time saved resulted from a reduction in use of time scheduled for meals, 10 percent of time saved from scheduled exercise events and the remaining 42 percent from all other events.

The following paragraphs show the time comparisons in specific crew activity areas and include recommendations for future planning. It should be noted that crew times frequently depend only on the individual men and will not be exact, but the recommended time for future planning would be improved scheduling estimates since they are based on actual performance.

The man-systems activities included the following: (1) adjective check list,* (2) behavioral acoustics, (3) descriptive sentence tests, (4) diary, (5) EEG experiment, (6) group confinement inventory, (7) glycerol based drink, (8) habitability inventory, (9) hostility scale, (10) human describing function, (11) isolation symptomatology, (12) lighting experiment, (13) LRC psychomotor test, (14) personal space measure, (15) photography, (16) Pico projector, (17) psycho-acoustics, (18) psychologist interview, (19) RATER, (20) sleep log, (21) sociometric questionnaire, (22) subjective stress scale, and (23) primary affect scale.

For man-systems activities the scheduled mean time per crewman per day was 94 minutes, but the actual mean time per day per crewman was 56 minutes. The mean average for 5 of the events required more time for performance than allocated, 13 events required less time for performance than allocated, and 5 were performed in the predicted time.

*The Adjective Check List was used by one of the backup crewmen to collect data for his own personal research.

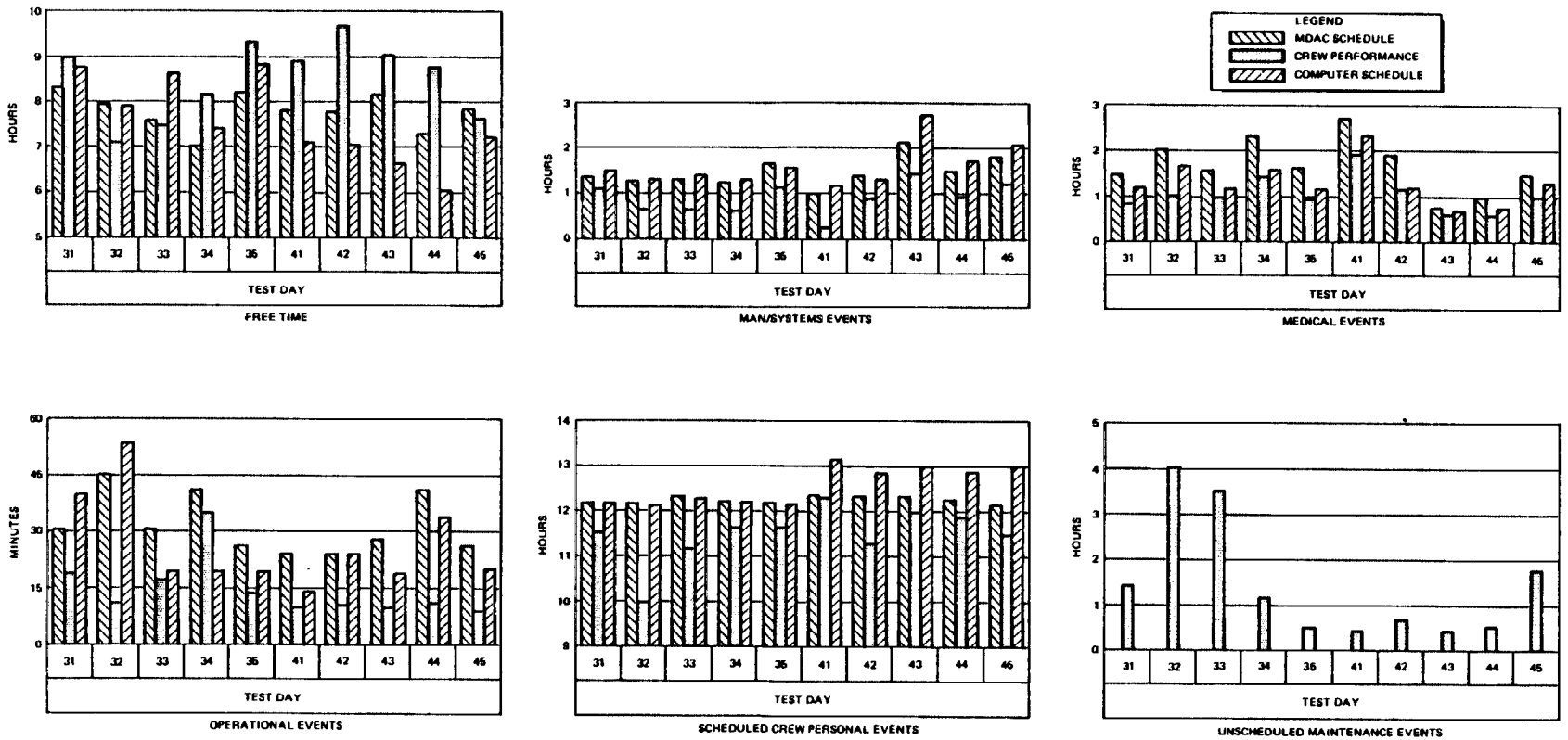


Figure 3-45. 90-Day Manned Test Event Times-Scheduled vs Crew Performance (Crew Mean Time)

Table 3-25

EVENT MEAN TIME PER DAY PER CREWMAN (FOR DAYS: 31-35, 41-45)

Event or Event Group	MDAC Schedule	Crew Performance	Computer Schedule
Man Systems Events	1 hr 34 min	0 hr 56 min	1 hr 42 min
Medical Events	1 44	1 04	1 24
Operational Events	36	16	28
Scheduled Crew Personal Events	12 20	11 45	12 47
Free Time	7 46	8 30	7 39
Unscheduled Maintenance	-	1 29	-

The following listed events are considered likely candidates for future tests and the changes noted are recommended for planning of future tests:

Event	Scheduled Time/CM	Actual Time/CM	Recommended Planning
LRC Psychomotor test	10 min/test	5 min/test	5 min/test
Sleep log	5 min/day	2 min/day	5 min/CM/ day
Diary	15 min/day	**	**

The medical area consists of the following activities: (1) alveolar air samples, (2) bacteria sample count, (3) bacterial sensor experiment, (4) biomedical checks, (5) blood samples, (6) dermal swabs, (7) exercise, (8) medical interview, (9) nose/throat swabs, (10) skin fold measurements, (11) spirometer, (12) station surface swabs, (13) tritium drink, (14) urine samples, (15) visual acuity tester, (16) EKG, and (17) food consumption data.

The scheduled mean time per crewman per day for medical activities was 1 hour and 44 minutes and the actual mean time per crewman per day was 1 hour and 4 minutes. One of the events required more time for performance than allocated, 13 of the events required less time for performance than allocated, and 3 were performed within scheduled times.

The following changes should be noted for future planning:

Event	Scheduled Time/CM	Actual Time/CM	Recommended for Planning
Bacteria Sample Count	27 min/day	8 min/day	1) 1 min/sample
Biomedical checks	15 min/day	9 min/day	2) 10 min/day
Blood Samples	10 min/day	17 min/day	20 min/day
Exercise	45 min/day	33 min/day	3) 35 min/day
Medical Interview	10 min/day	4 min/day	5 min/day

1) This activity could not be accurately monitored due to inadequate TV coverage. The recommended planning time is based upon actual time logged for the event plus information resulting from crew debriefings.

2) This event was originally scheduled as a two-man event due to requirement for blood pressure measurement. Subsequent to test start each crewman implemented procedure for taking his own blood pressure.

**This activity could not be adequately observed due to restrictions previously mentioned in the report. It is recommended that for future planning it be considered an event to be performed during crew free time periods.

3) Figure 3-46 graphically portrays the exercise schedule. On day 32, this event was cancelled for crewmen 1 and 2 who were performing required unscheduled maintenance on the VD-VF unit. Days 43 and 44 were Saturday and Sunday, on which exercise was not scheduled.

The operational events category consists of the following activities: (1) aerosol particle analysis, (2) alpha air monitor filter change, (3) commode liner change, (4) garbage can check, (5) mass balance data collection, (6) mass spectrometer verification, (7) monitor instruments, (8) pencil dosimeter - read and charge, (9) safety inspection, (10) sample passout, (11) station atmosphere samples, (12) TV camera maintenance, (13) VD-VF liquid transfer, and (14) water samples/tests.

The scheduled mean time per crewman per day was 36 minutes and actual crewman performance required 16 minutes per day. Every event required less time to perform than was allocated. The following changes should be noted for future planning:

Event	Schedule Time/CM	Actual Time/CM	Recommended for Planning
Mass Balance Data Collection	30 min	10 min	1
Water Samples/Tests	28 min	21 min	2

R292-III

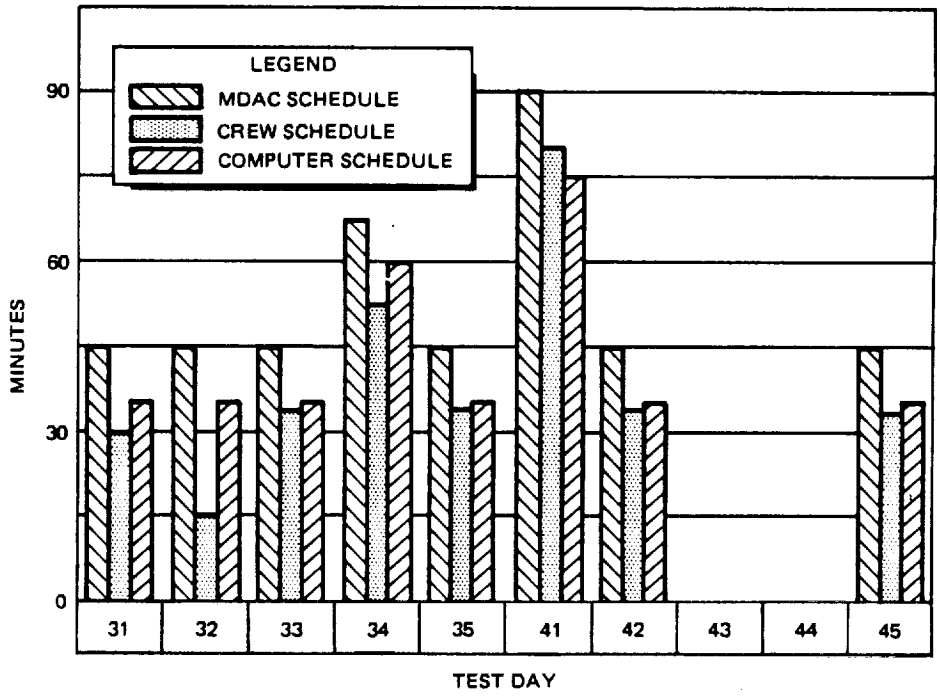


Figure 3-46. Exercise – Mean Time per Crewman

1 Depends upon type of report and whether via computer or verbal. For an operation similar to that conducted during the test, time allocation of 15/min/report is recommended.

2 This activity varied in time from 10 minutes to 55 minutes dependent on requirements of a predetermined schedule and additional requirements added during the test.

Figure 3-47 presents scheduled versus actual performance. This graph is presented to show variations between actual and scheduled performance of these events.

Scheduled crew personal events consist of the following: (1) bed linen change, (2) body hygiene—shave, (3) body hygiene—wash, (4) cabin cleaning, (5) laundry, (6) meals, (7) sleep, and (8) waste management.

NOTE: Performance times in personal events are highly individual and time estimates for scheduling would best be obtained during the observations of crew training activities.

The scheduled mean time per crewman per day was 12 hours and 20 minutes and actual crew performance required 11 hours and 45 minutes per crewman per day. The sleep period required more time than allocated. Six events required less time than allocated and one was performed within specified time.

Event	Scheduled Time/CM	Actual Time/CM	Recommended for Planning
Body Hygiene	40 min/day	22 min/day	25 min/day
Meals	210 min/day	123 min/day	1 150 min/day
Sleep	480 min/day	540 min/day	2 540 min/day

1 Figure 3-48 presents a graph of the scheduled vs actual meal times. Observing TV in conjunction with meals is reason for sharp increase on days 42 and 45.

2 Figure 3-49 presents a graph of the scheduled vs actual sleep times. Sleep time is defined as time of entry into the bunk area for sleep period until departure from the curtained area after the sleep period.

The unscheduled maintenance group includes all unpredicted maintenance and repair of SSS and experiment equipment, crew response to staff requests for monitor or adjustment of equipment, crew and outside staff discussion on fault analysis, and unscheduled medical events.

The mean time per crewman per day was 1 hour and 29 minutes during the 10-day period. The VD-VF maintenance and repair for days 32, 33, and 45 is considered as unscheduled in that it was originally scheduled to be performed on day 44. In addition, because of a complication which occurred during boiler replacement, it was necessary to disassemble the unit, clean the component and reassemble the unit. Unscheduled maintenance time during this 10-day period is slightly higher than for the entire 90-day test

R292-III

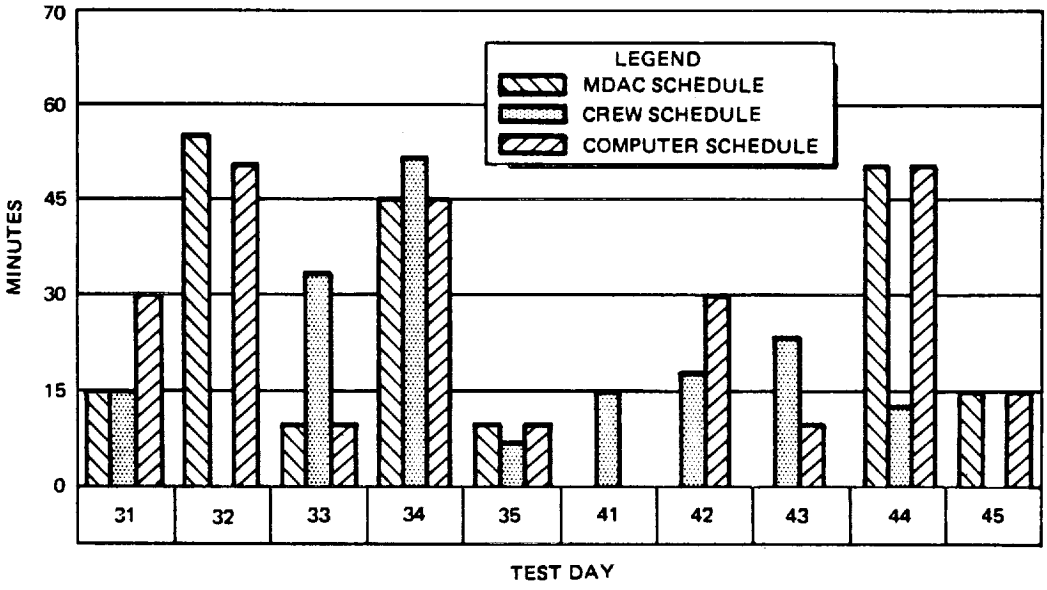


Figure 3-47. Water Samples/Tests Crewman 2

R292-III

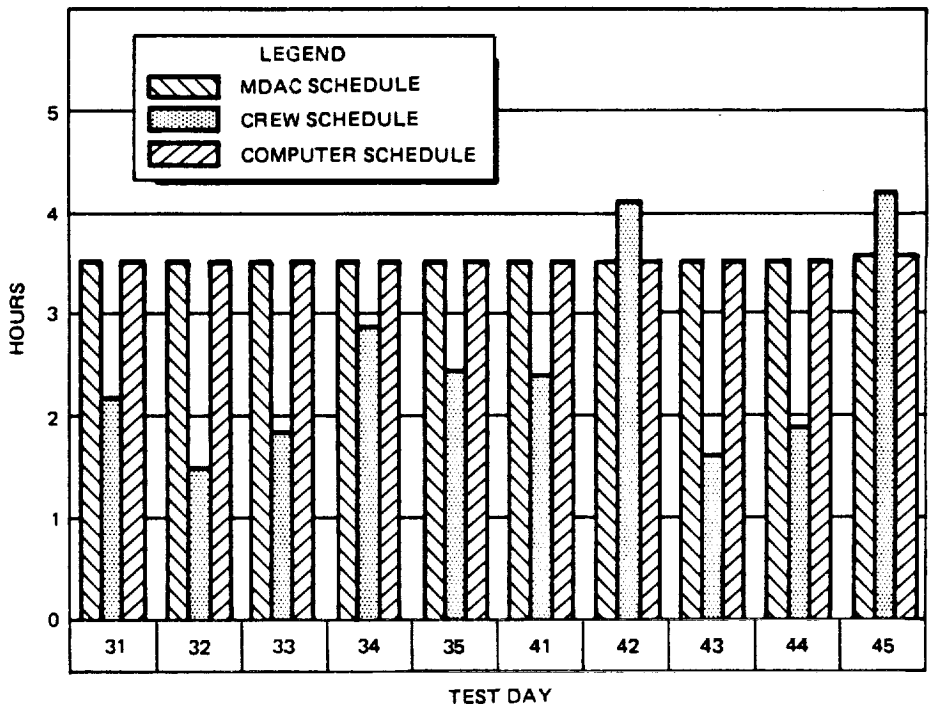


Figure 3-48. Meals—Mean Time per Crewman

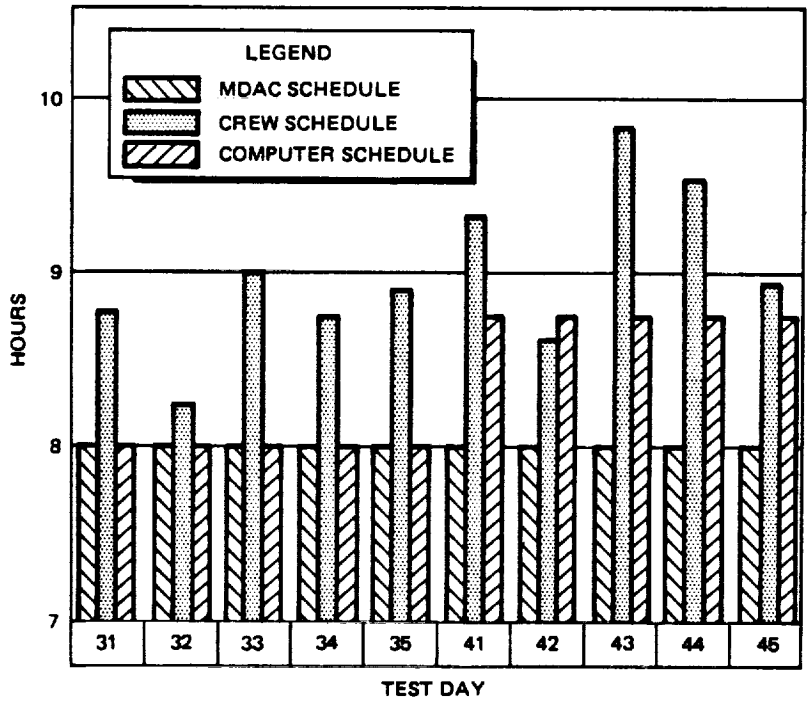


Figure 3-49. Sleep—Mean Time per Crewman

period and when graphically presented very clearly shows the necessity for a flexible crew activity schedule to accomplish the necessary events and yet not unduly perturbate the scheduled events. On day 32, it was necessary to delete scheduled exercise to permit the uninterrupted completion of repair of the VD-VF unit; however, all other scheduled events were accomplished. It is recommended that the principle of flexibility in schedule be adhered to in planning for future tests.

3.5.6 Conclusions

The mission activity analysis objectives of exercising and evaluating the planning and scheduling capabilities of the SSMM and of providing scheduling support to the 90-day manned test were successfully met. The planning model's mission event profile accurately reflected the requirements and constraints contained in the crew events matrix and was one of the key tools used in manual planning and formulation of the daily crew activity schedule. The one-day model successfully sequenced daily events into crew activity schedules that were operationally acceptable. The use of the SSMM for rapid generation of new schedules during the test proved its capability to update as needed. A response to an operational request to delay sleep start times for crewmen 3 and 4 for 1 hour resulted in production of revised crew activity schedules for a 7-day period. This was accomplished and results returned within 24 hours.

The LRC-designed data submittal format for the crew events matrix requires operational personnel to perform a partial task analysis of all events in which the crew will participate and further requires an early definition of mission

constraints. It provides an easy format for operational personnel to describe in their own language the input data and operational constraints necessary for manual crew activity scheduling or crew activity scheduling by use of the SSMM.

The manpower and time allocated for data collection and formatting of crew event data were inadequate for a development test in which change is required up to test start to maximize the number of test objectives that can be met.

The use of both the time-lapse video tape and the MAA monitor's log for recording data was marginally adequate for this experiment. Neither of these were satisfactory in themselves. The time-lapse system can record only one area of the chamber at a time and crew event identification is frequently difficult. The 8-hour shift for MAA monitors was too long a period of time for the monitors to provide continuous attention to crew activity. Numerous errors were noted in the manual logs after the fifth hour of shift duty. This correlates with monitors' statements that the 8-hour shift was too long.

The MAA monitor could not effectively monitor and log the activities when all four crewmen were up at one time. The diversity of activity in different areas of the SSS did not permit adequate coverage of activities by either use of the video time-lapse recorder or in manual logging.

3.5.7 Recommendations

The LRC-designed data submittal format for the crew event matrix should be utilized in future manned tests. Further, it should be considered for use in crew activity scheduling for manned flights in that it serves as a forcing function to perform a detailed analysis of crew activities and provides for the early definition of mission constraints.

Any future manned development test should provide for a task analysis early in the program to insure realistic event time estimates and crew procedures, and to provide identification of those key factors in crew events which can be used as a measure of performance.

Although the schedules used were acceptable, on future manned missions of longer duration with dynamic experiment programs, a more easily handled onboard crew activities schedule should be provided which can be updated whenever necessary. This requires the development of an onboard update capability. A study effort should be conducted to define a more effective method for monitoring and logging of crew activities.

Manual and SSMM activity schedules were both operationally acceptable in event sequencing for the 90-day test. Since the use of the computer shows more than an order of magnitude advantage in the time required to generate and update activity schedules, future manned tests should make use of computer-generated crew activity schedules as much as possible.

It is important that the present scheduling philosophy be maintained; that is, the crew activity schedule is a management tool and should provide as much flexibility as possible to permit continuous attention to unscheduled requirements without disruption of the remaining schedule for the day.

3.6 BEHAVIORAL ACOUSTICS

Previous space cabin simulation studies (Reference 3-18) as well as astronaut comments have indicated that noise levels in space capsules are a source of irritation and possibly could degrade performance. Some concern has also been expressed with the effects of constant long-term exposure (for long-duration missions) on hearing. Although noise levels in space cabins are generally lower than those commonly accepted for industrial exposure, the occupants of a space capsule are exposed to a moderately high level for 24 hours each day while most earthbound workers, once they reach home, have a relatively long recovery period at low noise levels each day.

Noise aboard a spacecraft is generated by a variety of sources, including the life support system, the compressors for pressurization and air conditioning, movements, communication, and operation or maintenance activities of other crew members. Due to space and weight limitations, it has not been possible to completely isolate the crew from relatively high noise levels even during sleep periods. Special care was taken to minimize noise during equipment design and layout of the 90-day test. Interest in the effects of long-term exposure, as well as the interaction of the noise with reduced cabin pressure and extended periods of isolation, suggested that a test for noise effects should be incorporated in the 90-day test.

The objective of the noise testing was to develop information which could be used to establish criteria for future long-duration mission noise levels through:

A. Determining if the noise exposure resulted in shifts in auditory thresholds.

B. Evaluation of the possibility that continued noise would cause a progressive degradation in speech communications.

C. Assessing habituation or sensitization to the ambient noise.

D. Determining the crew's attitudes toward the ambient noise.

Since the primary purpose of the 90-day simulation was to test the life support equipment, the noise experiments were limited by a basic concern that they in no way reduce likelihood of completion of the 90-day test. This required that they utilize a minimum of crew time, that schedules could be revised in case of competing critical work loads, and that minimal additional equipment would be required.

3.6.1 Test Equipment and Methods

Three separate psycho-acoustic tests were incorporated in the SSS. The tests were audiometry, speech interference, and annoyance or acceptability rating. These tests were given at weekly intervals during the 90-days. Two pretests and two post-tests were also given.

The audiometric test measured changes in the absolute hearing thresholds of the subjects. Tones were presented to the crewmen at frequencies of 0.5,

1, 2, 3, 4, and 6 kHz. A continuous-tracking audiometer was used. The crewmen in the chamber wore circumaural earphones. The audiometer presented each tone to each ear for 30 seconds.

The tone had an initial amplitude 10 db below audiometric zero (Reference 3-19). The amplitude increased at a rate of 4 db/sec when a hand-held switch was depressed. As soon as the crewman could hear the tone, he released the switch and the amplitude decreased until he could no longer hear the tone, at which time he depressed the switch again. A pen recorder tracked the amplitude, and the median value was considered the absolute threshold for each frequency. Each ear was measured independently.

The speech comprehension test involved having the crewman circle, on a multiple-choice form, the word presented over the headset. Words were mixed with recordings of cabin (both crew quarters and equipment room) background noise. The amplitude of the word was adjusted during taping to a level which allowed about 50 percent of the words to be correctly identified. This level was established in a preliminary study. Two different approaches were included in the speech test. The first approach used 6 rhyme words for the total set of possibilities (mop, hop, shop, top, cop, and pop). The second approach involved a total of 50 different rhyme word sets of 6 each. Two tests were incorporated because it was believed that the repeated word set would be most sensitive while the larger test would be more representative of normal speech and would control for memory artifacts.

The acceptability or annoyance test was conducted to determine if the crewmen habituated or were sensitized to the noise. If the crewman habituated, the noise would become progressively less objectionable. If they were sensitized, cabin noise would become increasingly annoying. Crewmen were asked to compare pairs of recorded noises for "acceptability." One of the pair was a recording of the cabin ambient noise. The other noise was "pink" noise, that is, random noise filtered to approximately equal sound pressure levels in each octave. Pink noise was presented first for 2 seconds. This was followed by 1 second of silence and then 3 seconds of cabin ambient noise and 3 seconds of silence. During the 3-second silent period, the crewman indicated his preference by pushing the response button once if the first noise was more acceptable or twice if the second noise was more acceptable. Levels of the pink noise were varied by the experimenter to determine a level as acceptable as the cabin ambient. Recordings of both equipment room and crew quarters noises were used during each test session.

The audio equipment used to present the noise tests is shown in Figure 3-50. The arrangement permitted the normal use of the audiometer; level adjustment, mixing, and presentation of two prerecorded audio signals; and communication over the test headset. A pushbutton circuit (Figure 3-51) operated the audiometer and recorded acceptability test responses. Two special headsets were required because the low-frequency response of the normal intercom and audiometer headsets was not adequate for the communication or acceptability testing.

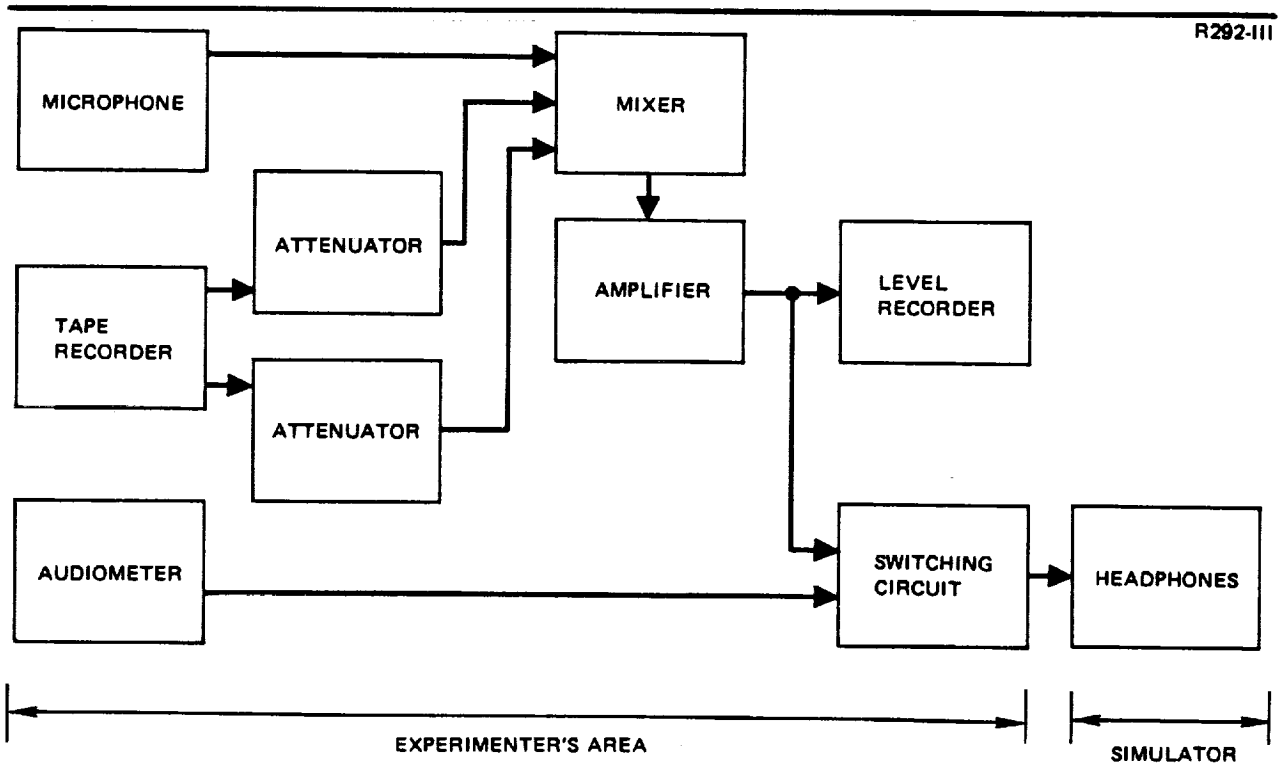


Figure 3-50. Audio Circuit

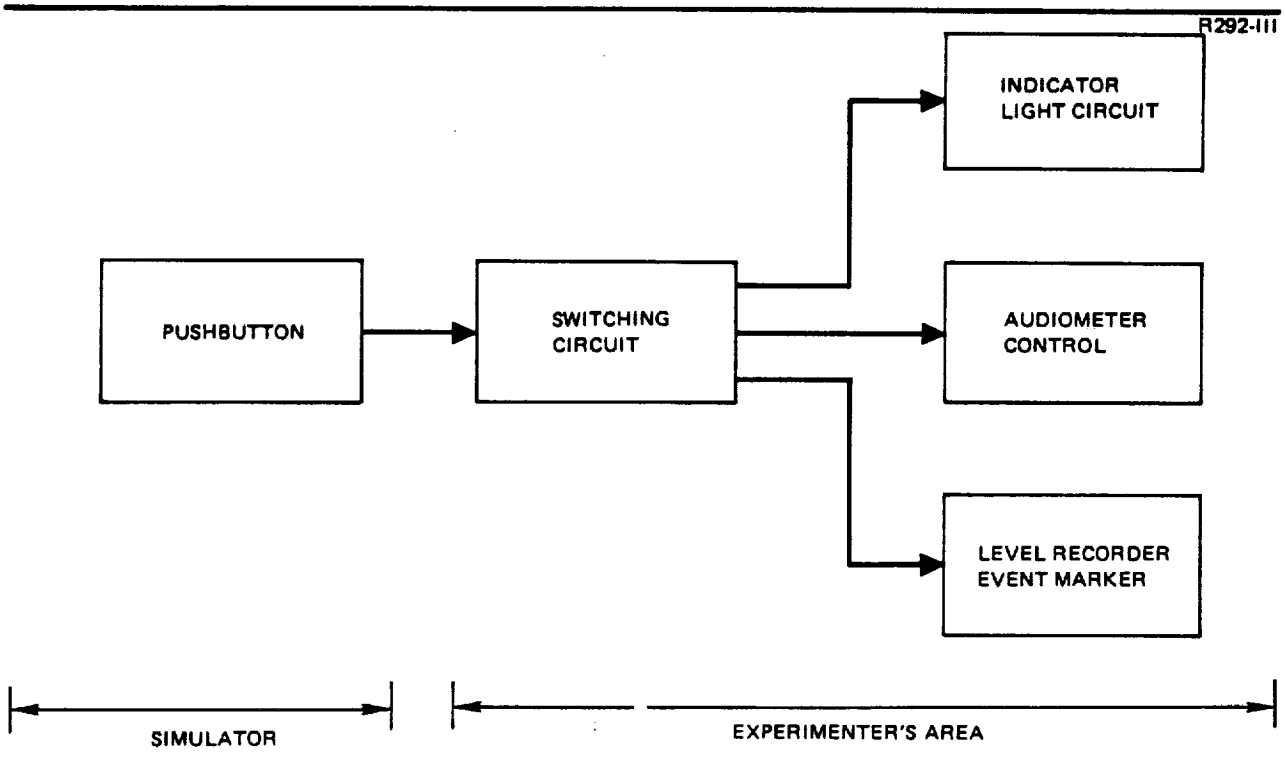


Figure 3-51. Pushbutton Response Circuit

The calibration equipment used to analyze the sound presented to the crewman is shown in Figure 3-52. In each case, the headphones were placed on an artificial ear, and the acoustic signal heard by the crewman was analyzed. The audiometric calibration data (Figure 3-53) show good correspondence with the old standard for audiometric zero (Reference 3-18). Speech peak levels for the speech comprehension tests are shown in Table 3-26. Figure 3-54 shows the spectra of the artificial ambient noises used during the test. The pink noises are represented in Figure 3-55.

Crew reactions to the acoustic environment were evaluated by application of the habitability questionnaire (Section 3.3) every 14 days and hostility scale (Section 3.4.2.1) every 7 days during the test. In addition, a debriefing was held the day following crew exit from the chamber. Approximately 15 minutes were spent on a discussion of the noise in a nondirective way so that spontaneous reactions could be elicited and immediate general reactions assessed.

The detailed noise questionnaire (Appendix E) was given during the first noise post-test, 2 days after exit from the chamber. The questionnaire was designed to elicit data about specific noise problems, desired noise level in comparison to the two levels in the SSS, and the adequacy of the noise test battery.

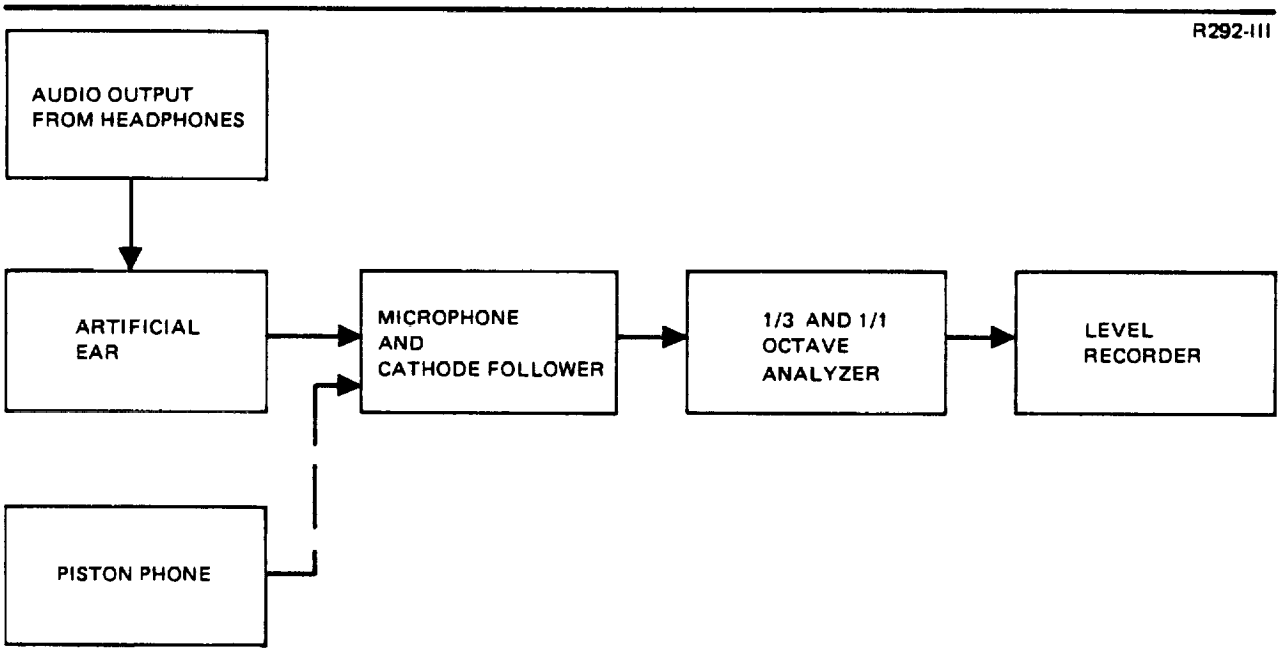


Figure 3-52. Calibration System

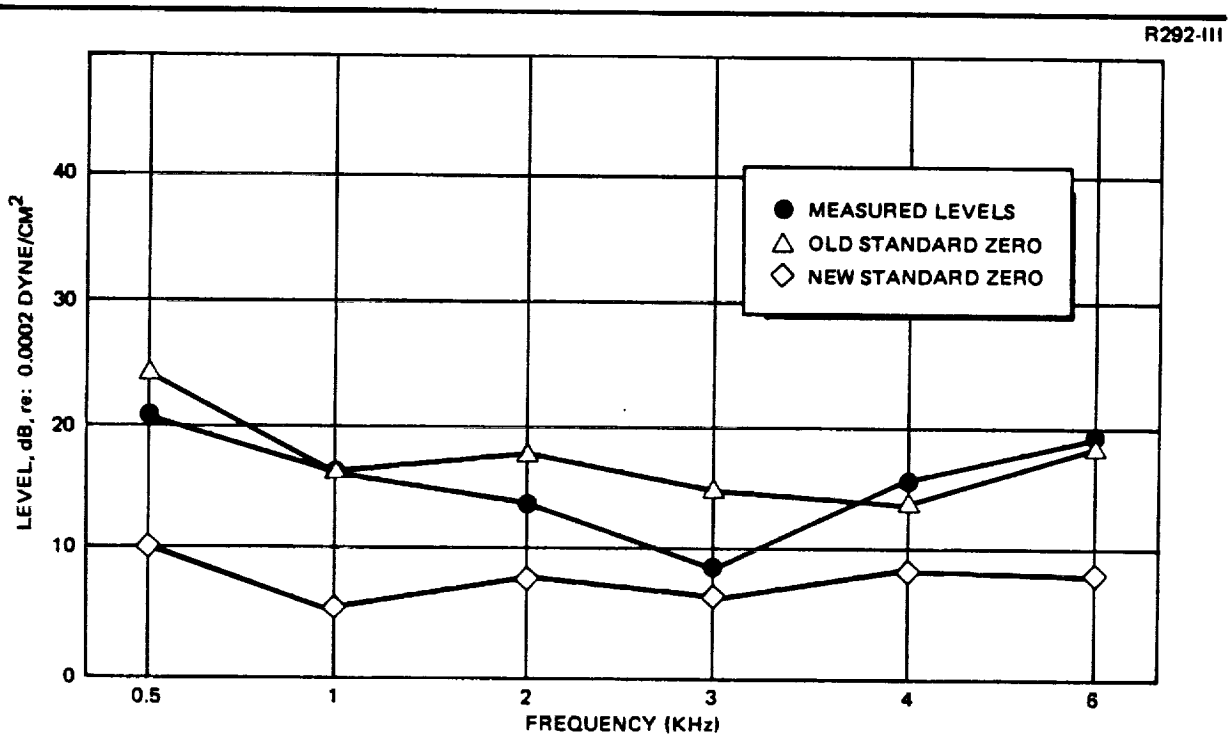


Figure 3-53. Audiometric Calibration Data

Table 3-26

SPEECH PEAK LEVELS USED DURING SPEECH COMPREHENSION TESTS

(expressed in peak overall sound-pressure level, db)

	Mixed Word Sets		Repeated Word Set	
Crewman	Low Ambient	High Ambient	Low Ambient	High Ambient
1	68	70	70	74
2	62	70	67	78
3	68	69	67	76
4	67	71	66	74
Average	66.25	70.0	67.5	75.5

R292-III

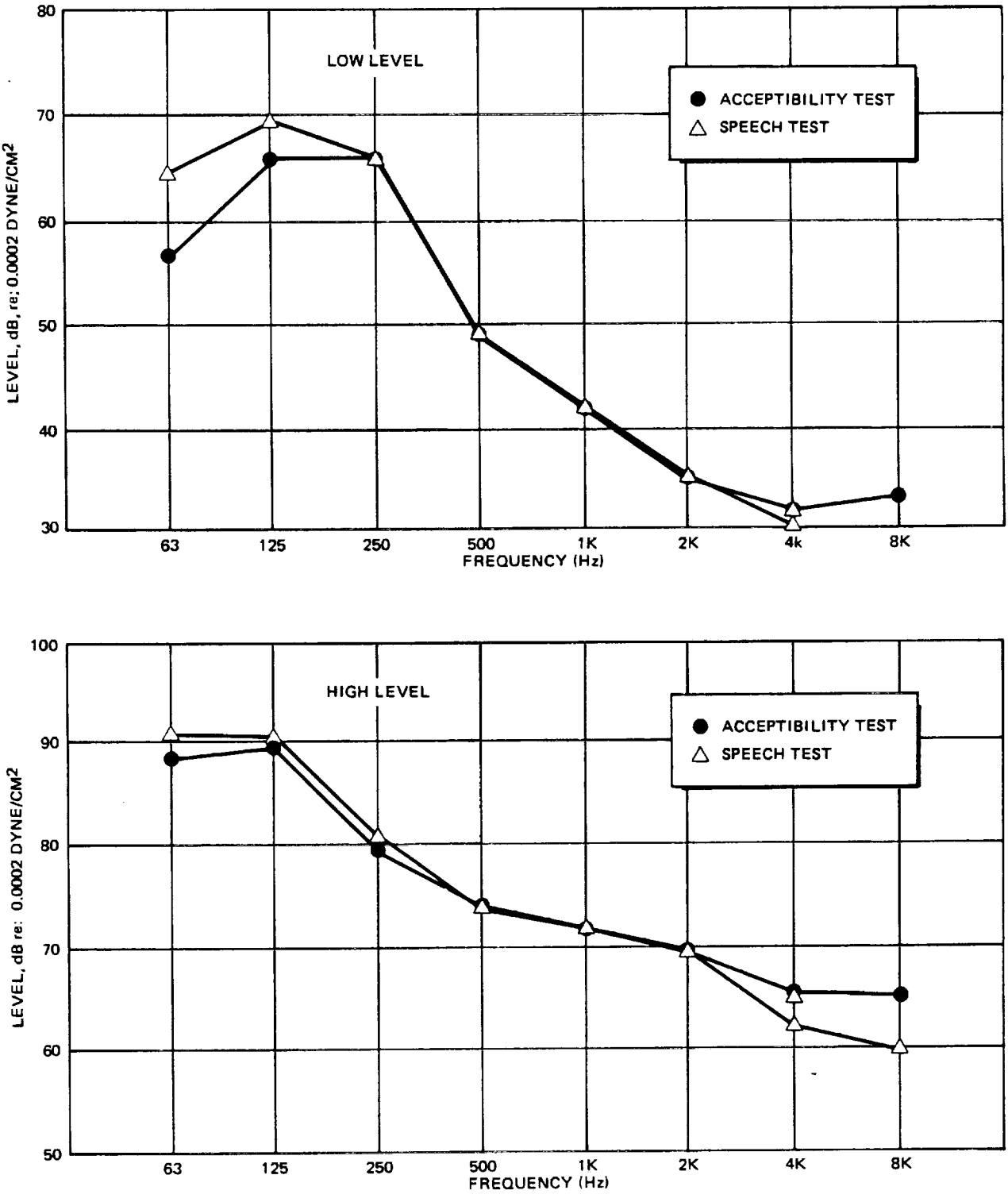


Figure 3-54. Ambient Noise

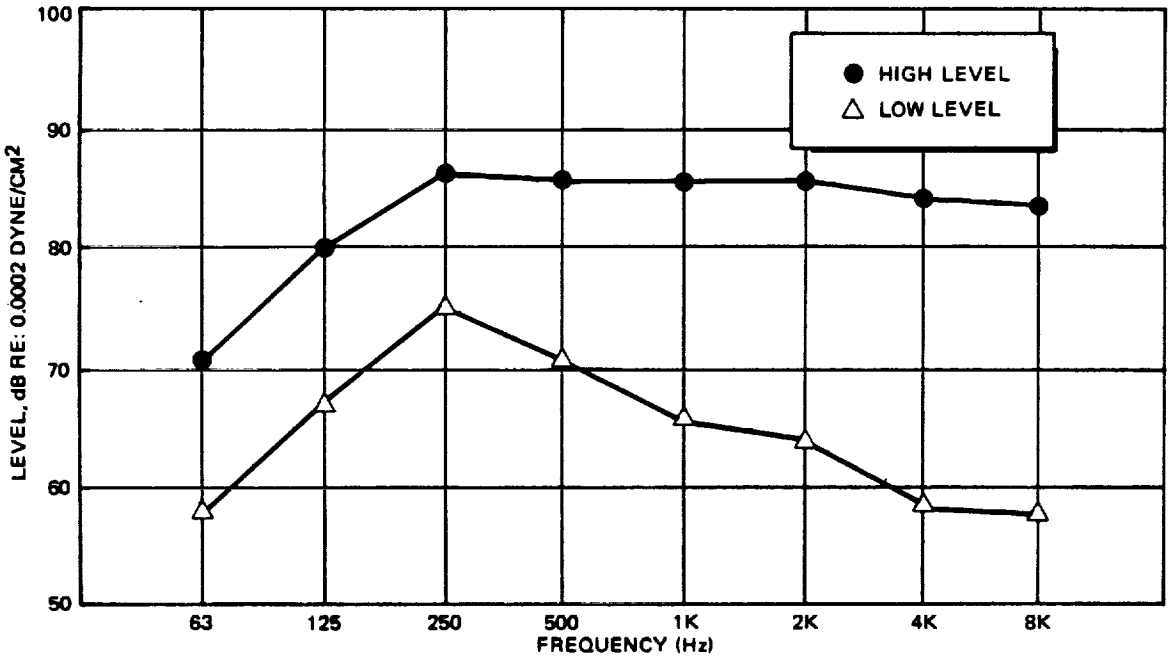


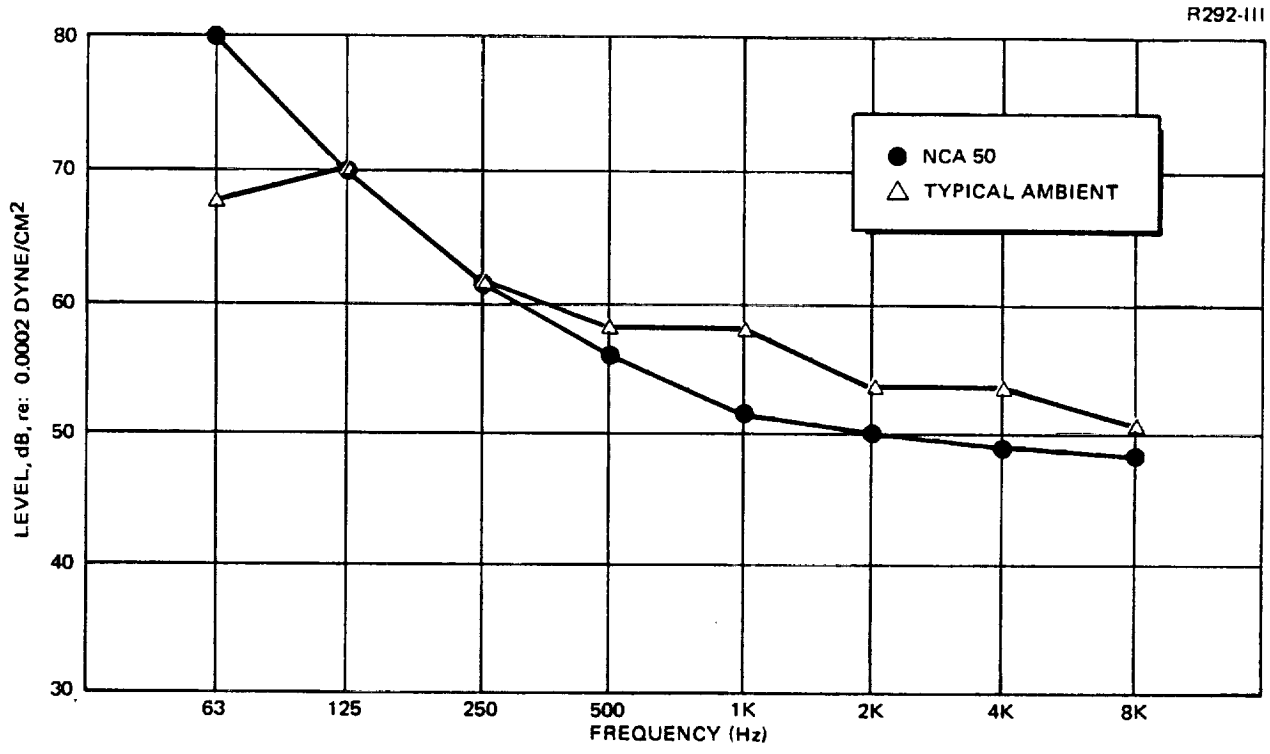
Figure 3-55. Pink Noise Test Stimuli

To establish background levels for use in other procedures, noise levels at a number of points inside the SSS were measured before the test and three times during the 90-day period. The noise was not constant since various pieces of equipment cycled on and off independently. Moreover, equipment malfunctions required the substitution of backup equipment on several occasions during the test. The levels shown on the background noise tapes are considered to be representative. Typical background noise spectra are shown in Figure 3-56. The levels of the crew quarters and equipment area were 64 and 77 db(A), respectively.

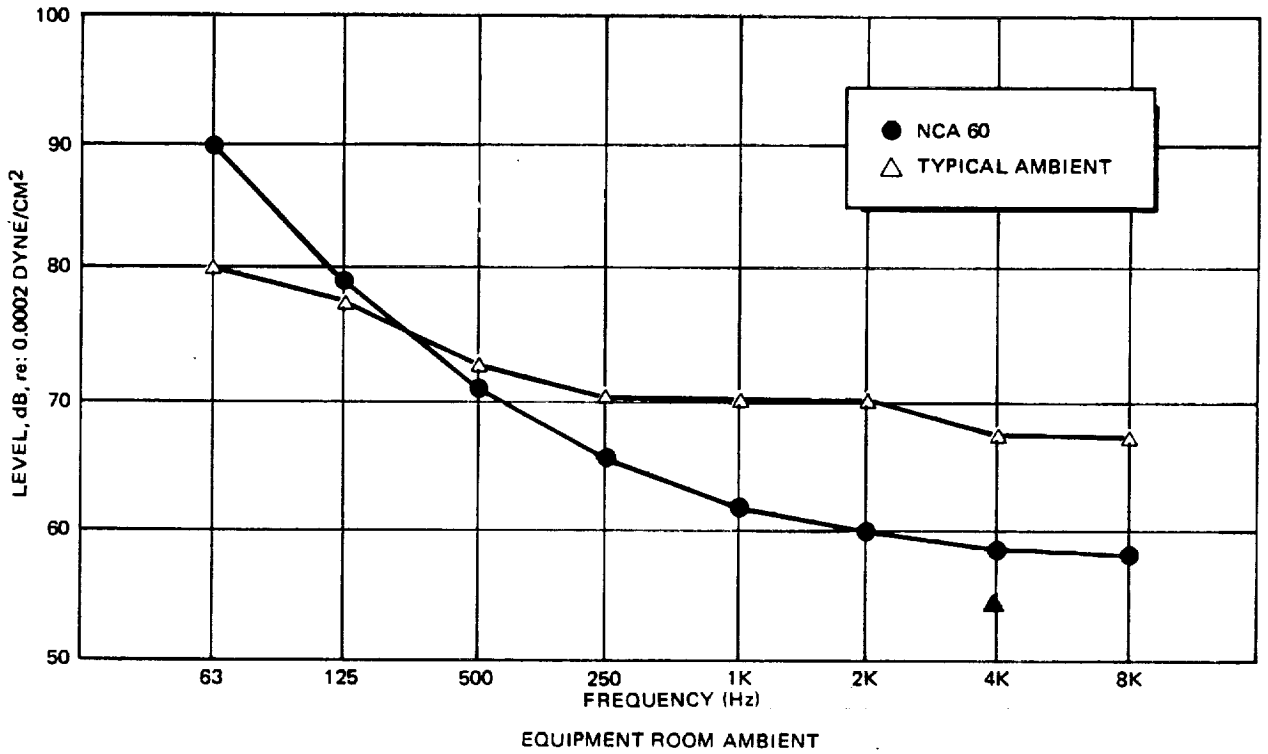
Noise measurements were obtained by recording noise on magnetic tape using a calibrated system to permit measurement of absolute levels. The recorded noise was later analyzed using a 1/3 and 1/1 octave band analyzer. Recordings were used to provide realistic sounds during the psychoacoustic testing.

3.6.2 Procedures

An initial briefing was held to introduce the experimenter, familiarize the crew with the test equipment and procedures, and provide general information concerning the nature of the study.



LIVING QUARTERS AMBIENT



EQUIPMENT ROOM AMBIENT

Figure 3-56. Background Noise Spectra

During the initial test session the instructions for each test were read. Prior to the speech comprehension testing, the speech level was slowly raised until the crewman estimated that he could understand one-half the words. The individual levels so established were found to be close enough to the 50 percent comprehension level to require no further adjustment. The first test was otherwise as described below.

Crewmen were tested in the SSS; the experimenter was located at a work station outside. Initial contact was made verbally through use of the intercom headset. Contact was made with the crewman, he was asked if the two experimental headsets, pushbutton, and two answer sheets were available and answer sheets labeled with the data and his name. He was then asked to put on the audiometer headset and push the button if he could hear the experimenter properly. The subject was then asked if he remembered the instructions for the audiometry test. If not, they were read. The system was then switched to the audiometry position and the audiometer started. Operation of the audiometer was automatic at this point.

After the audiometer had completed its cycle, the crewman was asked to switch to the alternate headset and again push the response button when he heard the experimenter properly. Instructions for the first part of the acceptability test were read if requested. The system was switched to the off position, the tape advanced to the start of the low ambient level acceptability test, and the mixer set to the required levels. The system was then set to the required levels. The system was then set to the recorder position and the first acceptability test tape played. The initial pink noise levels were set equal in overall sound pressure level to the cabin noises. This resulted in their being subjectively somewhat louder. The pairs were presented twice at this initial level, then once at 15 to 20 db attenuation (three of the four crewmen consistently rated the pink noise quieter at 15 db, one at 20 db attenuation). Subsequent adjustments were made by halving the distance between the two appropriate previous levels. An initial determination was thus made within five adjustments. Several additional 1 or 2 db adjustments were then made to assure the accuracy of the initial result, and the entire process repeated once. If there was inconsistency, several additional replications were made.

The crewman was then informed that the test was completed and that the next test was the high level acceptability test. This and the four sections of the speech comprehension test were then presented. Before each test the crewman was asked if he needed a repeat of the instructions, the tape was advanced to the appropriate point, and mixer levels were readjusted. After the test, the crewman was asked to have another crew member contact the experimenter.

3.6.3 Results

3.6.3.1 Audiometric Data

Good reliability was obtained within each test session. The "tracking" method of the audiometer provided approximately 5 test-retest measures of the threshold for each frequency. The standard deviation of threshold measurements is seldom less than 2.5 db. (See Reference 3-20 for a discussion of this point.) The procedure used in this experiment produced

repeatability at least this accurate. A horizontal median line drawn by eye through the approximately 10 data points for each frequency was used as the threshold value. Since, by inspection, this line was clearly accurate within 1 or 2 db, and since changes this small were not of interest, no further evaluation of within-day test-retest accuracy was done.

In contrast to the within-day consistency, large period-to-period variations were noted, occasionally as great as 20 db. These shifts were inconsistent, and may be attributed to any number of factors such as changes in cabin ambient noise, variations in earphone placement, changes in motivation, or true week-to-week variations in hearing acuity. Inspection of the individual audiometric data (Figure 3-57) indicates this large week-to-week variability. These graphs also indicate that crewmen 2 and 3 changed only slightly over the 90-day test period, but showed pre-post changes, while crewmen 1 and 4 show gradual changes over the 90-day test period, mainly at the 0.5, 1, 4, and 6 KHz. frequencies.

Multiple significance tests were used because of the idiosyncratic nature of hearing loss. (Major effects would be expected in the more "noise-sensitive" subjects and only at some frequencies. In an analysis of variance, this would show up as effects on several main variables, as well as several complex interactions.)

The "t" test was used to evaluate the statistical significance of the following: pre-post differences for each ear, each frequency, and each subject and early-late differences (using 3 weeks' data for each category), again for each ear, frequency, and subject.

A trend analysis was also performed to determine if a systematic change occurred in the period from the first pretest through the last test during the 90-day simulation. Tests were performed for each frequency, ear, and crewman, to determine the percentage of the variance accounted for by the trend line, the significance that its slope was different from zero, and the decibel change indicated by the trend. Since the trend analysis used more data points than the early-late comparison, it was a more sensitive test and identified more instances of significance.

Table 3-27 presents the significance test results. Eight pre-post-test changes were significant at the 0.05 level. However, only three of these correspond to significant early-late changes, suggesting that pre-post changes were not closely related to real changes during the 90-day period. Nine early-late tests were significant at the 0.05 level. These were all for crewmen 1 and 4, and mainly for one ear for each of these subjects. Seventeen of the more sensitive trend tests were significant at the 0.05 level. Fifteen of these were for crewmen 1 and 4.

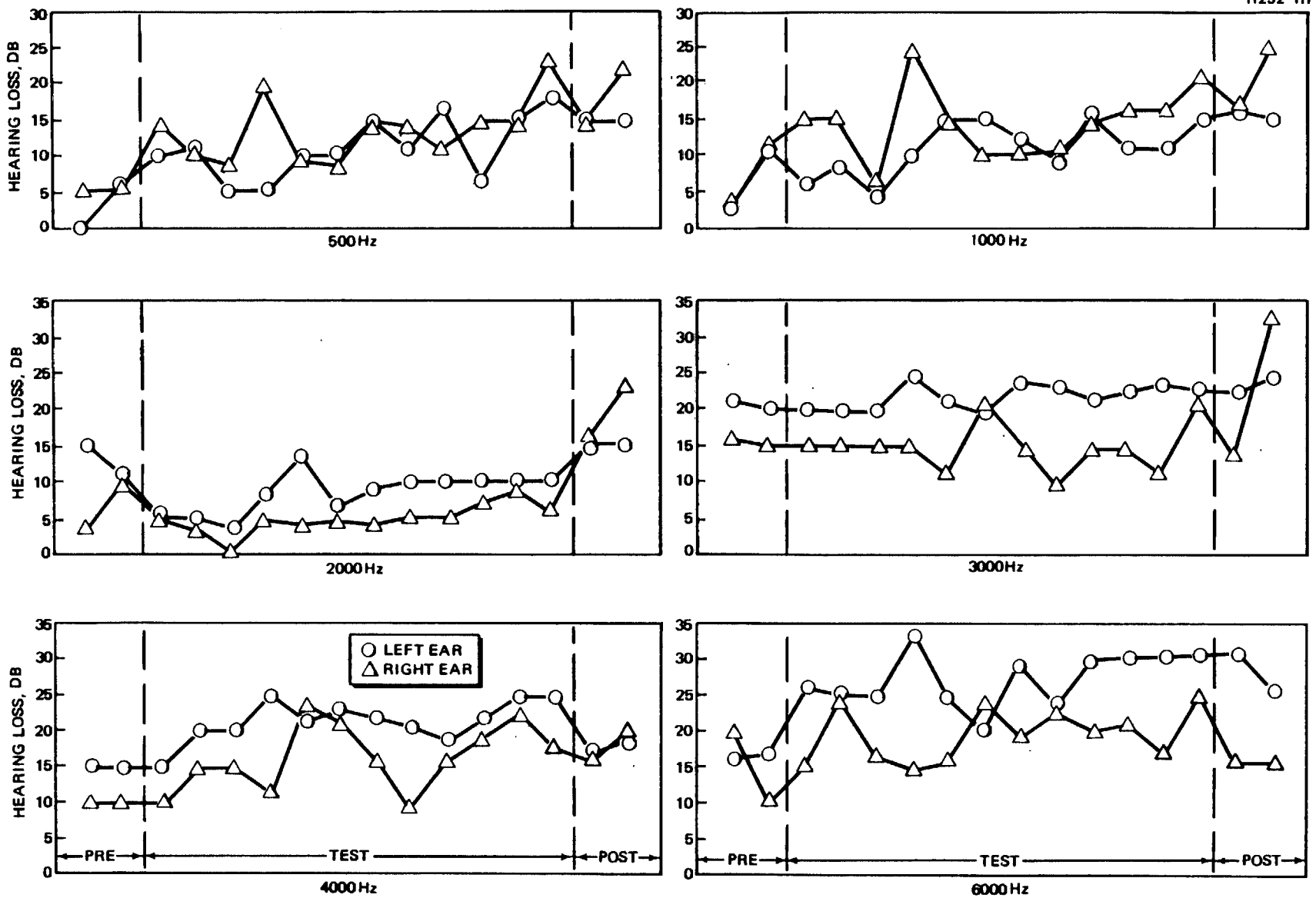


Figure 3-57. Weekly Audiometric Data, Crewman 1 (Page 1 of 4)

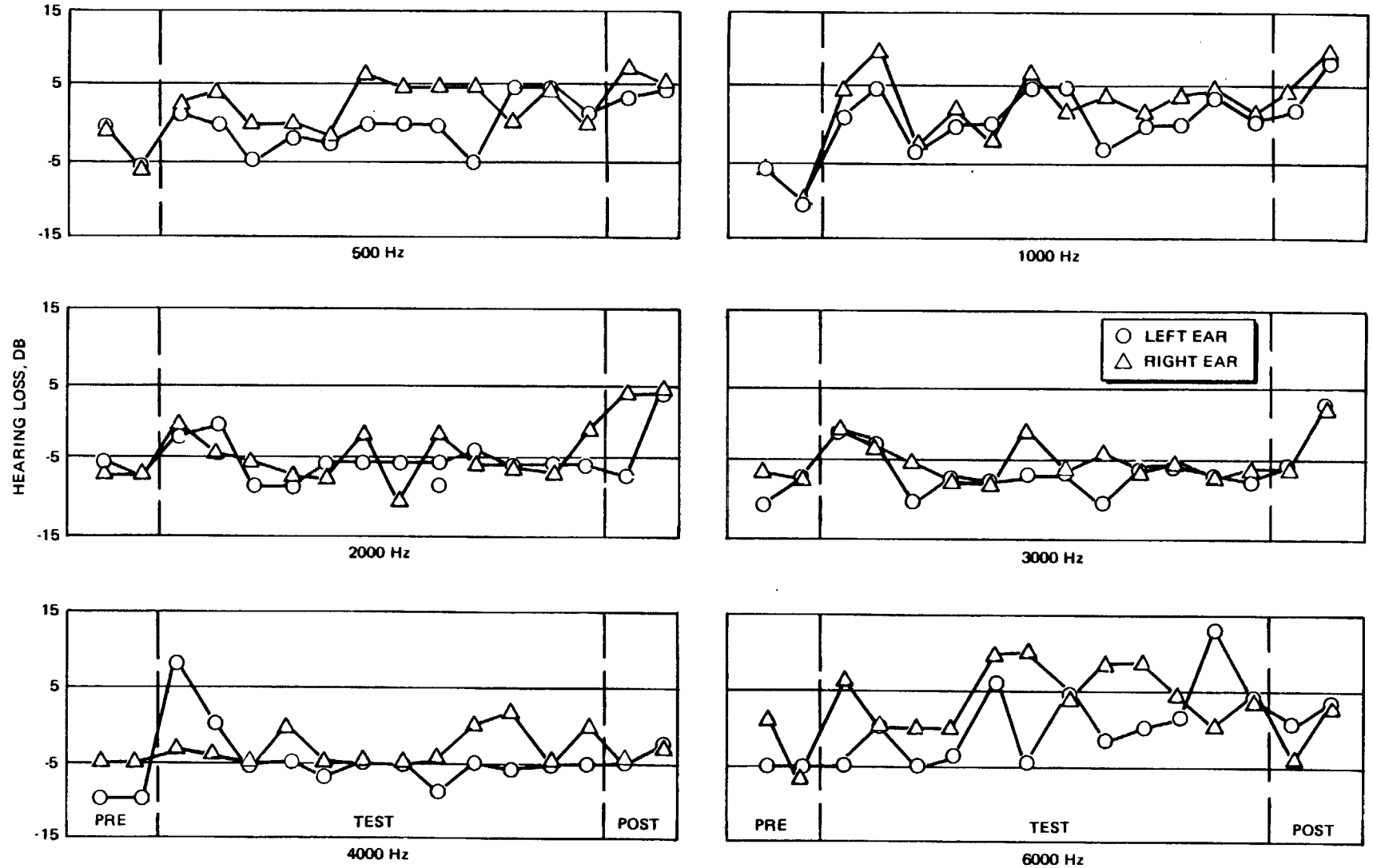


Figure 3-57. Weekly Audiometric Data, Crewman 2 (Page 2 of 4)

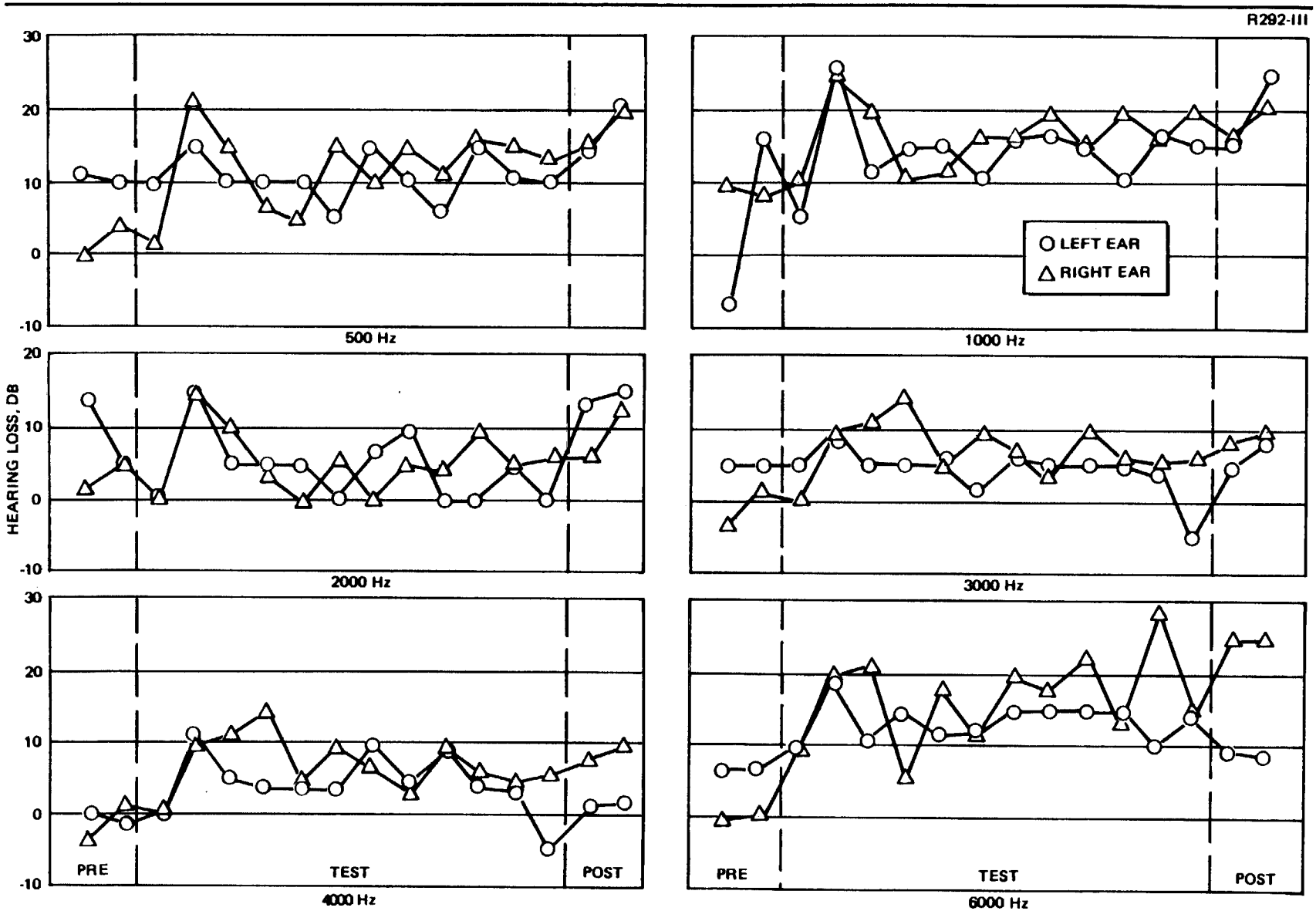


Figure 3-57. Weekly Audiometric Data, Crewman 3 (Page 3 of 4)

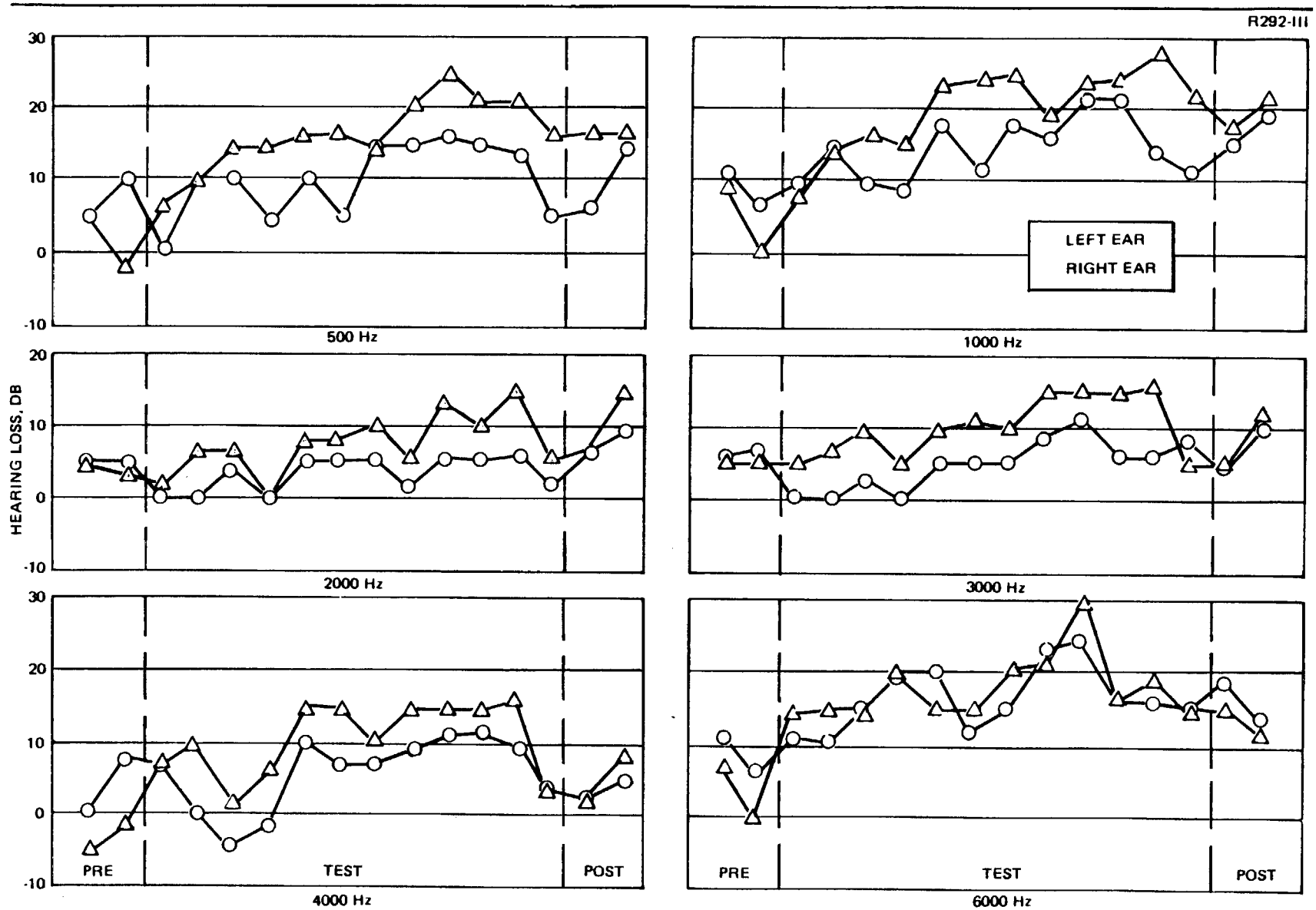


Figure 3-57. Weekly Audiometric Data, Crewman 4 (Page 4 of 4)

Table 3-27

AUDIOMETRY SIGNIFICANCE TEST RESULTS

f	Pre - Post		Early - Late		Regression Line		
(kHz)	Change	T	Change	T	Index r^2 (% of variance)	Slope	Δ(db)
			Crewman 1				
Left Ear							
0.5	9.5	2.433	4.333	1.115	30.6	0.727*	9
1	9.5	2.610	6.333	3.591*	29.9	0.681*	9
2	2.0	1.000	5.667	8.5**	0.0	-	-
3	3.0	2.121	3.333	10.0**	20.7	0.237*	3
4	2.5	5.0*	5.667	2.915*	44.5	0.629**	8
6	13.5	6.548*	5.667	17.**	32.3	0.877*	11
Right Ear							
0.5	13.5	3.857	6.667	1.971	30.8	0.813*	11
1	13.5	2.242	6.0	1.664	7.8	0.629	-
2	13.5	2.929	4.667	2.746	0.0	-	-
3	8.5	0.849	1.333	0.450	0.0	-	-
4	8.0	4.0	6.667	2.949*	22.4	0.690*	9
6	1.0	0.2	2.333	0.607	7.0	0.486	-

* Significant at 0.05 level
** Significant at 0.01 level

Table 3-27 (Continued)

AUDIOMETRY SIGNIFICANCE TEST RESULTS

f	Pre - Post		Early - Late		Regression Line		
(kHz)	Change	T	Change	T	Index r^2 (% of variance)	Slope	Δ(db)
			Crewman 2				
Left Ear							
0.5	7.5	+2.466	5.0	2.165	8.3	0.380	-
1	13	3.606	0.33	0.127	6.4	0.466	-
2	7	1.698	-2	-0.745	0.0	-	-
3	8	1.687	-2	-0.643	0.0	-	-
4	6	6.0*	-6	-1.475	0.0	-	-
6	6.5	4.33*	9.67	2.563	37.6	0.899**	12
Right Ear							
0.5	9	3.087	-1	-0.452	0.0	-	-
1	15	4.243	-0.33	-0.086	3.7	0.516	-
2	16	- †	-0.67	-0.277	0.0	-	-
3	4.5	1.116	-3	-2.324	0.0	-	-
4	1.5	1.0	3	1.389	9.0	0.281	-
6	3	0.530	1	0.349	3.8	0.488	-

† Pooled variance is zero
* Significant at 0.05 level
** Significant at 0.01 level

Table 3-27 (Continued)

AUDIOMETRY SIGNIFICANCE TEST RESULTS

f	Pre - Post		Early - Late		Regression Line		
(kHz)	Change	T	Change	T	Index r^2 (% of variance)	Slope	Δ(db)
			Crewman 3				
Left Ear							
0.5	7	1.980	0.667	0.302	0.0	-	-
1	15.5	1.236	-2.333	-0.405	0.0	-	-
2	5	1.104	-5.	-1.060	9.4	-0.574	-
3	1.5	1.0	-5.333	-1.486	13.5	-0.387	-
4	3	3.0	-5.	-1.112	0.0	-	-
6	2	2.0	-1.333	0.394	0.0	-	-
Right Ear							
0.5	15.5	4.841*	1.667	0.281	15.1	0.787	-
1	10.5	4.200	0.333	0.072	10.5	0.598	-
2	5	3.536	0.333	0.065	0.0	-	-
3	6	1.576	-1.333	-0.286	0.0	-	-
4	9.5	3.528	-1.667	-0.447	0.0	-	-
6	25	-†	2.333	0.366	30.1	1.321*	17

† Pooled variance is zero
* Significant at 0.05 level
** Significant at 0.01 level

Table 3-27 (Continued)

AUDIOMETRY SIGNIFICANCE TEST RESULTS

f	Pre - Post		Early - Late		Regression Line		
(kHz)	Change	T	Change	T	Index r^2 (% of variance)	Slope	Δ(db)
			Crewman 4				
Left Ear							
0.5	3	0.583	4.33	0.958	10.4	0.578	-
1	8	2.263	4.33	1.245	19.5	0.632*	8
2	2.5	1.667	3.33	2.132	0.0	-	-
3	0.5	0.164	5.67	4.715**	14.8	0.435	-
4	-0.5	-0.117	7.33	1.677	8.8	0.600	-
6	7	1.627	4.0	2.502	22.5	0.754*	10
Right Ear							
0.5	16.5	4.714*	9.67	3.371*	67.8	1.516**	20
1	14.5	2.594	11.33	3.488*	63.5	1.549**	20
2	7	1.698	4.67	1.4	24.2	0.585*	8
3	3.5	1.0	4.67	1.228	32.8	0.679*	9
4	9.5	3.8	5.33	1.186	33.7	1.097*	14
6	9.5	2.357	1.667	1.387	21.4	0.949*	12

* Significant at 0.05 level
** Significant at 0.01 level

Inspection of the individual data in Figure 3-57 and the related significance tests in Table 3-27 suggest that crewmen 2 and 3 changed only slightly during the 90-day test, but did show pre-post-test changes. Crewmen 1 and 4 seemed to show hearing loss during the 90-day test, but mainly at 0.5, 1, 4, and 6 kHz. On the basis of these observations, data were grouped into six categories: loss (crewmen 1 and 4) versus no loss (crewmen 2 and 3) and low (0.5 and 1 kHz), medium (2 and 3 kHz) and high (4 and 6 kHz) frequencies. Each of these categories is plotted versus time in the graphs in Figure 3-58.

These plots are quite representative of the raw data, since only a few isolated raw data points fall a distance of greater than 5 db from the appropriate graph in Figure 3-58. Summary data for this categorization method are shown in Table 3-28. Large pre-post differences exist for all six categories. However, the loss and no-loss groups have similar pre-post changes. In fact, the loss group shows less pre-post change than the no-loss group. The no-loss group shows no more than 0.5 db early-late loss, while the loss group shows early-late losses of about 5 db.

Table 3-29 shows the trends for the six summary categories. Again, the trend analysis is slightly more sensitive, showing larger changes for the loss group. The no-loss group shows virtually no trend.

Table 3-28

AUDIOMETRIC DATA COMPARING LOSS AND NO-LOSS GROUPS

	Pre - Post			Early - Late		
Frequency	Loss	No Loss	Difference	Loss	No Loss	Difference
Low	11.0	11.6	-0.6	6.6	0.5	6.1
Medium	4.5	6.6	-2.1	4.1	-1.5	5.6
High	6.3	6.7	-0.4	4.7	0.2	4.5

Table 3-29

AUDIOMETRY SIGNIFICANCE TEST
RESULTS COMPARING LOSS AND NO-LOSS GROUPS

	Loss			No Loss		
Frequency	Index %	Slope	Change db	Index %	Slope	Change db
Low	74.2	0.733**	8	0.0	-	-
Medium	70.6	0.478**	5	0.0	-	-
High	20.1	0.422*	5	0.0	-	-

* Significant at 0.05 level
** Significant at 0.01 level

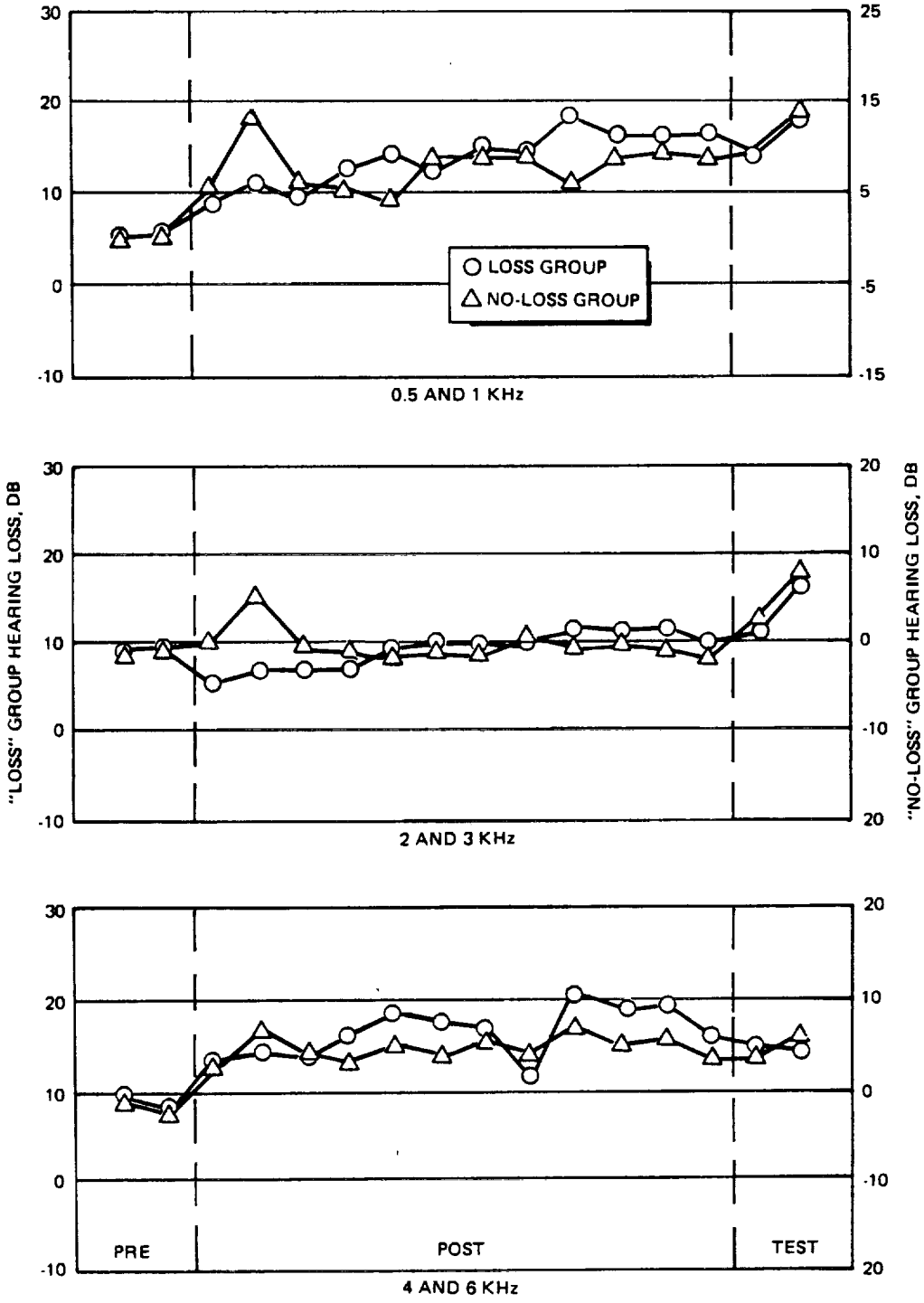


Figure 3-58. Audiometric Data in Summary Categories

3.6.3.2 Acceptability Tests

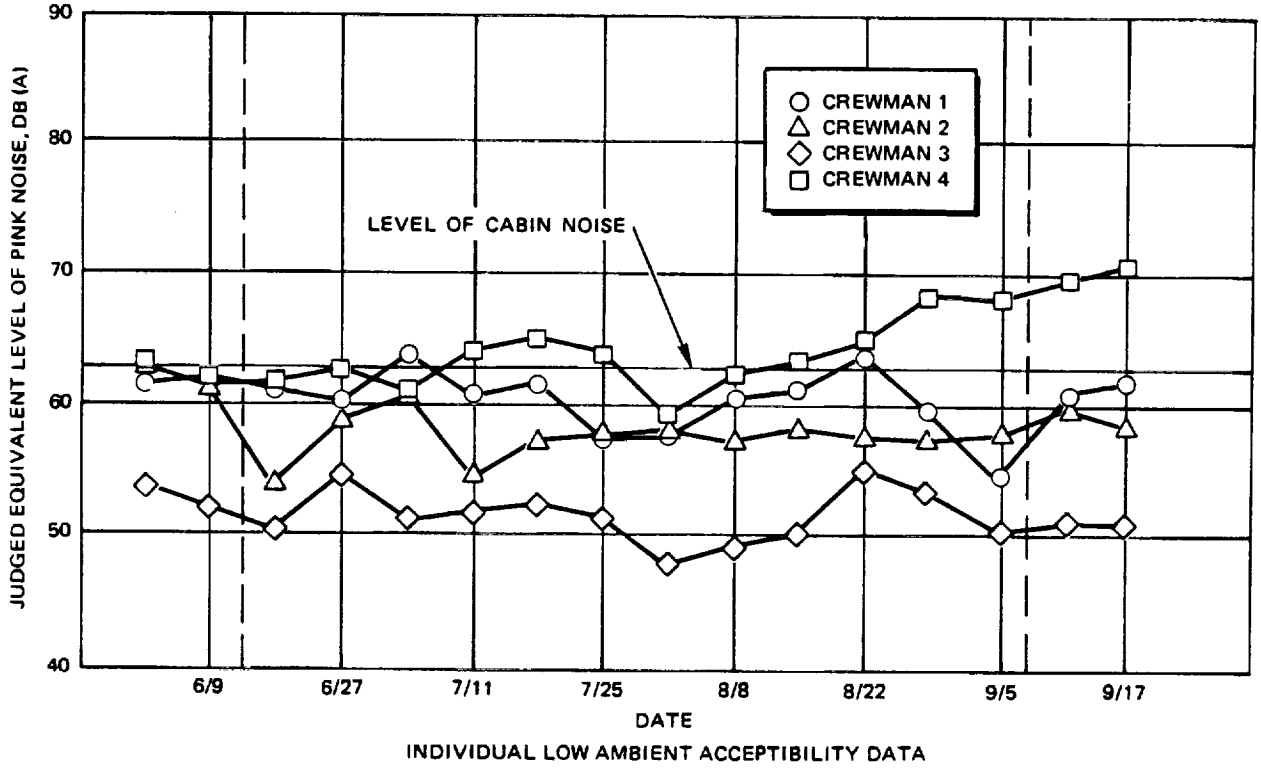
Figure 3-59 shows the individual results for the low and high cabin ambient acceptability tests. The statistical tests in Table 3-30 show that only one crew member changed consistently. (The early-late significance for crewman 2 is probably an artifact since the more sensitive trend test showed no effect.) Even in this case, the trend indicated only a 3-db change (the noise becoming less acceptable). However, this crewman showed pre-post changes of more than 6 db, mainly due to decreased acceptability of the cabin noises during the post-test. This would indicate that although the crewman found the cabin noises slightly unpleasant, his major reaction was to find displeasure in hearing it again after the test was over. This aspect of sensitization was not predicted, but seems reasonable.

Although there were longer-term changes, many adjacent testings showed 0 or 1 db differences. Test-retest data within a given day showed a truly remarkable consistency. Differences of greater than 2 db were extremely rare. Thus, week-to-week variation is not due simply to inaccuracy in the tests, but indicates a real underlying difference. Average data are shown in Figure 3-60. The total range of variation occurring before the post-test was never more than 5 db.

3.6.3.3 Speech Comprehension Tests

Speech comprehension results were very consistent. The first three testings of the mixed-set test were invalidated because of procedural problems, preventing pre-post significance tests for this phase. However, the pre-post results for the repeated-group test provide a good estimate of these missing data. Data for individual crewmen are shown in Table 3-31. Only one pre-post test was significant at the 0.05 level. However, none of the individual early-late and only one of the slope tests were significant. Averaged tests based on all four crewmen are shown in Table 3-32. The only significant change is in the pre-post and slope of the repeated-word-set test at high ambient level, and this change was in the direction of improvement with time.

Averaged data for the four speech comprehension subtests are shown in Figures 3-61 and 3-62. From the summary graphs, the range of most of the data points can be seen to be about three words (12 percent) for the mixed-group tests and two words (17 percent) for the repeated-group tests. The single significant slope for averaged data represents a change of 13 percent. Previous work with the modified rhyme test (Reference 3-21) shows a slope at the 50 percent comprehension level of about 3 percent per db change in masking level. Work with the repeated group test shows its slope to be about 6 percent per db, due to more careful control of level and similarity of words. Thus, effects equivalent to about 3-db change in noise level were noticeable with the sensitivity of this experiment. This emphasizes the lack of meaningful change experienced.



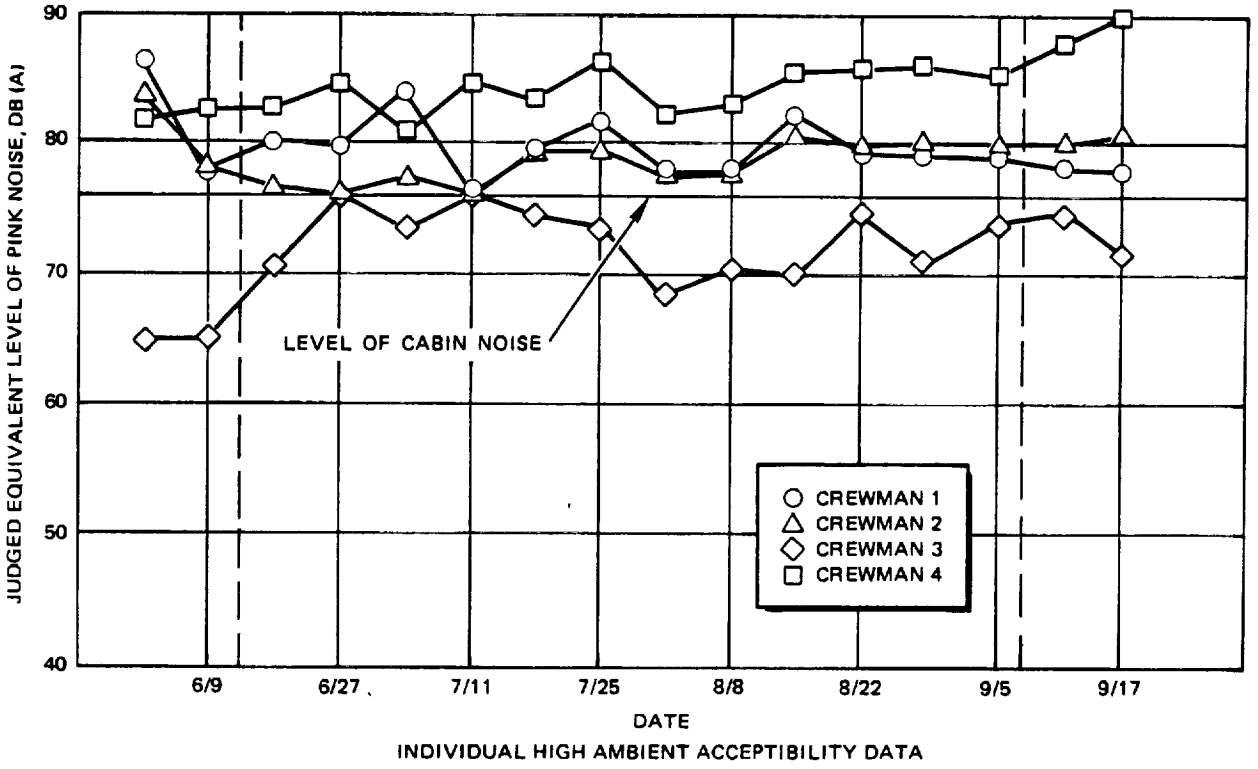


Figure 3-59. Ambient Acceptibility Data

Table 3-30

ACCEPTABILITY SIGNIFICANCE TEST RESULTS

Crewman	Noise Level	Pre - Post Change	Pre - Post T	Early - Late Change	Early - Late T	Regression Line Index r^2 (% of variance)	Regression Line Slope	Regression Line Δ(db)
1	Lo	0.75	1.342	2	0.671	1.6	0.234	-
	Hi	4.75	1.0	2.67	2.219	1.7	0.270	-
2	Lo	3.75	3	0.67	0.277	1.4	0.260	-
	Hi	0.25	0.089	-3.167	-7.181**	0.0	-	-
3	Lo	1.0	1.0	-0.67	-0.353	0.0	-	-
	Hi	-8.5	-5.667	0.67	0.316	0.0	-	-
4	Lo	-7.25	-8.093*	-4.67	-3.396*	10.3	-0.295	-
	Hi	-6.25	-6.063*	-2.67	-2.218	20.3	-0.232*	3
Mean	Lo	-0.44	-0.700	-0.67	-0.532	0.0	-	-
	Hi	-2.44	-1.348	-0.623	-1.106	0.0	-	-

* Significant at 0.05 level
** Significant at 0.01 level

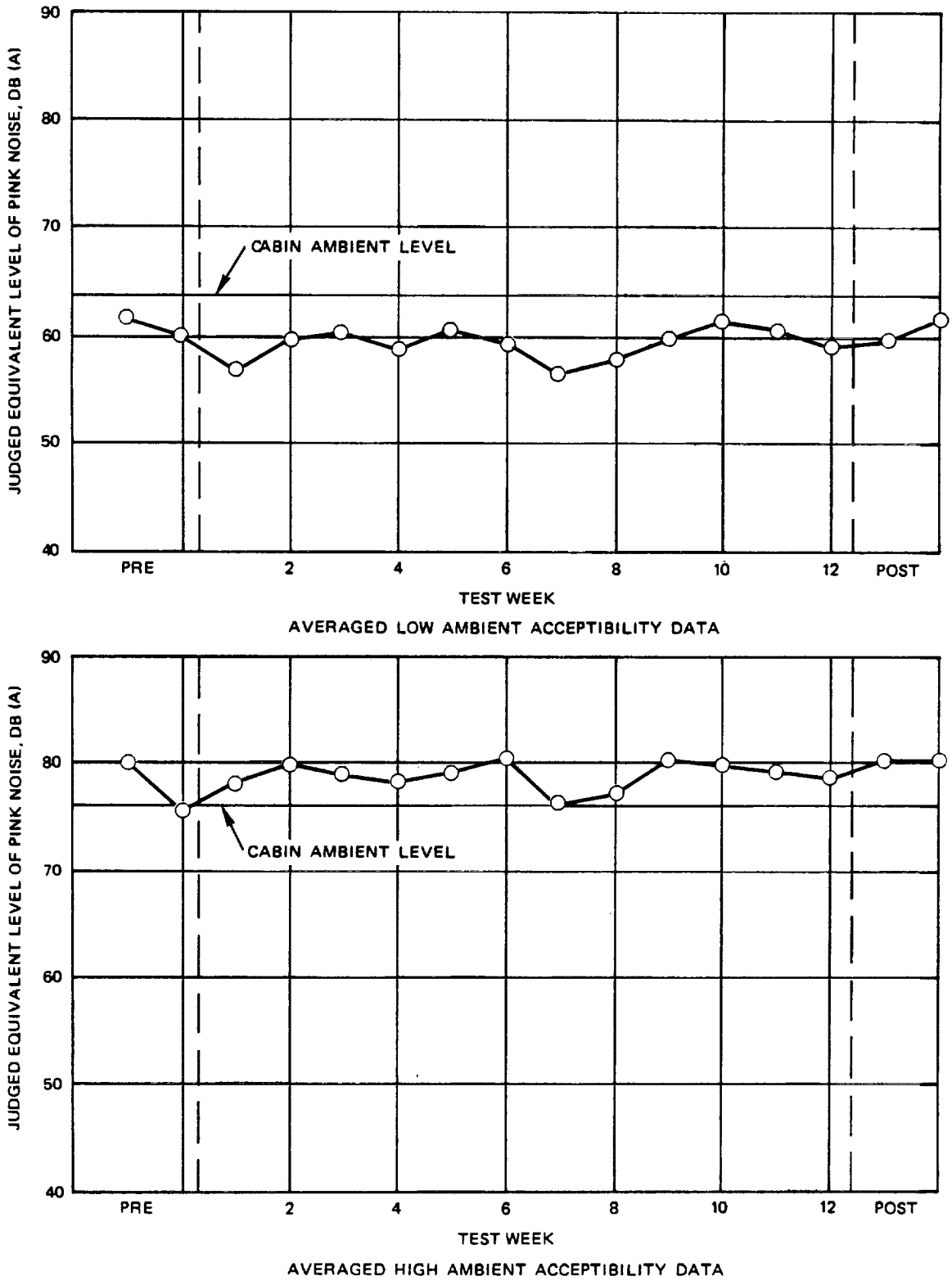


Figure 3-60. Average Ambient Acceptibility Data

Table 3-31

SPEECH COMPREHENSION SIGNIFICANCE
TEST RESULTS FOR INDIVIDUAL CREWMEN

Crewman	Word Sets	Noise Level	Pre - Post Change	Pre - Post T	Early - Late Change	Early - Late T	Regression Line Index r^2 (% of variance)	Regression Line Slope	Regression Line Δ(words)
1	Mixed	Lo	-	-	-2.67	-1.315	7.0	-0.318	-
		Hi	-	-	-0.33	-0.2	0.0	-	-
	Repeated	Lo	-	-	0.33	0.379	0.0	-	-
		Hi	-	-	-1.33	-0.918	0.0	-	-
2	Mixed	Lo	-	-	1.0	-0.802	0.0	-	-
		Hi	-	-	-1.33	-0.718	0.0	-	-
	Repeated	Lo	-1.5	-1.342	-0.67	-1.0	3.9	-0.114	-
		Hi	-4.0	-4.0	-1.0	-0.866	55.1	-0.259**	3.4
3	Mixed	Lo	-	-	0.0	0.0	0.0	-	-
		Hi	-	-	-1.33	-0.555	0.0	-	-
	Repeated	Lo	+6	6*	-0.67	-0.292	0.0	-	-
		Hi	-	-	0.67	1.0	0.0	-	-
4	Mixed	Lo	-	-	-1.33	-1.265	0.0	-	-
		Hi	-	-	-2.0	-2.121	8.3	-0.2	-
	Repeated	Lo	-0.5	0.447	-1.67	-1.89	1.5	-0.108	-
		Hi	-		0.0	0.0	0.0	-	-

* Significant at 0.05 level

NOTE: Missing pre-post data due to pretest procedural difficulties.

Table 3-32

SPEECH COMPREHENSION SIGNIFICANCE
TEST RESULTS FOR AVERAGED DATA

		Pre - Post		Early - Late		Regression Line		
Word Set	Noise Level	Change	T	Change	T	Index r^2 (% of variance)	Slope	Δ(words)
Mixed	Lo	-	-	-0.75	-2.405	0.0	-	
	Hi	-	-	-1.25	-1.168	0.0	-	
Repeated	Lo	-0.29	0.485	-0.67	-1.265	0.0	-	
	Hi	-1.96	-4.504*	-0.58	-1.107	28.3	-0.111*	1.5 words, 13%

*Significant at 0.05 level

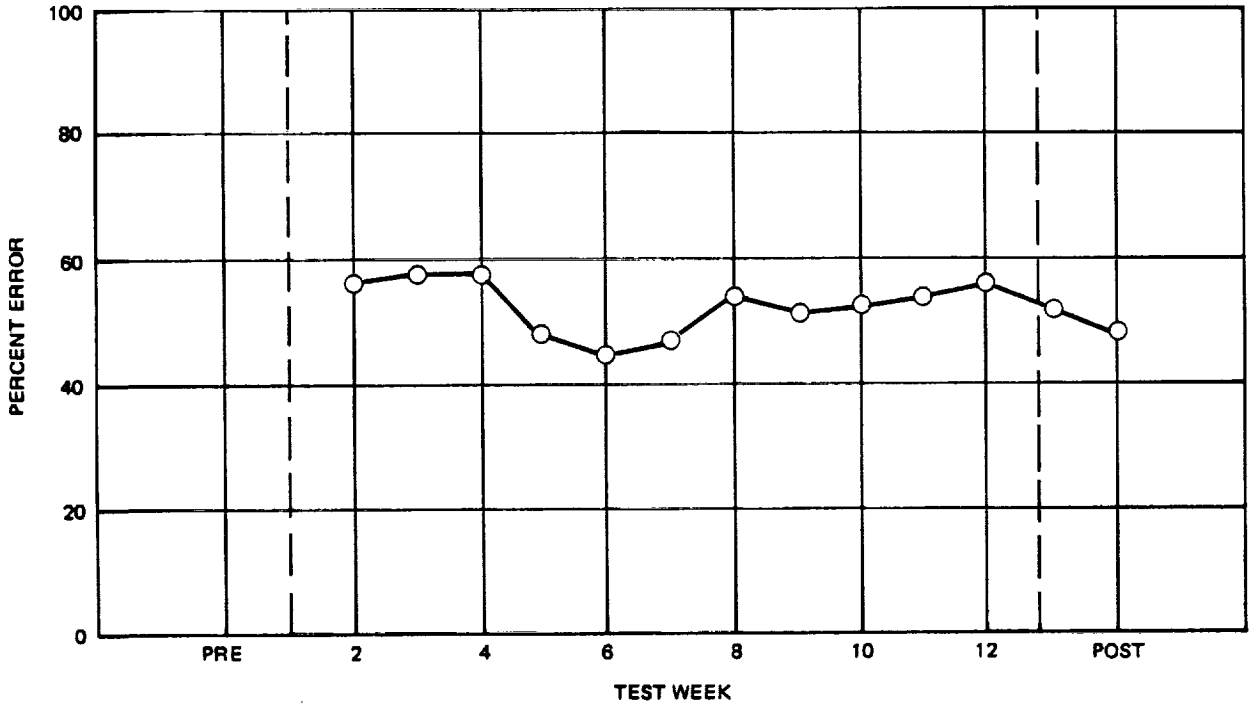
3.6.3.4 Habitability Questionnaire

Habitability questionnaire data relating to noise is shown in Table 3-33. Averaged responses were all slightly worse than "good" and did not vary a great deal during the test. Crew quarters and hygiene area were similar in noise level, and the similar ratings provide evidence of test validity. Both areas were rated slightly above "good," showing them to be acceptable both absolutely and relative to the other factors rated. The equipment area noise, however, was rated only slightly better than fair, well below average ratings for all items. This clear differentiation between the two areas will also be seen in several questionnaire items.

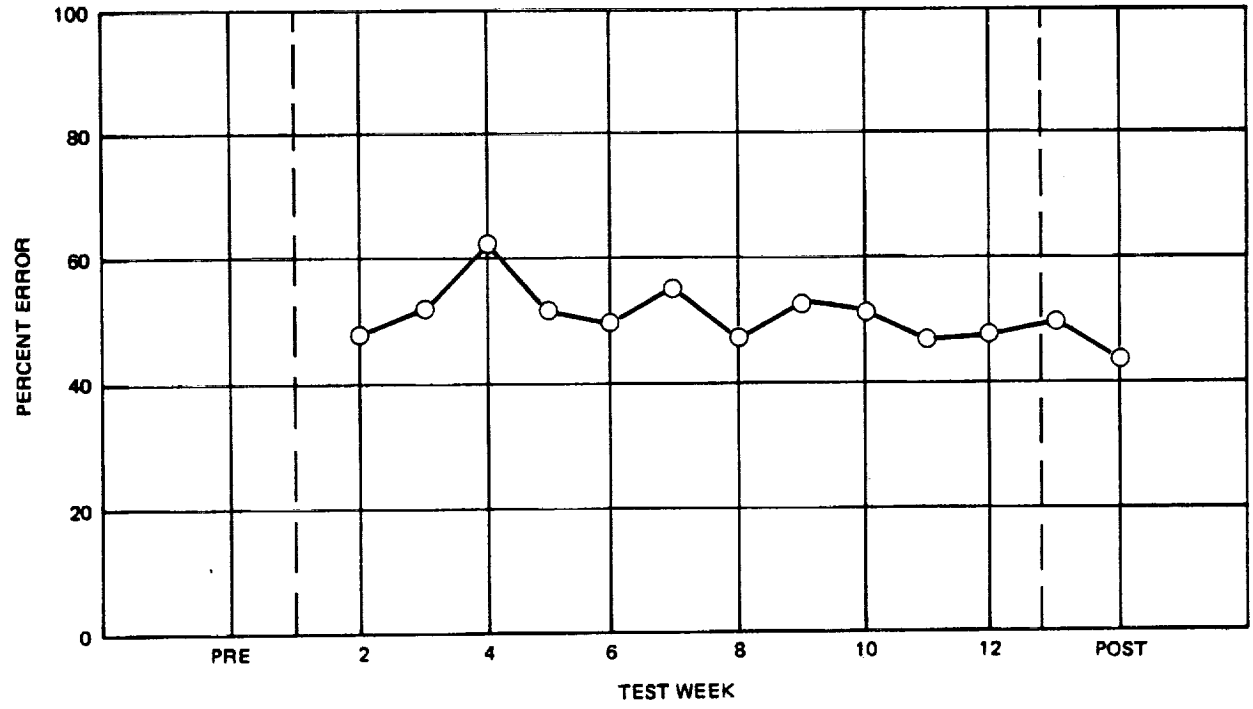
All five items of audio equipment (internal PA, intercom out, intercom in, entertainment speaker, and entertainment earphones) were rated somewhat below the average for all items and in a range representing only fair satisfaction. However, as mentioned in Section 3.3.2.1, this was due to the poor frequency response of the equipment.

3.6.3.5 Hostility Scales

In Figure 3-63 it may be seen that the acoustical environment of the crew compartment consistently evoked a lower hostility score than did that of the equipment compartment. The results are in keeping with those of the habitability questionnaire. Method of application and composition of the hostility scales are discussed further in Section 3.4.2.1.

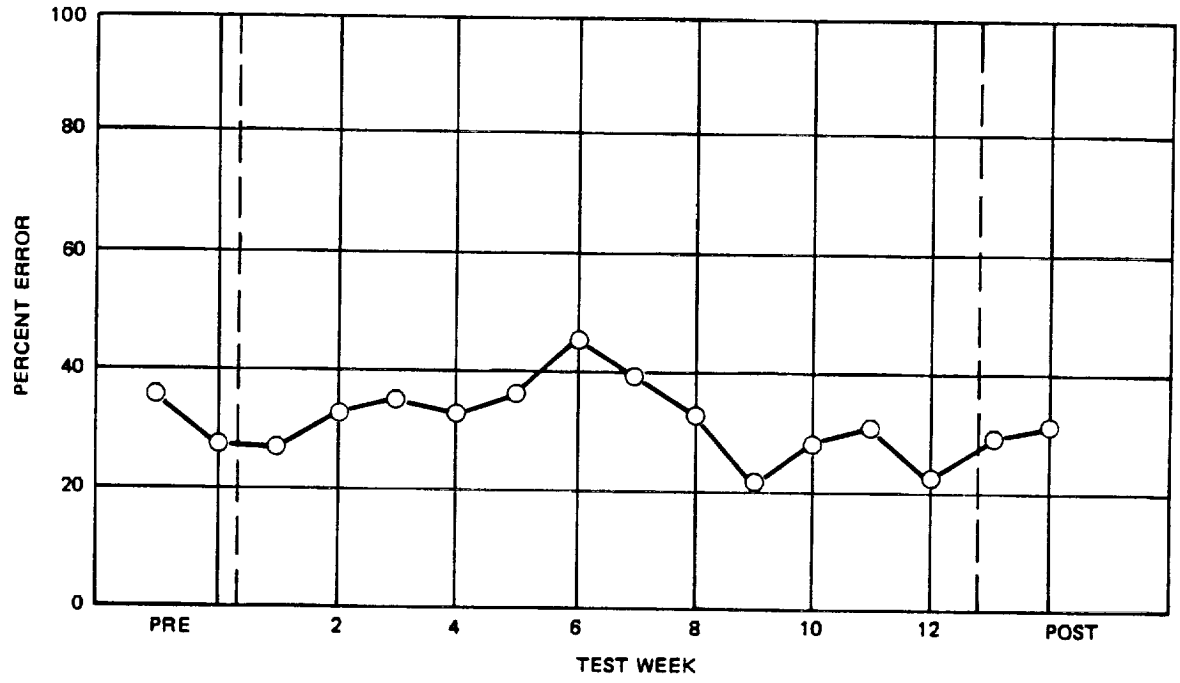


AVERAGED LOW AMBIENT MIXED WORD SET SPEECH COMPREHENSION DATA

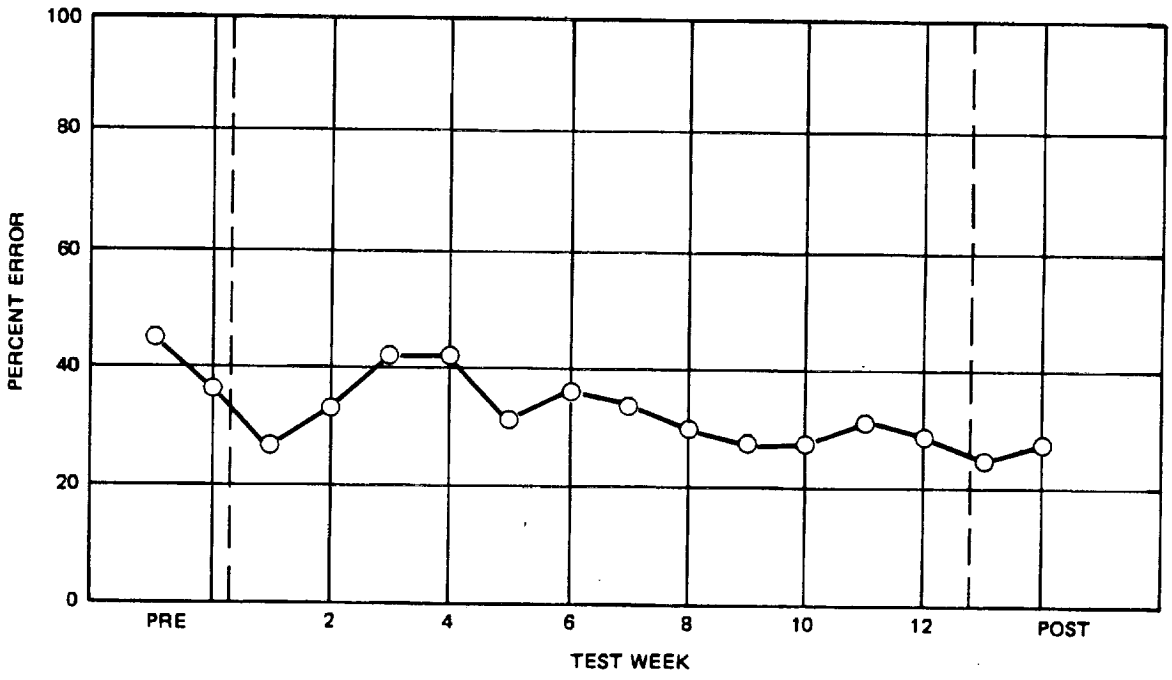


AVERAGED HIGH AMBIENT MIXED WORD SET SPEECH COMPREHENSION DATA

Figure 3-61. Mixed Word Set Speech Comprehension Data



AVERAGED LOW AMBIENT REPEATED WORD SET SPEECH COMPREHENSION DATA



AVERAGED HIGH AMBIENT REPEATED WORD SET SPEECH COMPREHENSION DATA

Figure 3-62. Repeated Word Set Speech Comprehension Data

Table 3-33

NOISE-RELATED HABITABILITY DATA

	Day							
	6	21	35	49	63	77	90	Average
Crew quarters noise	2.25	1.75	2.00	2.00	2.00	2.00	1.75	1.96
Hygiene area noise	2.00	2.50	1.50	2.00	2.00	1.75	1.75	1.75
Equipment quarters noise	3.25	3.00	3.00	2.75	2.75	2.50	3.00	2.89
Internal public address	2.33	2.50	3.00	2.75	2.75	2.25	2.62	2.60
External intercom	3.25	2.50	2.88	2.75	2.75	2.75	2.75	2.80
Internal intercom	2.33	2.50	2.50	2.75	2.63	2.50	2.50	2.53
Entertainment speaker	3.88	2.25	3.00	3.12	3.25	3.12	3.12	3.11
Entertainment headset	3.00	2.75	2.75	2.50	2.75	2.50	3.12	2.77
Average for all 58 items	2.25	2.21	2.13	2.15	2.20	2.18	2.26	2.20

1 = Excellent
2 = Good
3 = Fair
4 = Poor

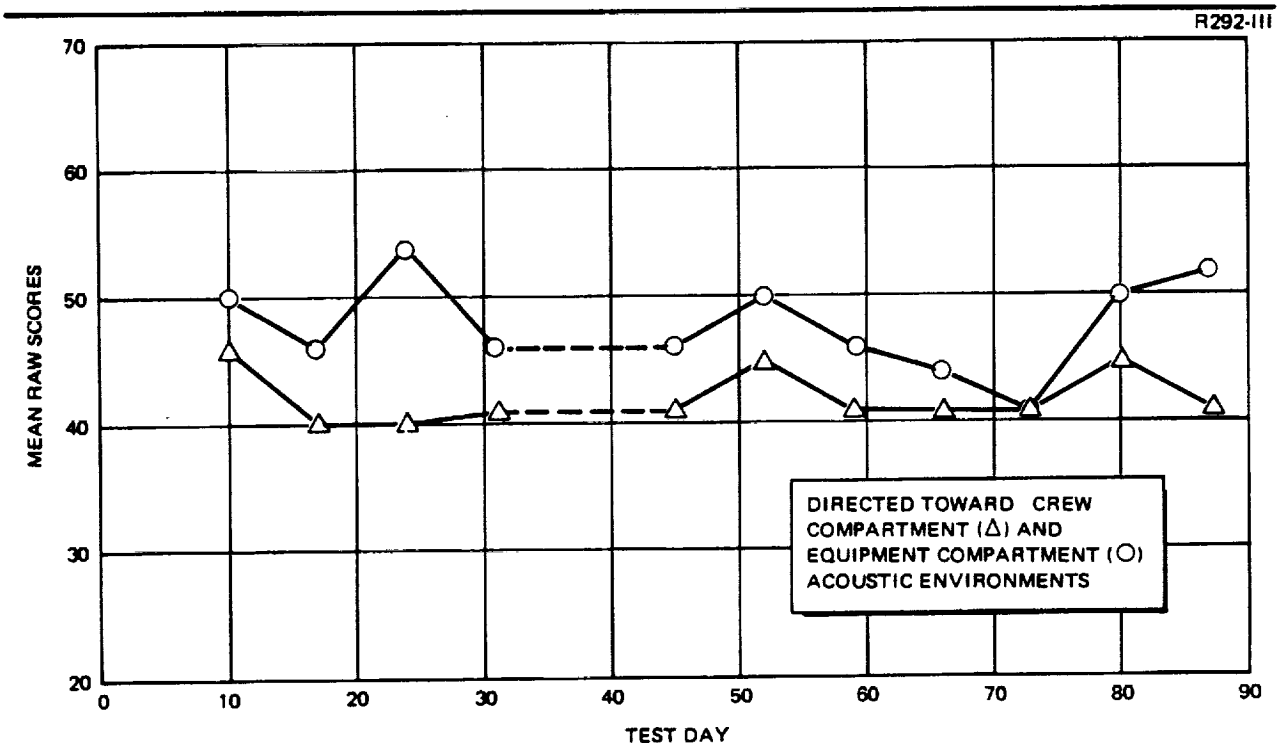


Figure 3-63. Hostility Scale Crew Mean Values

3.6.3.6 Debriefing Information

Results of the post-test debriefing are presented here in summary form. Crew members agreed that random noises (those occurring intermittently and in an unpredictable way, such as pumps) were the major noise problem, and that these were noticed while trying to sleep or because they awakened the crew members. Intermittent noises also distracted the crew when they were taking the acoustic tests. Three crew members accepted the present background noise levels, while one thought they were somewhat high. The only hearing problems noticed were ringing in the ears, which occurred in the chamber for one crew member and after the conclusion of the test for a second.

There was some difficulty in communicating within the chamber, evidenced by frequent need to repeat comments. Outside communications were sometimes difficult, depending on the individual corresponded with and the communications channel used.

The acoustic tests were viewed as reasonable, but the ambient noise used in the tests was judged to be louder than the actual cabin ambient level and somewhat unpleasant. The tests also seemed quite long. The use of a repeated word list was criticized because the crew members remembered the past week's responses and felt that past experience influenced their responses.

The noise questionnaire applied during the post-test debriefing and the crew responses are included in Appendix E. These responses support both habitability questionnaire and debriefing results. The crew members rated the living quarters noise (question 1) as "about as loud as tolerable" and suggested levels either the same or "slightly quieter" for future living quarters (question 2). However, they felt the equipment room noise was "about as loud as tolerable" or "too loud" (question 3), and 3 of the 4 crew members felt the equipment room noise would have been too loud as a living quarters ambient, the other crew member rating it "about as loud as tolerable" (question 10).

All crew members reported intermittent noises such as pumps, talking, and the noise from cabinet and equipment room doors as the major noise problem—one which interfered with sleep.

General criticisms of the acoustics tests were that they were boring and long and that the loud ambient noise and associated pink noise were somewhat unpleasant. Crewmen preferred the audiometry and unanimously disliked the acceptability test. Several spontaneous comments were made during the tests to the effect that the acceptability matching was difficult due to the dissimilarity of stimuli, although crewmen seldom deviated more than 1 db in replications within one test period. Occasionally, a crewman would "drift" in his responses for a short period, consistently preferring one stimulus for a while, then the other. This may have been due to lack of concentration, indicating that although accurate matches could be made, the amount of mental effort required for the task was considerable.

Specific suggestions for future tests included eliminating the acceptability test, shortening the battery, and giving the battery less frequently. Problems cited were the distraction of intermittent noises and the use of the same speech comprehension word list each week.

3.6.4 Discussion

The results from the acceptability matching and speech comprehension tests would appear to be of only minor importance. Although one crewman showed sensitization during the acceptability test, his dislike of the cabin noises was also evident from subjective reports. The relative dislike of the equipment room ambient may be shown by the fact that the equipment room noise was rated somewhat noisier than the equivalent db(A) level pink noise while the sleeping area noise was rated quieter than the db(A) level of the pink noise. However, the mechanism involved is not clear.

Although speech comprehension levels did not change, the crew subjectively reported difficulty in speech comprehension during the 90-day test. Study of this problem would require sampling of typical communications, distances, and speakers, and could not be measured adequately with the tests used.

Audiometric results were both unexpected and difficult to interpret. In contrast to the other behavioral acoustics tests, audiometric week-to-week variability was great enough to obscure important differences. Thus, examination of individual responses is not very fruitful. A lumping of data into six categories provided a better idea of the effects observed, but even here meaningful changes may be obscured. The most difficult finding to interpret is the pre-post differences which occur equally over all crewmen. Since the two crewmen who exhibited no hearing acuity changes during the 90-day test also showed this pre-post effect, it has been concluded that this effect is an artifact. The increased hearing loss during the second post-test strongly suggests that motivation played a part in the pre-post differences, since the crew members felt closure at the end of the 90-day test and were less interested in the post-test efforts.

Despite difficulties in interpreting some of the audiometric trends, it is fairly clear that two of the crewmen showed hearing decrements during the 90-day period. This is somewhat unexpected due to the low levels involved and suggests that concern for hearing changes be continued in future tests. The sources of the rather large week-to-week variation are not obvious and should be studied before further tests to assure that audiometric monitoring will provide straightforward and meaningful data. It is likely that intermittent background noises had some effect on the audiometric tests, and some additional effort should be made to provide quieter future audiometric environments. Earphone placement often provides additional variance, especially at high frequencies. Additional testing to identify earphones with the optimum combination of attenuation of external noises and freedom from sensitivity to earphone placement would be beneficial. The problem of motivational effects has not been solved, mainly because the majority of audiometric work is concerned only with rather large losses or changes over time and/or the identification of individuals who exhibit gross evidence of malingering or psychological hearing problems.

Choice of future psycho-acoustic tests is straightforward because the audiometric test provided adequate measurement of the important changes and was at the same time considered the least objectionable. The limited time required to administer only the audiometric test would appear to be very satisfactory to the crew members. Also, the type of audiometry done was automated and self-contained and could be easily adapted to self-administration and placement within a space station.

The use of two cabins with significantly different noise levels provided a good comparative evaluation of noise level acceptability. The sleeping area ambient level was clearly reasonable, although one of the crew members would have preferred it quieter. However, the equipment area levels were not well accepted. Although this was a source of displeasure, the fact that the crew could leave the noisier area and did not have to spend a great deal of time there makes the equipment area noise level also reasonable. The crew would certainly suggest that the equipment area noise be reduced somewhat and/or their time in this area be reduced. However, it is doubtful that such levels in similar areas would cause a major problem in the future.

The problem of intermittent noises was not studied in great detail. However, crew reports indicate that this is a critical area for future improvements. The major emphasis here would be on further isolating the sleeping area from intermittent noises which are bound to occur during normal activities and further quieting of major intermittent noise sources such as pumps.

3.6.5 Conclusions and Recommendations

The following conclusions were reached regarding the effects of SSS ambient noise on the crew members:

A. Two of the four crew members experienced some hearing loss in one ear. Recovery apparently occurred during the post-test period. Of these two cases, the one showing consistent trends was also characterized by pretest hearing loss (at least 10 db at frequencies above 1,000 Hz.). Random variation between weeks prevented a detailed description of hearing patterns.

B. Only one crew member showed a trend of acceptability change (less than 3 db in the direction of decreased cabin noise acceptability). This crew member showed even more dislike for the cabin noise during post-tests and reported the most subjective irritation with the cabin noise.

C. The speech comprehension tests showed no consistent significant effects.

D. The attained levels of NCA 55 and 70 [64 and 77 db(A)] were close to minimum-desired and maximum-tolerable noise levels. The difference between NCA 55 and 70 represents a clear and important change in acceptability.

E. Intermittent noises were a meaningful source of dissatisfaction, especially when trying to sleep.

Based on these conclusions and an analysis of the adequacy of the testing program, the following recommendations are offered:

A. Efforts should be made to increase the consistency of audiometric data. Possible approaches are further reduction of background noise (possibly by use of a helmet to reduce bone-conducted noise or some sort of quiet area) and increased precision of earphone placement. Crew activities should be scheduled and the crew alerted to produce minimal noise.

B. Ear protection devices could be considered for use when sleeping, both to reduce noise exposure if signs of hearing degradation occur and to minimize the disturbance of intermittent noises.

C. Future acoustic tests should be limited to audiometry. Although acceptability tests showed the sensitization of one crew member, his dissatisfaction was also observed during the debriefing and on the post-test questionnaire.

D. If acceptability tests are considered, care should be taken to provide a gradual onset and decay of stimuli (probably at least 500 msec) to minimize startle and annoyance. Future pre- and post-acceptability tests would provide the necessary data without the dissatisfaction due to repeated testing.

E. Future interest in speech comprehension should be limited to assessing the absolute amount of (rather than change in) communication interference. This could be done with a simulation prior to long-term missions or by monitoring repetitions in normal conversation during a mission.

F. The NCA 55 and 70 noise levels achieved appear to be reasonable for future minimum standards.

G. Additional reduction of the equipment area noise by at least 5 db or reduction of time required in the equipment area would be desirable but probably not critical.

H. Additional reduction of living quarters ambient by 5 to 10 db would be desirable if it did not tend to cause increased awareness of intermittent noises. However, this reduction should have low priority compared to a large number of other habitability concerns.

I. An effort should be made to reduce intermittent noises such as pump noise, door noise, and talking, especially in the sleeping quarters.

J. Some improvement of all the audio systems would be desirable. Improvement of the intercommunications system, especially with regard to consistency of performance under all conditions and with all users, might be critical in case of emergency.

3.7 EEG MONITORING AND SLEEP STUDIES

This program provided for the acquisition and analysis of electroencephalographic (EEG) and electrooculographic (EOG) recordings taken from 39 nights of sleep divided between two crewmen. Approximately 350 hours of data were acquired and analyzed.

Equipment required for collection, monitoring, and recording of the EEG and EOG was selected. All items to be within the SSS were screened for toxicity and flammability in compliance with the MDAC material control program.

A data collection and monitoring station consisting of telemetry receivers, tape recorder, and chart recorder was installed in the vicinity of the SSS. The station was located to minimize interference with operation of the SSS support facilities. A reliable physiological telemetry link between the SSS crew and the recording station was established.

An automatic scoring system was designed for both of the crewmen participating in this experiment on the 90-day manned test. Six sleep classifications were provided — awake, rapid eye movement (REM), and stages 1 through 4, as defined by the Association for the Psychophysiological Study of Sleep (APSS) (Reference 3-19). In addition, movements and artifacts were also detected.

The crew members were indoctrinated in the roles of the EEG and EOG recordings, and trained in the methodology of preparing themselves for them. The importance of proper electrode attachment technique and correct electrode placement was stressed, since the quality of the EEG data obtained is dependent upon proper homologous positioning and achievement of minimum resistance from the scalp-to-scalp positions. An electrode resistance tester was included for this function. The crew members were also trained in the use of the telemetry and the scheduling of the recording sessions.

Recording during the 90-day manned test was in accordance with previously established protocol. A trained technician initiated and monitored the recording sequence, maintained a data collection log, and noted unusual circumstances. He also monitored (from outside the SSS) the crew's preparation efforts and noted the effectiveness of electrode application.

The sleep scoring system developed and validated on baseline data was applied to the sleep recordings collected during the 90-day test. In addition to detailed printout of sleep stage classifications, the following was also provided for each overnight record.

A. Graphic representation of sleep stage occurrence (sleep print).

B. Duration of each major sleep stage period and summary of total amount of time spent in each sleep stage, ratio of time spent in various stages, number of transitions between stages, number of movements, ... In all 45 parameters were extracted from the daily sleep information for each subject to attempt to obtain a

measure of the "quality" of the sleep. These parameters and the results are discussed further in the text.

C. Plots of energy within specific bandwidths (e.g., delta, sigma) as a function of time.

3.7.1 Instrumentation

Two biotelemetry transmitters (Figure 3-64) were placed in the chamber. They provided a pulsewidth frequency-modulated signal at approximately 88 MHz containing four multiplexed channels of data. Only one transmitter was used; the other was kept in reserve as a standby. A signal source in the chamber provided an 82-microvolt, 5-Hz square wave for calibration. The calibrator box contained a circuit which measured the resistance of each pair of electrodes after application.

The receiving antenna and lead wire were simply an insulated piece of wire strung inside the chamber along the wall just below the ceiling. After passing through a hermetic feedthrough to the outside of the chamber, this wire mated with a shielded wire which led to the data recording station. The demodulated data, two channels of EEG and two of EOG, were recorded on tape and simultaneously displayed on a chart recorder. Three of the recorded channels were read back immediately and also displayed on the chart recorder to insure proper operation of the recording system. A time code generator, synchronized with one in the control room, produced IRIG B signals which were also recorded on tape, and a binary output for display on the chart recorder.

Placement of EEG and EOG electrodes followed the recommendations pertinent to sleep research and published by the National Institute of Health (NIH) (Reference 3-22).

A log book was maintained for recording data pertinent to the sleep recordings, particularly regarding artifacts, comments by the crewman concerning attitude, subjective evaluation of his sleep, naps taken during the day, and other pertinent information.

3.7.2 Selection and Training of Participants

All four crewmen participated in a training session on May 27 (17 days before the test). Topics discussed included the collection of EEG and EOG as information pertinent to sleep stage identification, sleep research in general and objectives of this project in particular; operation of the telemetry system, application of electrodes, and, also typical checkout and calibration problems. Each crewman received a pamphlet listing materials to be used, procedures for operation of telemetry, application and checking of electrodes. Each crewman had an opportunity to apply electrodes to the other, to learn the placement of electrodes, operate and calibrate the telemetry, and observe the resulting EEG during various conditions such as eyes open, eyes closed, alertness, and resting. All participants showed significant interest in this study and were able to obtain a good, clean recording.

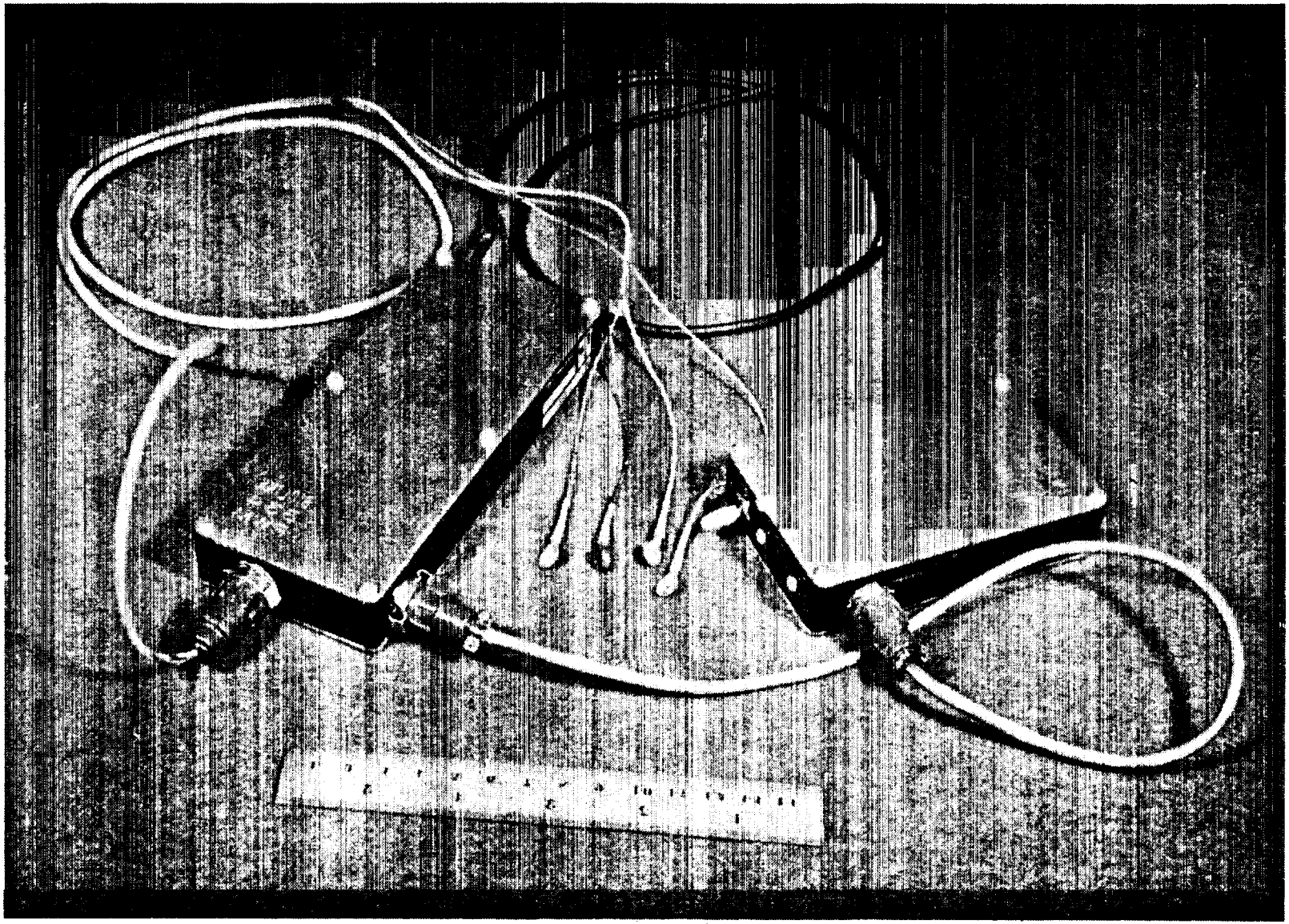


Figure 3-64. Biotelemetry System

NOT REPRODUCIBLE

Two crewmen were selected on the basis of EEG recorded during this session, the criterion being a relatively high level of alpha activity. A board-certified neurologist compared this remotely obtained EEG with the clinical EEG done in her laboratory and concurred with the selection.

3.7.3 Baseline Recording Session

For the purpose of obtaining baseline sleep information from the selected participants, crewmen 1 and 3 were instrumented for recording on June 7 and 8 between 2300 and 0630. Both crewmen slept in hospital beds (adjustable) placed in one of the rooms in the laboratory. Each applied electrodes to the other (under supervision) and tested performance of the equipment; that was done in a separate room, removed from their sleeping quarters.

At 2300 to 2315, when crewmen reported readiness for sleep, the majority of the lights were shut off resulting in a dark-to-low luminance condition. In case of need, individual table lamps were available. One EEG channel and two channels of EOG were recorded from each crewman.

The Pattern Recognition Group personnel monitored and documented the recording sessions. Two outside consultants (specializing in sleep research) participated in the first night's recording, made final decisions on electrode placement, evaluated the first hour of recording, and the next day participated in initial sleep scoring (using the manual-visual method).

3.7.4 Data Collection

Three periods of data collection were scheduled: days 1 through 10; days 42 through 45; and days 85 through 90. Data collection was begun at 2300 hours on the first day, the first scheduled sleep for crewman 1. No recordings were made of the other crewman, who was on the early sleep schedule (1300 to 2100), until his third scheduled sleeping period. Data were taken during 10 consecutive nights for the former, 9 consecutive nights for the latter, during this early period.

Availability and cost of chart paper made it possible to record only the first two sessions from each subject at a speed which permits manual scoring of sleep. The rest of the sessions the paper was run just fast enough to check the quality of recording and read the time code for later elimination of artifacts and interference from the computer-aided analysis.

Problems encountered included some unavoidable interference from various electrical appliances around the chamber, and occasional loss of signal due to a sleeper either rolling on top of the telemetry or knocking off an electrode. It has been determined that more than 90 percent of the data collected was usable for the subsequent data analysis.

3.7.5 Data Analysis

The analysis of the recorded data involved several processing operations. The basic analysis was the automatic scoring of each 30-second epoch of the recorded EEG/EOG data into a sleep stage (or a movement or artifact categorization). This was accomplished using a pattern recognition design

procedure. A functional block of the processing and analysis is shown in Figure 3-65. The analog EEG data are sampled at 68.5 Hz and quantized to 10 bits. The resulting digital data are then processed by a FFT (Reference 3-23) algorithm to extract the frequency information from 0 to 34 Hz in 1-Hz increments for each 30 seconds. These 34 parameters, representing the amplitude squared values v^2/Hz of the frequency constituents in the EEG, form part of the input to the pattern recognition system for subsequent classification.

The design of the classification system involves a pattern recognition learning algorithm which classifies each 30-second epoch into one of five sleep stage categories (awake, 1 or REM, 2, 3 and 4). A detailed discussion of this design algorithm can be found in Reference 3-24. As illustrated in Figure 3-65, four separate classification systems are designed, using the baseline data as the training sample to perform dichotomous classifications at each node (labeled 1 through 4 in Figure 3-65). A decision tree structure is thus evolved. At node 1 the dichotomization involves separating stages 3 and 4 from all others. Node 2 separates stage 3 from stage 4. Node 3 provides the identification of the awake state and Node 4 separates stage 2 from stages 1 and REM.

In addition, the frequency information and the raw digital data are also processed in a REM detection and logic operation to detect the presence of rapid eye movements, gross body movements, and contaminating noise and spurious artifacts. The REM detector utilizes the total power in the EEG trace, the total power in the opposed waves in the EOG, and the sharpness

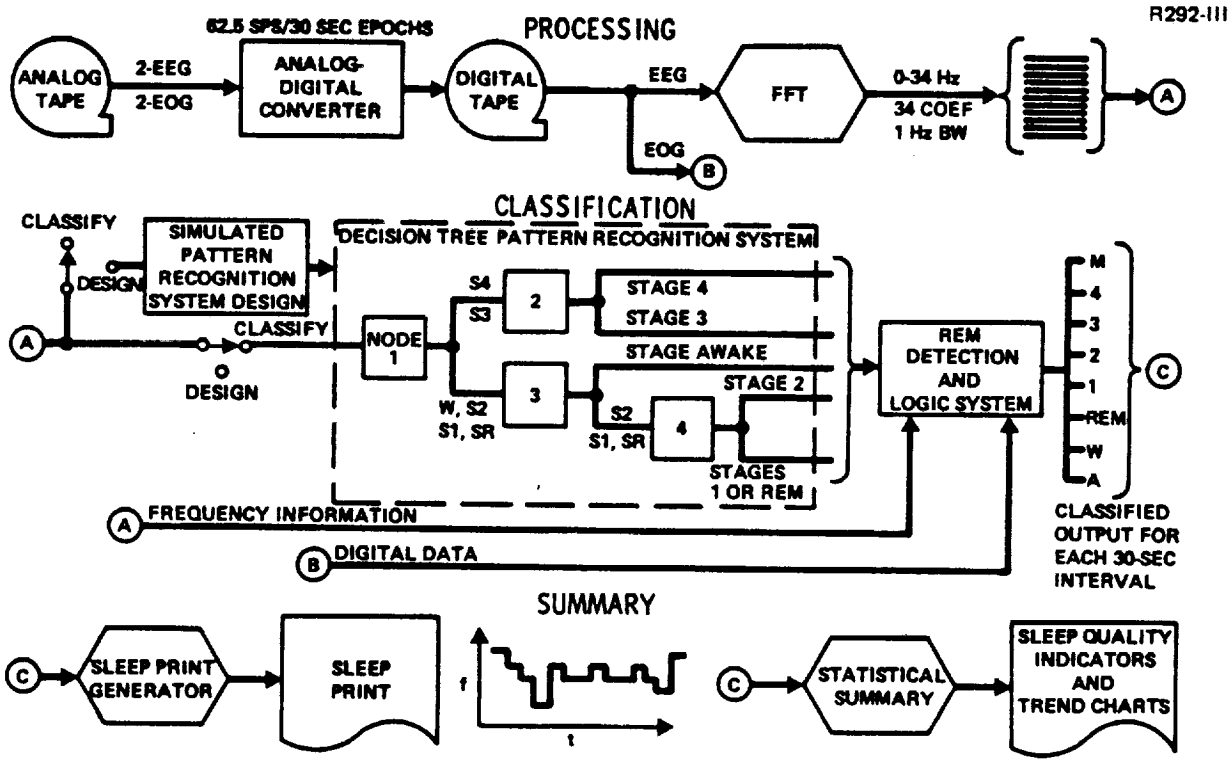


Figure 3-65. Automatic Sleep Scoring and Sleep Performance Analysis

of these opposed waves to detect rapid eye movement. The body movement and artifact detection is based on a multiple thresholding of the power contained in the lower and higher frequencies. If the 30-second interval contains sufficient energy in the high frequencies to exceed a threshold, or sufficient energy in the ratio of the upper frequencies to the total energy to exceed a second threshold, then an artifact indication is noted. If the energy is concentrated in very low frequencies (0 to 1 Hz) and is of large magnitude, then a body movement indication is provided.

The corresponding output from this REM detection and logic operation is used to supplement or override the classification of the decision tree. A movement detection will override all classifications other than stages 3 and 4. A REM detection will override the stage 1 classification, or a stage 2 classification if that epoch is preceded by a movement; and finally the artifact detection will override all decision tree classifications and cause the last epoch classification to be carried through until the artifact is over. Figure 3-66 is an example of the computer printout illustrating the operation of the automatic scoring system.

The output from the scoring system was then processed by a computer program from which the sleep print is generated. Four adjacent 30-second classification outputs are averaged and a sleep stage noted for that 2-minute interval. Each 2-minute interval was plotted to provide a ready display of the crewmen's sleep over the entire sleep period (Figure 3-67). In addition, the quantities used to evaluate the quality of the crewmen's sleep were also computed. These 43 parameters, four histograms and a table include length of time in each stage, total sleep time, total awake time, number of movements, number of sleep stage transitions, etc. (see Figure 3-68). Finally a statistical summary of each of 43 parameters was computed for all of the sleep periods in the cabin for each crew member. These are provided in tabular (Figure 3-69) and graphical form to display trends and inconsistencies in sleep behavior. The entire operation, including sleep scoring and statistical summary and plotting, took about 3 to 3-1/2 hours for each 9 to 10 hour sleep period using an XDS 930 computer.

3.7.6 Results

The scoring of the sleep records is the fundamental step in arriving at an assessment of sleep quality. However the output of the scoring systems, a stage categorization for each 30-second epoch of sleep, is still too extensive to be easily absorbed. Further data reduction is in order.

Sleep researchers rely on certain accepted parameters extracted from the scored data as well as sleep prints and plots of the delta activity in evaluating sleep. For the most part, these parameters deal with the rhythmic nature of the sleep, and the relative and absolute quantities of the various sleep activities. Most parameters are not related to the very fine structure of sleep.

In the course of extracting these parameters, the first step is to obtain those which do use fine structure — namely, those dealing with movement or arousal episodes. Then the 30-second data are combined to provide 2-minute

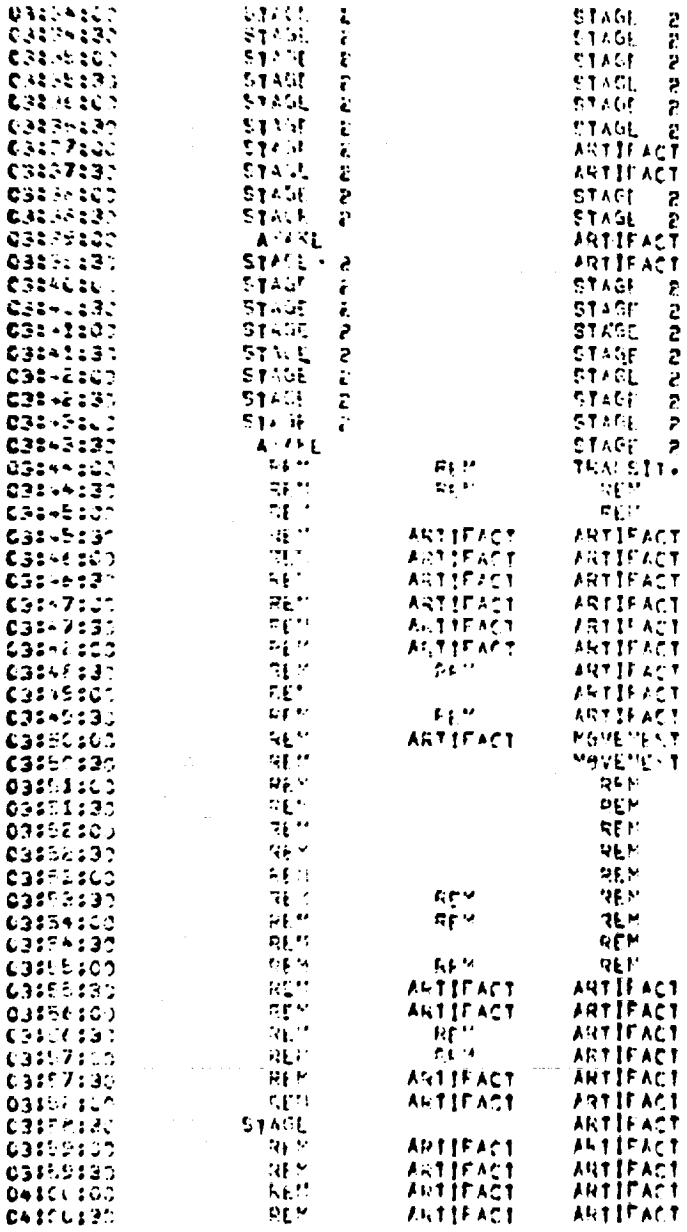
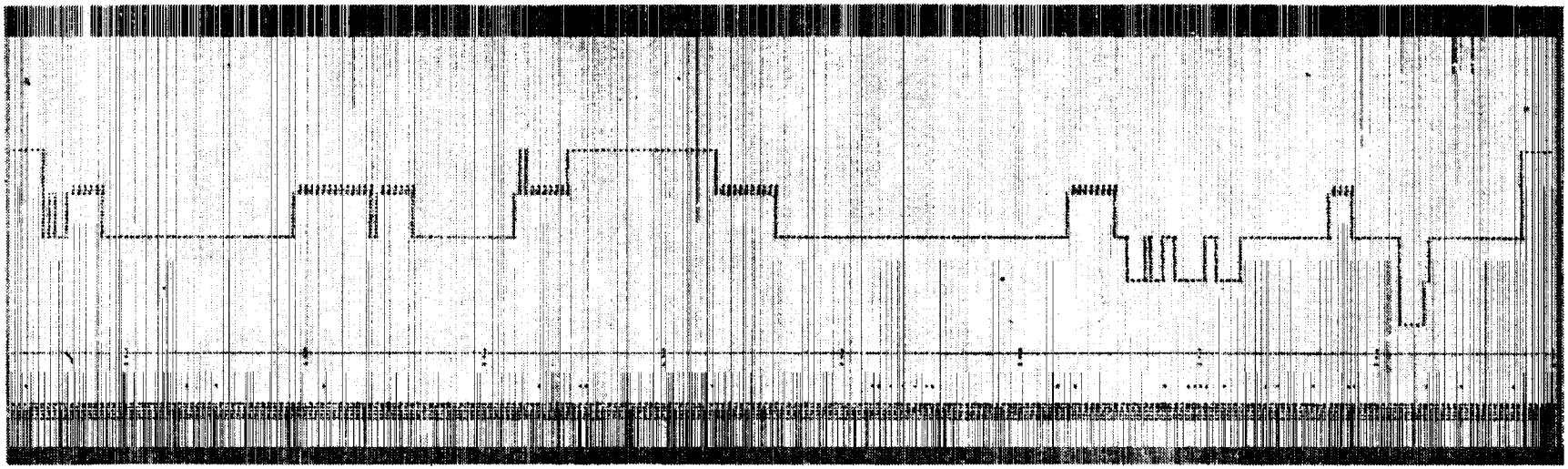


Figure 3-66. Computer Printout—Automatic Sleep Scoring

NOT REPRODUCIBLE



NOT REPRODUCIBLE

Figure 3-67. Unaltered Sleep Cycle—Automatic Scoring for Night 1

```
CM-1              90 DAY RUN
TEST NO. 3  ANALOG TAPE NO. 3
RECORDED AFTERNOON JUNE 16,1970
DIGITIZED JULY 7,1970


ADAV
 1. TOTAL BED TIME                                          820    MINUTES  1
 2. TOTAL SLEEP TIME                                        446    MINUTES  2
 3. TOTAL WAKE TIME                                          74    MINUTES  3
 4. TOTAL STAGE 1                                             4    MINUTES  4
 5. TOTAL STAGE 2                                           296    MINUTES  5
 6. TOTAL STAGE 3                                            30    MINUTES  6
 7. TOTAL STAGE 4                                             8    MINUTES  7
 8. TOTAL STAGE REM                                         108    MINUTES  8
 9. TOTAL MOVEMENT TIME                                      19    MINUTES  9
10. TOTAL STAGE NON-REM                                     338    MINUTES 10
11. TOTAL OF STAGES 3 AND 4                                  38    MINUTES 11
12. TOTAL OF STAGES 2, 3, AND 4                             334    MINUTES 12
13. WAKE TIME BEFORE THE FIRST STAGE 2                       10    MINUTES 13
14. WAKE TIME DURING SLEEP                                   52    MINUTES 14
15. WAKE TIME AFTER LAST SLEEP                               12    MINUTES 15
16. TIME BEFORE THE FIRST STAGE 2                            10    MINUTES 16
17. TIME BEFORE THE FIRST STAGE 3                            42    MINUTES 17
18. TIME BEFORE THE FIRST STAGE 4                            44    MINUTES 18
19. TIME BEFORE THE FIRST STAGE REM                          68    MINUTES 19
20. AVERAGE DURATION OF MOVEMENTS                            .8    MINUTES 20
21. AVERAGE DURATION OF AROUSALS                            3.4    MINUTES 21
22. AVERAGE DURATION OF STAGE NON-REM                      58.5    MINUTES 22
23. AVERAGE DURATION OF STAGE REM                          18.6    MINUTES 23
24. AVERAGE REM-TO-REM INTERVAL                            83.9    MINUTES 24
25. PERCENT WAKE OF TOTAL BED TIME                         14.23   PERCENT 25
26. PERCENT SLEEP OF TOTAL BED TIME                        85.77   PERCENT 26
27. PERCENT MOVEMENT TIME OF TOTAL BED TIME                 3.56   PERCENT 27
28. PERCENT WAKE BEFORE FIRST STAGE 2 OF TOTAL WAKE TIME   13.51   PERCENT 28
29. PERCENT OF WAKE DURING SLEEP OF TOTAL WAKE TIME        70.27   PERCENT 29
30. PERCENT OF WAKE AFTER SLEEP TO TOTAL WAKE TIME         16.22   PERCENT 30
31. PERCENT STAGE 1 OF TOTAL SLEEP TIME                     .90    PERCENT 31
32. PERCENT STAGE 2 OF TOTAL SLEEP TIME                   66.37    PERCENT 32
33. PERCENT STAGE 3 OF TOTAL SLEEP TIME                    6.73    PERCENT 33
34. PERCENT STAGE 4 OF TOTAL SLEEP TIME                    1.79    PERCENT 34
35. PERCENT STAGE REM OF TOTAL SLEEP TIME                 24.22    PERCENT 35
36. PERCENT STAGE NON-REM OF TOTAL SLEEP TIME             75.78    PERCENT 36
37. PERCENT STAGES 3 AND 4 OF TOTAL SLEEP TIME             8.52    PERCENT 37
38. PERCENT STAGES 2, 3, AND 4 OF TOTAL SLEEP TIME        74.89    PERCENT 38
39. NUMBER OF MOVEMENT EPISODES                              34             39
40. NUMBER OF AROUSAL EPISODES                               14             40
41. NUMBER OF STAGE NON-REM EPISODES                          7             41
42. NUMBER OF STAGE REM EPISODES                              6             42
43. NUMBER OF STAGE CHANGES                                  30             43
44. DISTRIBUTION OF EPISODE DURATION IN MINUTES
                 2| 4| 6| 8|10|12|14|16|18|20|22|24|26|28|30|32|34|36|38|40|42|44|46|48|50|52|54|56|58|60|62|64|66|68|70|72|74|76|78|MORE
  MOVEMENT  34|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
  AROUSAL   14|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
  NON-REM      |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
  REM          |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
45. TIME OF EACH REM-TO-REM INTERVAL IN MINUTES
    80.0 124.5  69.5  30.5 109.0
```

Figure 3-68. Sleep Parameters

NOT REPRODUCIBLE

ALTERED SLEEP CYCLE	2	3	4	5	6	7	8	9	10	42	43	44	45	46	86	86	87	88	89	AVE
TOTAL REC TIME	470	434	403	344	446	398	428	516	512	348	564	468	53C	478	58C	58C	58C	590	588	476
TOTAL SLEEP TIME	488	384	366	31C	342	354	424	5C8	47C	318	548	432	51C	424	494	478	486	488	496	420
TOTAL WAKE TIME	42	48	34	34	104	44	4	8	42	30	16	26	14	54	18	34	28	24	32	34
TOTAL STAGE 1	34	90	32	3C	110	84	68	32	68	2	18	38	26	24	16	88	44	84	86	62
TOTAL STAGE 2	31P	248	224	204	224	PC8	176	358	33C	848	406	248	382	292	38C	334	316	364	344	296
TOTAL STAGE 3	0	C	2	14	2	0	C	1C	1C	14	6	0	4	12	4	C	2	4	4	6
TOTAL STAGE 4	0	0	0	C	0	0	C	C	2	0	C	C	C	0	C	C	0	C	0	0
TOTAL REM	80	48	108	6C	6	62	18C	1C8	6C	84	124	106	126	96	9P	116	124	102	122	96
TOTAL MOVEMENT TIME	1	1	1	1	4	1	1	11	13	1	38	33	38	16	3+	58	35	59	11	16
TOTAL NON-REM	348	338	298	29C	334	292	244	4CC	41C	864	428	326	384	328	4C2	362	362	414	374	342
TOTAL OF STAGES 3 AND 4	0	0	2	14	2	0	0	1C	12	14	6	0	4	12	4	0	2	4	4	6
TOTAL OF STAGES 2, 3+ AND 4	312	248	226	22C	P24	PC8	176	368	342	862	412	248	388	304	384	334	318	368	348	308
WAKE TIME BEFORE FIRST STAGE 2	1C	6	4	4	20	C	0	0	4	C	2	6	14	8	1C	4	8	6	14	6
WAKE TIME DURING SLEEP	14	18	6	4	30	22	C	8	30	C	12	0	C	C	2	3C	20	18	18	12
WAKE TIME AFTER SLEEP	18	24	24	26	54	22	4	0	C	30	2	20	C	46	C	1C	0	0	C	15
TIME BEFORE FIRST STAGE 2	16	10	1C	12	38	8	8	C	8	C	4	10	16	22	22	32	24	8	14	12
TIME BEFORE FIRST STAGE 3	-	-	42	32	64	-	-	42	42	42	34	-	38	50	42	-	58	42	36	-
TIME BEFORE FIRST STAGE 4	-	-	-	-	-	-	-	-	82	-	-	-	-	-	-	-	-	-	-	-
TIME BEFORE FIRST REM	58	102	64	48	260	126	244	7C	66	98	68	128	8C	84	146	110	160	140	76	111
AVERAGE DURATION OF MOVEMENTS	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
AVERAGE DURATION OF AROUSALS	4	11	4	5	9	7	22	3	5	7	2	6	1	11	2	5	8	4	3	6
AVERAGE DURATION OF NON-REM	62	123	56	69	221	63	117	67	74	72	61	7C	66	75	68	78	64	71	66	81
AVERAGE DURATION OF REM	20	33	28	15	5	21	195	23	14	20	16	28	27	27	23	32	15	23	25	22
AVERAGE REM-TO-REM INTERVAL	96	187	180	88	C	76	0	79	81	81	81	91	84	1C4	82	1C4	63	10C	9C	82
PCT. WAKE OF REC TIME	9	11	9	1C	23	11	1	2	P	9	3	6	3	11	3	7	8	4	6	7
PCT. SLEEP OF REC TIME	91	89	9P	9C	77	89	99	98	9P	91	97	94	96	89	98	92	93	95	94	9P
PCT. MOVEMENT TIME OF REC TIME	0	0	C	C	1	C	0	2	3	0	4	7	4	3	4	11	7	10	2	3
PCT. OF WAKE BEFORE FIRST 2	24	13	12	12	19	C	0	C	1C	C	13	23	1CC	15	54	17	29	25	44	2P
PCT. OF WAKE DURING SLEEP	33	38	18	12	29	50	0	1CC	9C	0	7P	0	C	0	44	84	71	75	56	3P
PCT. OF WAKE AFTER SLEEP	43	9P	71	76	52	9C	1CC	C	C	1CC	13	77	C	8P	C	2P	0	C	0	3P
PCT. STAGE 1 OF SLEEP	8	23	9	1C	32	24	16	6	14	1	2	9	5	6	3	6	9	10	5	1P
PCT. STAGE 2 OF SLEEP	73	64	61	64	65	59	42	70	7C	78	74	67	69	69	77	7C	65	64	69	67
PCT. STAGE 3 OF SLEEP	3	0	1	5	1	0	0	2	P	4	1	0	1	3	1	0	0	1	1	1
PCT. STAGE 4 OF SLEEP	0	0	0	C	C	0	C	C	C	0	0	0	C	0	C	C	0	C	0	0
PCT. REM OF SLEEP	19	12	3C	19	2	18	42	21	13	17	23	25	25	23	19	24	26	25	28	21
PCT. NON-REM OF SLEEP	81	88	7C	81	98	82	58	79	87	83	77	75	75	77	81	76	74	75	7P	79
PCT. STAGES 2 AND 4 OF SLEEP	0	0	1	5	1	0	0	2	3	4	1	0	1	3	1	0	0	1	1	1
PCT. STAGES 2,3 AND 4 OF SLEEP	73	64	62	71	66	59	42	72	73	82	7P	67	7C	72	7P	7C	65	65	70	68
NUMBER OF MOVEMENT EPISODES	2	2	2	2	8	2	1	2C	19	1	48	47	36	2P	36	66	35	64	14	23
NUMBER OF AROUSAL EPISODES	10	16	11	1C	19	17	3	8	14	8	16	7	1C	8	16	8	10	19	12	11
NUMBER OF NON-REM EPISODES	6	3	5	4	2	8	2	6	6	4	7	8	6	8	6	8	6	6	6	8
NUMBER OF REM EPISODES	8	2	4	4	1	4	1	8	8	3	7	4	8	4	8	4	6	5	8	4
NUMBER OF STAGE CHANGES	2C	24	19	2C	3P	24	3	34	33	27	34	2P	28	24	34	2P	2P	41	2P	2P

Figure 3-69. 19-Day Summary Chart—Sleep Parameters, Altered Sleep Cycle

NOT REPRODUCIBLE

scoring epochs. This tends to minimize chatter in the scoring as the sleeper is near the boundary between sleep stages. Such smoothing is provided subjectively in the hand scoring of sleep records. The sleep print is plotted directly from these 2-minute data, and they form the basis for the great majority of the sleep parameters.

The computer provides a listing of the parameters extracted for each sleep period. A set of 43 numbers (Figure 3-68) are the primary output. Histograms of the duration of various types of sleep episodes (item 44, Figure 3-68) are given, as is a table of the REM-to-REM intervals (item 45, Figure 3-68). This listing is immediately followed by a graphic representation of the sleep stages, the sleep print.

Figure 3-70 shows a sleep print from a normal individual (not one of the crewmen) and is considered to be a typical night. There is the regular transition through the stages, reaching stage 4 within an hour. The stage 4 episode lasts for perhaps half an hour and leads to the first REM period. A second stage 4 episode may or may not occur; but if it did, it would be in the second slow wave episode near the 2-hour mark. The plot of the delta activity above the sleep print provides a ready reference for slow wave sleep. The remainder of the night is spent in a regular REM-stage 2 cycle, with perhaps a minor amount of stage 3. Notice the relatively few stage changes.

R292 III

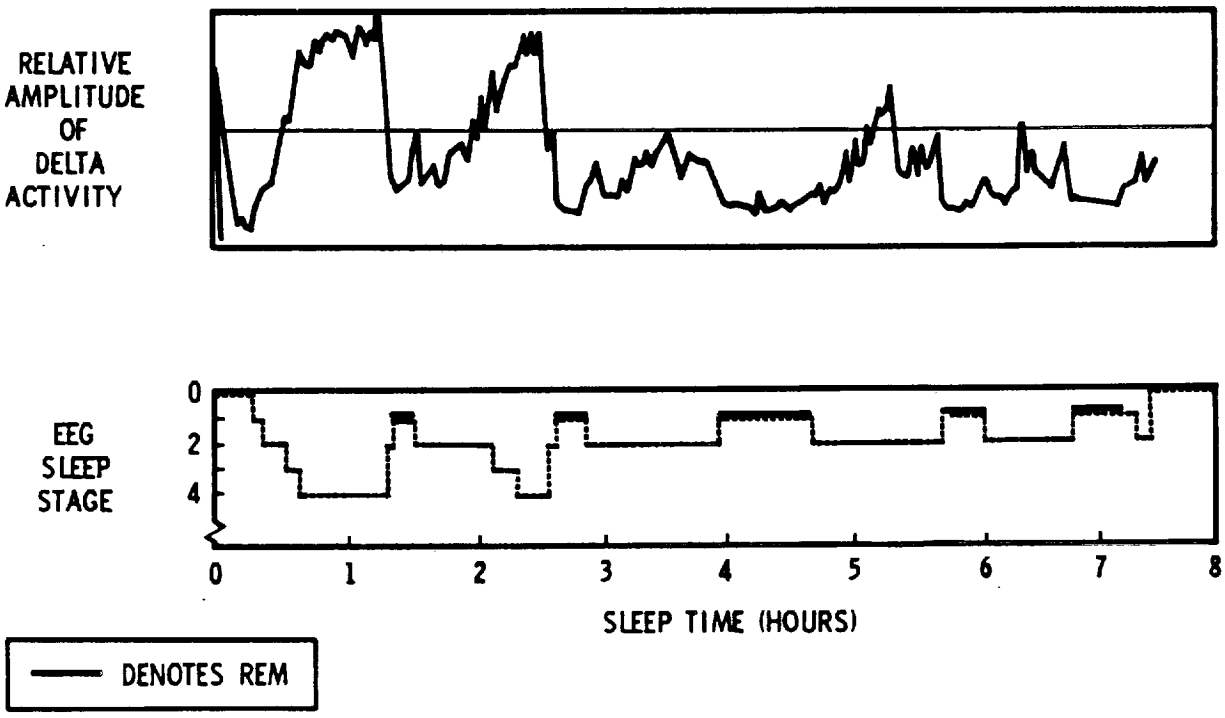


Figure 3-70. Delta Activity (0.2 to 2 Hz) and Sleep Stages vs Sleep Time Subject 02S Baseline

Figure 3-71 represents perhaps the closest approach, in the nights monitored during the test, to the prototype above. Many more stage changes than one would expect was one of the more striking features of chamber sleep; 2 to 4 times as many stage changes as normally encountered. Note also the limited amount of slow wave sleep.

Figure 3-72 shows one of the more troubled nights, occurring near the halfway point. Notice the long awake period and the many stage changes.

With these sleep prints, relative levels of delta activity were also plotted. The rigid criteria defined for stages 2, 3, and 4 perform a coarse quantization of what appears to be a somewhat continuous increase and decrease in low frequency activity (0.5 to 2 Hz). To highlight this waxing and waning of delta activity, a time history of activity in the delta band was plotted, based also upon 2-minute epochs. These plots tend to reveal more clearly the rhythmic nature of the sleep patterns which may be been obscured by the sleep stage quantifications. These also show the rhythmicity of sleep, delta being minimal during REM and stage 1, and building up to a maximum in stage 4.

The sleep parameters are tabulated in a summary chart for each of the participating crewmen (Figure 3-73 and 3-74). The parameters are subdivided by types. First comes the grossest - total bed time, sleep time, and wake time. Next is a breakdown by sleep parameters and combinations of sleep parameters. The time to onset of each stage is followed by the average duration of certain episodes. Then most of these are converted to percentages. Finally, the number of episodes of various types and the number of stage changes are given. All nights for one of the crewmen are shown on this chart as well as the average value for each parameter.

Probably the most striking item on this chart is the lack of slow wave sleep. One crewman averaged 30 minutes per night for stages 3 and 4 combined and the other averaged only 5 minutes per night. This result is not out of keeping with results of other confinement studies.

To facilitate the search for trends, bar charts are produced for each of the parameters. Figure 3-75 shows total wake time for crewman 1. A downward trend is exhibited during the first 5 days showing an adaptation to the new environment. There is then a rising trend, showing up most dramatically during the last 5 day recording period as the anticipation of the end of the 90-day test mounted.

3.7.7 Conclusions

Using the biotelemetry system and with a minimum of training of the crewmen, it has been demonstrated that consistent and reliable monitoring of the physiology of crewmen in confinement can be performed. Little crew discomfort was noted although some consideration should be given to easing the electrode application task. A skull cap or other head covering with prepared electrodes (such as that developed by Dr. J. Frost, Baylor University for NASA-MSC) should be considered for subsequent experiments.

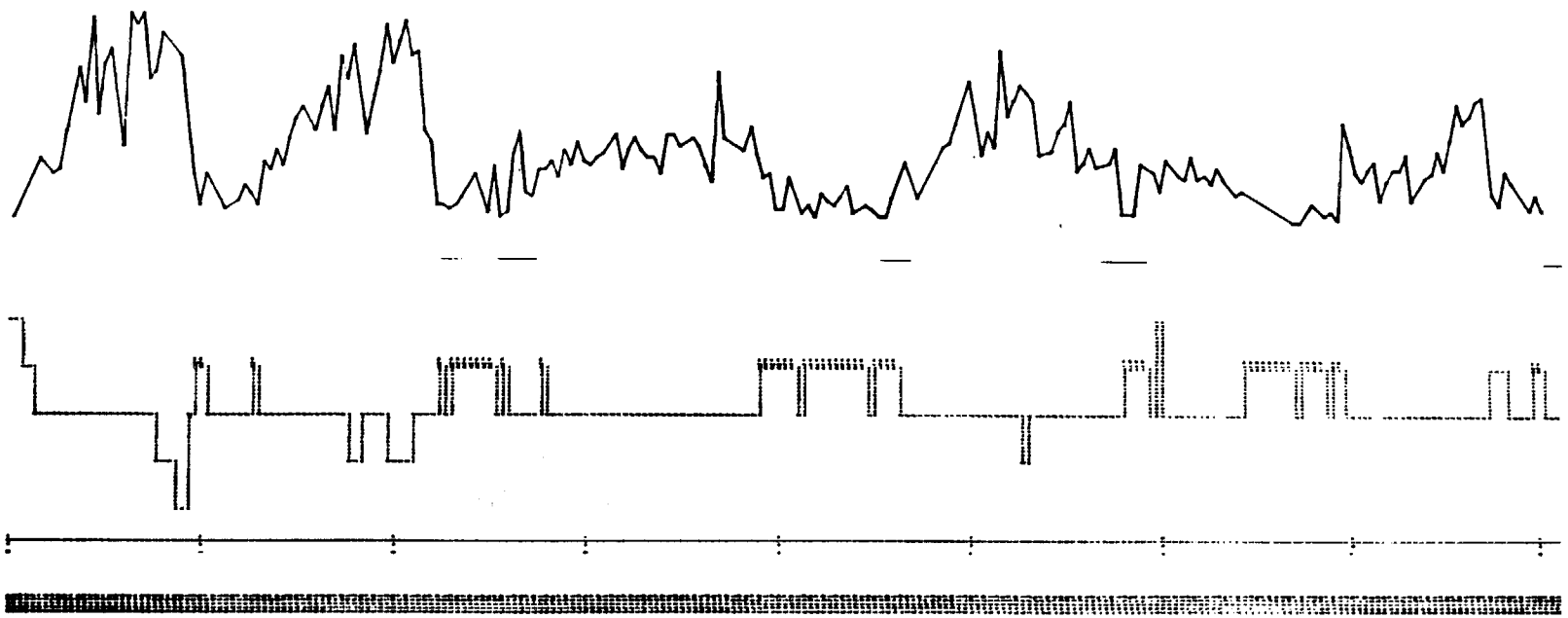


Figure 3-71. Sleep Print—Unaltered Sleep Cycle

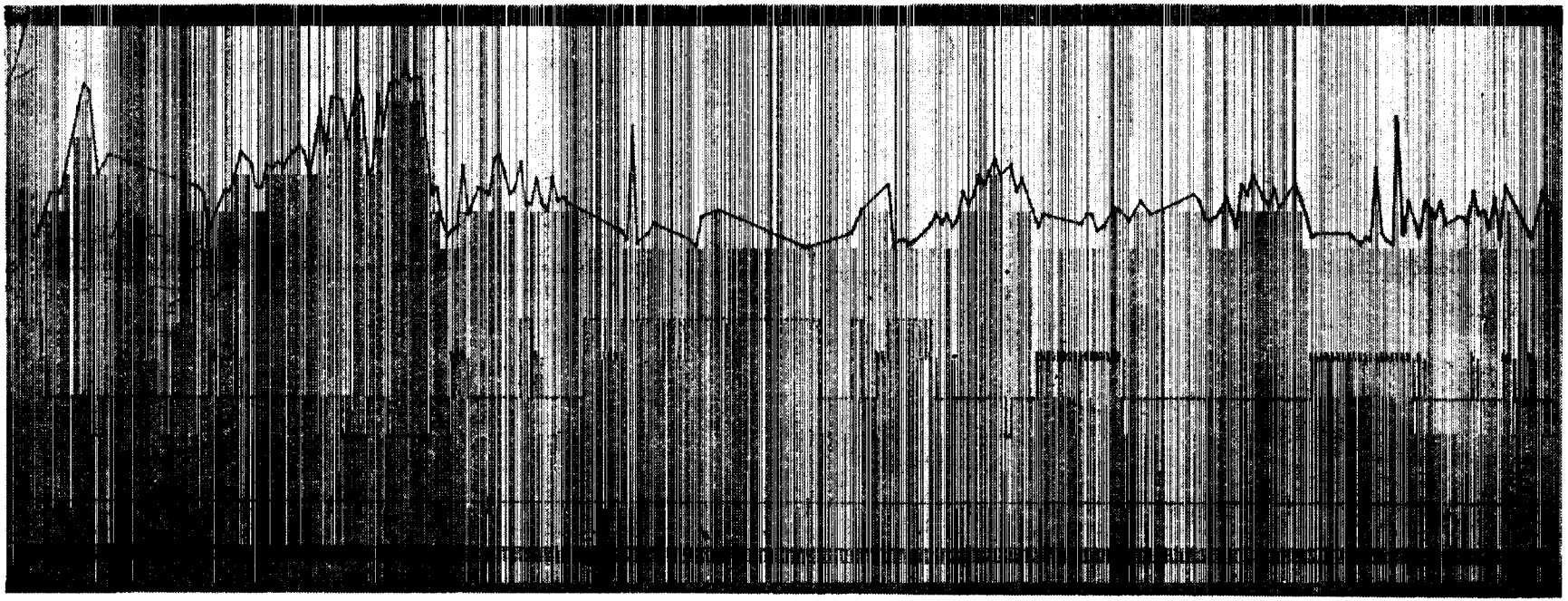


Figure 3-72. Sleep Print and Delta Plot, Automatic Scoring— Unaltered Sleep Cycle for Night 42

UNALTERED SLEEP CYCLE	1	2	3	4	5	6	7	8	9	10	42	43	44	45	46	85	86	87	88	89	AVE
TOTAL BED TIME	520	502	504	376	488	470	530	468	472	468	580	578	508	388	498	504	380	452	464	564	485
TOTAL SLEEP TIME	446	454	466	354	482	466	486	446	448	452	468	544	416	342	446	428	274	396	410	430	433
TOTAL WAKE TIME	74	48	38	22	6	4	44	22	24	16	112	34	92	46	42	68	106	56	54	134	52
TOTAL STAGE 1	4	22	14	4	10	10	8	2	12	0	4	8	8	4	6	24	8	22	2	10	9
TOTAL STAGE 2	296	328	316	252	342	344	334	328	316	326	324	378	292	250	328	240	174	242	330	312	303
TOTAL STAGE 3	30	14	28	22	20	18	34	16	44	24	30	36	34	30	26	38	30	54	10	22	28
TOTAL STAGE 4	8	0	6	6	4	6	2	2	0	2	0	0	2	0	2	2	0	6	0	0	2
TOTAL REM	108	90	102	70	106	88	108	98	76	100	110	122	80	58	84	124	62	72	68	86	91
TOTAL MOVEMENT TIME	19	4	2	0	1	3	2	8	9	3	3	3	5	5	3	59	15	2	0	2	7
TOTAL NON-REM	338	364	364	284	376	378	378	348	372	352	358	422	336	284	362	304	212	324	342	344	342
TOTAL OF STAGES 3 AND 4	38	14	34	28	24	24	36	18	44	26	30	36	36	30	28	40	30	60	10	22	30
TOTAL OF STAGES 2, 3, AND 4	334	342	350	280	366	368	370	346	360	352	354	414	328	280	356	280	204	302	340	334	333
WAKE TIME BEFORE FIRST STAGE 2	10	10	2	8	4	2	10	0	8	12	10	8	68	8	22	38	46	6	18	68	18
WAKE TIME DURING SLEEP	52	36	36	6	2	0	18	22	4	0	102	14	2	4	8	0	2	50	6	66	22
WAKE TIME AFTER SLEEP	12	2	0	8	0	2	16	0	12	4	0	12	22	34	12	30	58	0	30	0	13
TIME BEFORE FIRST STAGE 2	10	10	2	8	8	2	10	0	10	12	12	8	68	10	22	40	48	10	18	70	19
TIME BEFORE FIRST STAGE 3	42	54	114	88	46	238	48	56	42	52	30	36	118	28	56	58	68	72	46	108	70
TIME BEFORE FIRST STAGE 4	44	-	116	26	52	36	58	74	-	54	-	-	188	-	60	68	-	84	-	-	-
TIME BEFORE FIRST REM	68	78	60	38	58	50	144	86	56	70	74	76	128	88	86	90	104	106	70	134	83
AVERAGE DURATION OF MOVEMENTS	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0
AVERAGE DURATION OF AROUSALS	5	4	5	2	1	2	3	2	8	2	9	3	5	9	3	6	18	11	3	7	5
AVERAGE DURATION OF NON-REM	59	44	43	37	52	46	39	57	45	37	41	48	58	44	56	32	44	74	41	58	48
AVERAGE DURATION OF REM	19	10	11	11	21	15	16	25	13	14	13	18	18	13	14	16	12	14	10	14	15
AVERAGE REM-TO-REM INTERVAL	84	51	53	54	83	66	46	93	58	48	54	69	66	53	66	44	35	83	49	56	61
PCT. WAKE OF BED TIME	14	10	8	6	1	1	8	5	5	3	19	6	18	12	9	13	28	12	12	24	11
PCT. SLEEP OF BED TIME	86	90	92	94	99	99	92	95	95	97	81	94	82	88	91	85	72	88	88	76	89
PCT. MOVEMENT TIME OF BED TIME	4	1	0	0	0	1	0	2	2	1	1	1	1	1	1	12	4	0	0	0	1
PCT. OF WAKE BEFORE FIRST 2	14	21	5	36	67	50	23	0	33	75	9	24	74	17	52	56	43	11	33	51	35
PCT. OF WAKE DURING SLEEP	70	75	95	27	33	0	41	100	17	0	91	41	2	9	19	0	2	89	11	49	39
PCT. OF WAKE AFTER SLEEP	16	4	0	36	0	50	36	0	50	25	0	35	24	74	29	44	55	0	56	0	27
PCT. STAGE 1 OF SLEEP	1	5	3	1	2	2	2	0	3	0	1	1	2	1	1	6	3	6	0	2	2
PCT. STAGE 2 OF SLEEP	66	72	68	71	71	74	69	74	71	72	69	69	70	73	74	56	64	61	80	73	70
PCT. STAGE 3 OF SLEEP	7	3	6	6	4	4	7	4	10	5	6	7	8	9	6	9	11	14	2	5	7
PCT. STAGE 4 OF SLEEP	2	0	1	2	1	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1
PCT. REM OF SLEEP	24	20	22	20	22	19	22	22	17	22	24	22	19	17	19	29	23	18	17	20	21
PCT. NON-REM OF SLEEP	76	80	78	80	78	81	78	78	83	78	76	78	81	83	81	71	77	82	83	80	79
PCT. STAGES 3 AND 4 OF SLEEP	9	3	7	8	5	5	7	4	10	6	6	7	9	9	6	9	11	15	2	5	7
PCT. STAGES 2,3 AND 4 OF SLEEP	75	75	75	79	76	79	76	78	80	78	76	76	79	82	80	65	74	76	83	78	77
NUMBER OF MOVEMENT EPISODES	34	7	3	0	1	5	3	12	16	5	6	6	9	9	6	67	22	4	0	3	11
NUMBER OF AROUSAL EPISODES	14	15	10	10	11	8	15	18	4	2	13	15	7	5	8	12	4	6	15	11	10
NUMBER OF NON-REM EPISODES	7	9	9	8	7	8	10	6	8	9	11	9	7	7	7	11	7	5	9	8	8
NUMBER OF REM EPISODES	6	9	9	7	6	7	9	5	8	9	10	8	6	6	7	10	6	5	9	7	7
NUMBER OF STAGE CHANGES	30	37	51	34	41	36	57	40	50	48	52	46	35	34	38	56	34	48	33	34	42

Figure 3-73. 20-Day Summary Chart—Sleep Parameters, Unaltered Sleep Cycle

ALTERED SLEEP CYCLE	2	3	4	5	6	7	8	9	10	42	43	44	45	46	86	86	87	88	89	AVE
TOTAL BED TIME	470	434	400	344	446	398	428	516	512	368	566	460	530	478	520	520	520	590	528	476
TOTAL SLEEP TIME	428	386	366	310	342	354	424	508	470	318	548	432	510	424	494	478	486	558	496	439
TOTAL WAKE TIME	42	48	34	34	104	44	4	8	42	50	18	28	20	54	18	36	28	24	32	34
TOTAL STAGE 1	36	90	32	30	110	84	68	32	68	2	18	38	26	24	16	28	44	54	26	42
TOTAL STAGE 2	312	248	224	204	224	208	176	358	330	248	406	288	352	292	386	334	316	368	344	298
TOTAL STAGE 3	0	0	2	14	2	0	0	10	10	14	4	0	4	12	4	0	2	4	4	5
TOTAL STAGE 4	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
TOTAL REM	80	48	108	60	6	62	180	108	60	54	124	106	126	98	92	116	124	142	122	98
TOTAL MOVEMENT TIME	1	1	1	1	4	1	1	11	11	1	32	33	32	16	34	88	35	89	11	18
TOTAL NON-REM	348	338	258	250	336	292	244	400	410	264	424	326	384	328	402	362	362	416	374	342
TOTAL OF STAGES 3 AND 4	0	0	2	14	2	0	0	10	12	14	4	0	4	12	4	0	2	4	4	5
TOTAL OF STAGES 2, 3, AND 4	312	248	226	220	226	208	176	368	342	262	412	288	356	304	386	334	318	362	348	300
WAKE TIME BEFORE FIRST STAGE 2	10	6	4	4	20	0	0	0	4	0	2	6	14	8	10	4	8	6	14	6
WAKE TIME DURING SLEEP	14	18	6	4	30	22	0	8	34	0	12	0	0	0	8	20	20	18	18	12
WAKE TIME AFTER SLEEP	18	24	24	26	54	22	4	0	0	30	2	20	0	46	0	10	0	0	0	15
TIME BEFORE FIRST STAGE 2	16	10	10	12	38	8	8	0	8	0	4	10	16	22	22	22	24	8	14	13
TIME BEFORE FIRST STAGE 3	-	-	42	32	66	-	-	42	42	42	34	-	38	50	42	-	58	42	36	-
TIME BEFORE FIRST STAGE 4	-	-	-	-	-	-	-	-	52	-	-	-	-	-	-	-	-	-	-	-
TIME BEFORE FIRST REM	58	102	64	68	260	126	244	70	66	58	62	128	80	84	146	110	160	140	76	111
AVERAGE DURATION OF MOVEMENTS	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
AVERAGE DURATION OF AROUSALS	6	11	4	5	9	7	22	3	5	7	2	6	1	11	2	5	8	4	3	6
AVERAGE DURATION OF NON-REM	62	123	58	69	221	63	117	67	74	72	61	70	66	75	68	78	64	71	68	81
AVERAGE DURATION OF REM	20	33	28	15	5	21	195	23	14	20	16	28	27	27	23	30	15	33	25	32
AVERAGE REM-TO-REM INTERVAL	95	157	100	88	0	78	0	79	81	81	81	91	86	106	82	106	63	100	90	82
PCT. WAKE OF BED TIME	9	11	9	10	23	11	1	2	8	9	3	6	3	11	3	7	5	6	6	7
PCT. SLEEP OF BED TIME	91	89	92	90	77	89	99	98	92	91	97	94	96	89	95	92	93	95	94	92
PCT. MOVEMENT TIME OF BED TIME	0	0	0	0	1	0	0	2	2	0	6	7	6	3	6	11	7	10	2	3
PCT. OF WAKE BEFORE FIRST 2	24	13	12	12	19	0	0	0	10	0	13	23	100	15	56	17	29	25	44	22
PCT. OF WAKE DURING SLEEP	33	38	18	12	29	50	0	100	90	0	75	0	0	0	44	56	71	75	56	39
PCT. OF WAKE AFTER SLEEP	43	50	71	76	52	50	100	0	0	100	13	77	0	85	0	28	0	0	0	39
PCT. STAGE 1 OF SLEEP	8	23	9	10	32	24	16	6	14	1	2	9	5	6	3	6	9	10	5	10
PCT. STAGE 2 OF SLEEP	73	64	61	66	65	59	42	70	70	78	74	67	69	69	77	70	65	64	69	67
PCT. STAGE 3 OF SLEEP	0	0	1	5	1	0	0	2	2	1	1	0	1	3	1	0	0	1	1	1
PCT. STAGE 4 OF SLEEP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PCT. REM OF SLEEP	19	12	30	19	2	18	42	21	13	17	23	25	25	23	19	24	26	25	25	21
PCT. NON-REM OF SLEEP	81	88	70	81	98	82	58	79	87	83	77	75	75	77	81	76	74	75	75	79
PCT. STAGES 3 AND 4 OF SLEEP	0	0	1	5	1	0	0	2	3	4	1	0	1	3	1	0	0	1	1	1
PCT. STAGES 2,3 AND 4 OF SLEEP	73	64	62	71	66	59	42	72	73	82	75	67	70	72	78	70	65	65	70	68
NUMBER OF MOVEMENT EPISODES	2	2	2	2	8	2	1	20	19	1	48	47	38	25	36	66	35	64	14	23
NUMBER OF AROUSAL EPISODES	10	10	11	10	19	17	3	8	14	5	16	7	10	5	16	8	10	19	12	11
NUMBER OF NON-REM EPISODES	6	3	5	4	2	5	2	6	6	4	7	5	6	5	6	5	6	6	6	5
NUMBER OF REM EPISODES	5	2	4	4	1	4	1	5	5	3	7	4	5	4	5	4	6	5	5	4
NUMBER OF STAGE CHANGES	28	24	19	30	35	26	3	36	33	27	34	29	28	26	36	28	29	41	22	28

Figure 3-74. 19-Day Summary Chart—Sleep Parameters, Altered Sleep Cycle

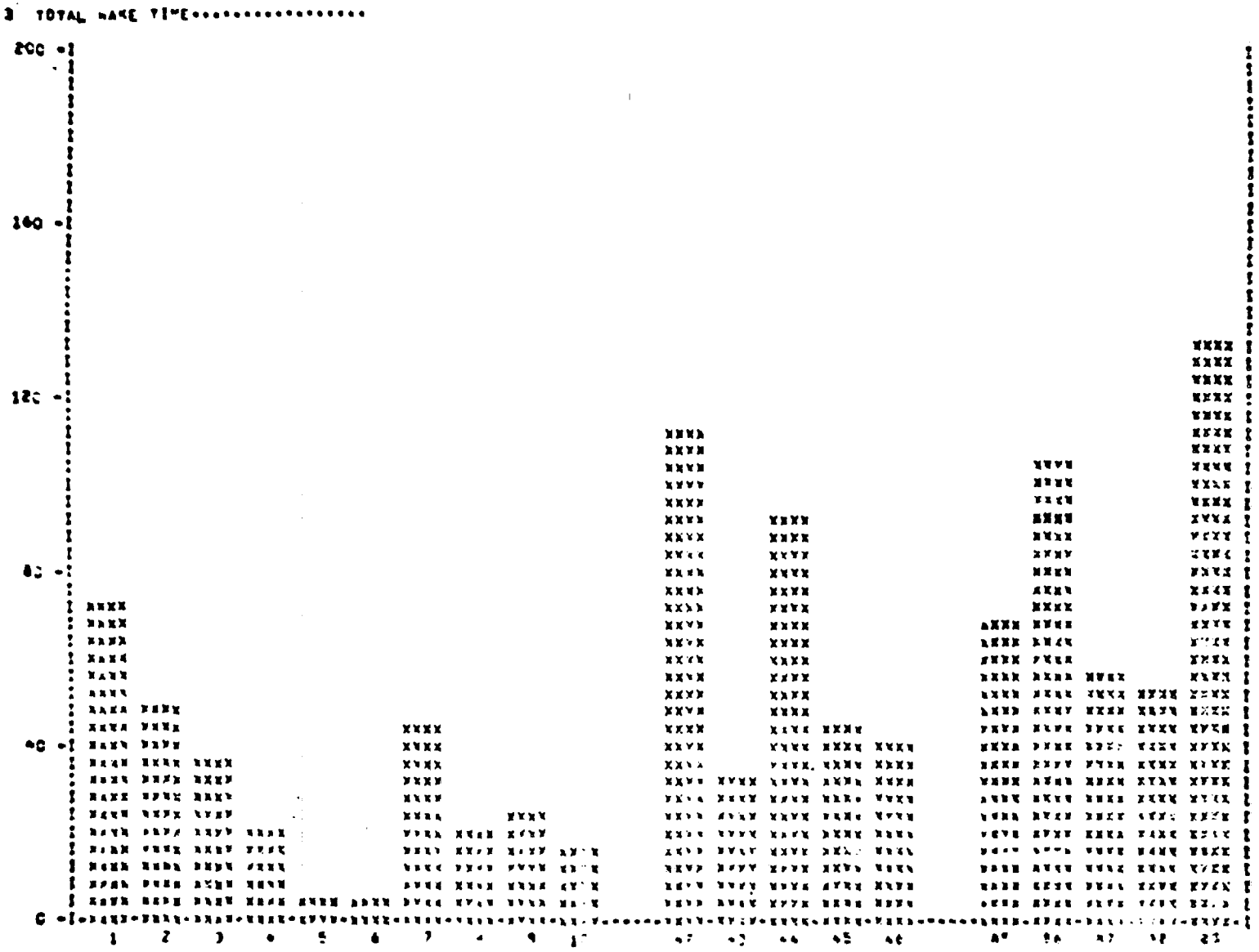


Figure 3-75. Trend Plot—Total Waking Time

A methodology has been developed which provides for the rapid processing of the EEG and related physiologic parameters. The automatic pattern recognition sleep scoring system has demonstrated sleep stage classification results consistent with those of a human scorer, without the inconsisttencies of the subjective scoring and eliminating the tedium of manual scoring. A statistical summary of sleep parameters is readily computed and trends in sleep activities displayed for evaluation of crewman status.

The analyzed data demonstrates a trend towards more sleep in the first 10 days of confinement, less sleep later on - although total bed time remains about the same and both crewmen appear to have obtained adequate sleep.

Total wake time tapered off during the first 10 days, reflecting some adaptation to the chamber. The amount of wake time before sleep showed a definite increase from the beginning to the middle to the end of the 90-day test, and wake time in bed after sleep also shows a definite increase with time.

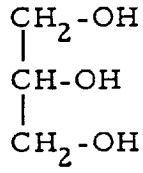
The sleep behavior of the crewmen monitored during this experiment appeared to deviate little during the course of the 90-day test. It was noted that both crewmen tended to have little slow wave sleep activity (stages 3 and 4), averaging 30 minutes per night for one crewman and a miniscule 5 minutes per night for the other.

The most interesting psychological changes in the crewmen occurred near day 60 as noted in Section 3.4. It is unfortunate that the limited scope of the sleep monitoring did not include this time period, since the correlation of sleep characteristics with other behavioral data could have provided significant information.

3.8 GLYCEROL FOOD SUPPLEMENT

During the 90-day test, crew members evaluated the acceptability of glycerol as a dietary supplement (sweetening agent) in two different 5-day periods. Evaluation took the form of hedonic ratings of acceptability and, through the use of portions of available urine and blood samples, verifications of the course of metabolic resolution of the material.

Glycerol dates from the earliest days of organic chemistry when its isolation from fat as an individual compound was first reported by Scheele in 1779 (Reference 3-25). Its name derives from the Greek "glukos," meaning sweet, since it had a sweetness almost as intense as sugar. Later, its structure was shown to be:



which in most aspects is quite similar to the structure of sugars.

Along with being found in food as a component of fat, free glycerol is present in small amounts in fermented materials such as beer, wine, and bread. Further, it is now commonly added in relatively small amounts to foods in which it is not normally present to confer desirable physical properties. It is also utilized because of its desirable solvent properties in the formulation of a wide variety of pharmaceutical preparations and is useful in the compounding of food flavorings. Glycerol is "generally recognized as safe" by the US Food and Drug Administration.

It was not until 1902 that Cremer demonstrated that glycerol was processed by the body to produce glucose when he reported that diabetics excreted additional sugar when fed glycerol (Reference 3-26). This gluconeogenic attribute of glycerol was later confirmed by Catron and Lewis in 1929 with the demonstration that ingestion of glycerol by fasting rats led to an increase in liver glycogen (Reference 3-27). Since then, extensive studies have been conducted which repeatedly show that the most important pathway of glycerol metabolism involves its rapid conversion in the body to glucose.

The current confidence regarding the low oral toxicity of pure glycerol has not always existed. It is possible that early preparations contained byproducts which resulted in reports of nausea, vomiting, and injurious effects. It remained for Johnson, Carlson, and Johnson in 1933 to effectively disprove injurious effects in animals and man when significant amounts of glycerol were consumed (Reference 3-28). They reported that after extensive preliminary testing in rats and dogs consuming almost one-half their diet as glycerol, they then fed 110 g of glycerol per day to 10 men and 4 women for 50 days. This amount of glycerol could provide about 1,985 MJ (475 Kcal) which would amount to almost 20 percent of the daily calorie requirement of the subjects. There were no significant changes in the blood and uring analyses performed nor was there a change in the basal metabolic rate. No evidence was observed of diarrhea, abnormal intestinal activity, sleeplessness, or excitement; all these effects having been previously reported by others.

Based on Reference 3-28 and other subsequent reports of the innocuous effect of the oral ingestion of glycerol by man, it was decided here to investigate the suitability of glycerol as a potential physicochemically regenerated food during long duration space missions (Reference 3-29). Two other aspects of the problem, aside from its nutritive qualities, had to be investigated; the feasibility of its manufacture from waste during the mission and its psychological acceptability.

The problem of manufacture has been pursued to the point where currently it can be stated that the feasibility of the following synthetic sequence has been demonstrated: (1) reaction of respiratory carbon dioxide and hydrogen to yield methane; (2) oxidation of methane to formaldehyde; (3) self-condensation of formaldehyde to produce formose sugars; and (4) hydrogenolysis of formose sugars to give glycerol plus other low molecular weight polyols. Separation of pure glycerol from the mixture remains to be accomplished.

The problem of acceptability of glycerol under simulated aerospace conditions is the subject of this section. The crewmen of the 90-day test agreed to consume 40 g per day of food-grade glycerol in four 10-g doses during two

different 5-day periods. They would also report their evaluation of various different flavorings and methods of ingestion. Concurrently, analyses of blood and urine samples would be conducted to determine the possible physiological effects of this supplement to their diet.

3.8.1 Materials and Methods

The glycerol used was reagent grade in accordance with the specifications of the American Chemical Society. It was diluted with distilled water to give a solution containing 1 g glycerol per cm^3 of final volume. Lemon and lime flavors were reconstituted juices obtained from a local supermarket as were other reconstitutable drinks such as Koolaid, dehydrated coffee and tea, used by the crew in combination with the glycerol.

The Glycerol solution was provided in a 1 liter adhesive foil covered plastic automatic dispenser set to deliver 10 cm^3 of the solution at one time. The crew was instructed to mix this quantity of solution with a single flavor or mixture of flavors, dilute with at least five volumes of water or beverage, and consume. The sweetness of 10 cm^3 of the solution was equivalent to about 1 teaspoon of sucrose. The crew was also instructed to allow at least 2 hours between ingestions, which could be before, during, after, or between meals. They were to record the total volume of liquid consumed and their subjective evaluation of the mixture using a five-point scale:

1 = like very much

2 = better than average

3 = acceptable

4 = might try again

5 = will never try again

This five-point scale satisfied the requirements of this experiment and is similar to a standard hedonic scale used in food preference studies.

The blood samples used were portions of the weekly collections described in Section 4.2.6. As a normal part of the serum lipid study performed on the samples by NMRI (Section 4.4.2), values for free serum glycerol were determined and are reported here.

Analysis of weekly urine samples for free glycerol was perfomed by MDAC using a variation of the Boehringer-Mannheim Corporation protocol for the enzymatic analysis of serum glycerol utilizing the following reactions.

Glycerol + Adenosine Triphosphate $\rightleftharpoons$ glycerol-1-phosphate + Adenosine Diphosphate

Adenosine Diphosphate + Phosphoenolpyruvate $\rightleftharpoons$ Adenosine Triphosphate + pyruvate

Pyruvate + Nicotinamide - Adenine Dinucleotide + Hydrogen $\rightleftharpoons$ lactate + Oxidized Nicotinamide - Adenine Dinucleotide

The reduction in absorbency of the solution at 366 nM due to the loss of NADH was equated with the glycerol present.

The accuracy of the method for urine samples and the recovery of added glycerol is indicated by the following excerpt from a letter by S. Klotzsh, Chief Chemist, Boerhringer Mannheim Corp.

"Following the methodology for serum, our laboratory assayed three different urine samples (0.5 ml per test) and also the same specimens with the addition of 1 mg and 2 mg percent of glycerol:

	Recovered Glycerol (mg%)		
Sample	1	2	3
Without addition	0.21	0.28	0.44
Plus 10 g glycerol/ml	1.25	1.28	1.37
Plus 20 g glycerol/ml	2.20	2.19	2.48
percent recovery	103;100	100;96	95;102

The urine was filtered prior to use to exclude particle interferences in the measurement of optical density. A difference of time or rate in comparison to serum samples was not observed."

3.8.2 Results

Glycerol as a food additive was quite acceptable to the crewmen. During the first trial period, there was considerable experimentation with various flavorings. In addition to its formulation as beverages, on a number of occasions it was added to cereal and fruits with good reports. As can be seen from Table 3-34, the recorded evaluations indicated it was considered to be better than average.

During the second period of ingestion, the acceptability declined somewhat to approximately average. The degree of experimentation with flavors was very much reduced and one of the crewmen was satisfied merely to dilute the glycerol with water throughout this phase. None of the crewmen in either of the test periods found any formulation to be unacceptable. General comments at the end of the test indicated the crewmen thought the taste of glycerol to be detectably different from sucrose. Its convenience as a sweetener was thought to be desirable.

Table 3-34

ACCEPTABILITY OF GLYCEROL AS A FOOD ADDITIVE

	Test Day			
	13 - 17		70 - 74	
Crewman	Number of Consumptions	Rating*	Number of Consumptions	Rating*
1	20	**	12	2.9 ± 0.1
2	20	2.1 ± 0.2	14	3.0 ± 0.1
3	14	2.2 ± 0.1	15	2.9 ± 0.1
4	20	1.3 ± 0.2	16	2.9 ± 0.1

* = Mean ± SEM. See text for description of rating scale.

** = Failed to give numerical rating.

Analysis of blood samples drawn immediately after the period of glycerol consumption (Table 3-35) indicated a nonsignificant rise ($P > 0.1$, t test) in the level of free glycerol when compared with the levels observed one week before and after the trial period. Even when all baseline values were pooled for statistical analysis, the increase was not significant.

The results obtained with urine samples are more difficult to interpret. There was a highly significant rise in the amount of glycerol excreted (Table 3-35). However, there was a wide difference in the levels of excretion by the different crewmen. This may be due to individual physiological variations, but other factors may also have had an effect. For instance, during the last few days of each test period, there were deviations from the protocol with regard to the time between consumptions and the amount consumed at a given time. Also, during the second test period, because of unanticipated losses of glycerol solution, not all crewmen held to the regimen for the scheduled usage; in fact, Crewman 1 terminated glycerol ingestion after only three days of this period because of the shortage. Further, some crewmen consumed "double doses" or single doses in rapid succession. It can be predicted this would result in elevated excretion of glycerol.

3.8.3 Discussion

As was expected, it was found here that the acceptability of glycerol was high. Since it is known that glycerol is very rapidly metabolized by the body to primarily glucose and to a lesser degree directly to carbon dioxide, it is not surprising that no elevation in serum-free glycerol was observed several hours after the last ingestion. In theory, the amount consumed could give

Table 3-35

SERUM AND URINE FREE GLYCEROL

Crewman	Serum Free Glycerol (mg%)				Urine Free Glycerol (mg/24 hr)			
	1	2	3	4	1	2	3	4
Sample Day*								
11	0.7	0.8	0.9	0.6	2.7	1.9	1.7	3.7
18	0.6	0.7	1.2	0.8	18.4	39.0	106.0	2.8
25	0.7	0.7	0.9	1.0	1.7	2.5	2.8	1.6
67	1.2	0.9	0.9	1.2	4.4	3.0	5.9	5.0
74	(1.2)	1.1	9.1	4.2	(3.3)	30.7	65.7	5.8
81	1.1	0.7	1.3	0.9	5.5	2.9	5.6	3.1

*NOTE: Trial Periods were: Days 13 to 17 and 70 to 74.

rise to a transitory three-fold increase in the serum level of glycerol; but this would be observed only if absorption was very rapid and measurements were performed within minutes after consumption.

It is thought that the rate of excretion of glycerol into the urine is directly proportional to the serum concentration of free glycerol. This may help to explain the difference observed between the amounts excreted before and after the first test period and the corresponding values obtained during the second collection of data. The mean volume of urine per man day of the first test period was $1,140 \pm 265$ cm^3 whereas it was $1,940 \pm 205$ cm^3 during the second period. The difference is significant ($P < 0.05$, t test). The same situation obtained with regard to the excretion of glycerol. During the baseline periods of the first glycerol ingestion, total excretion of glycerol was 2.24 ± 0.25 mg per day while during the second period, it was 4.43 ± 0.45 mg per day. Again, the increase was highly significant ($P < 0.01$, t test). Thus, the normal excretion rate of glycerol seems to parallel the total volume of urine, a situation which would be expected if glycerol excretion were a passive process.

The passive nature of glycerol excretion does not explain the extent of the elevation observed during test. The wide variations in glycerol excretion complicate the situation. However, the fact that the relative amounts excreted by each crewman during the two different test periods was essentially in the same order would suggest individual physiological differences. Further studies are planned. In any case, the average excretion of glycerol during the test represented less than 0.1 percent of the ingested amount and can be considered negligible.

Because of a shortage of glycerol during the second ingestion period, crewman 4 terminated his consumption of glycerol about 10 hours before beginning the collection of urine. As seen from Table 3-34, urinary excretion of crewman 4 had returned to normal values which indicates a very short retention time for excess glycerol in the body. This is consistent with known rates of glycerol metabolism as determined by studies involving radioactive glycerol and measurement of the excretion of radioactive metabolites such as carbon dioxide (Reference 3-26).

3.8.4 Recommendations

In future studies of the use of glycerol as a diet supplement, the following changes in protocol would be desirable:

A. Storage onboard of a 25 to 30 percent excess of glycerol solution to avoid problems associated with accidental spills.

B. Elimination of liquid flavorings and substitution of dehydrated or Koolaid type flavorings.

C. Greater emphasis during crew briefing of need to adhere to instructions regarding proper dilution of the glycerol solution and schedule of consumption.

D. Extension of glycerol consumption to periods greater than 5 days.

3.9 NON-INTERFERENCE PERFORMANCE ASSESSMENT (NIPA)

This portion of the program involved an evaluation of the feasibility of measuring onboard crew behavior on a non-interference basis, i.e., without requiring active participation of the crew.

Manned space missions planned for the foreseeable future will include onboard personnel in sufficient number and over sufficiently prolonged durations that problems associated with man in the system require increased attention. It is of vital importance to develop methods of performance assessment which will provide information on those aspects of the behavior of a man, or groups of men, which affect total mission performance. Thus, the objective of developing human performance measures is to apply them to reducing incidents of poor performance on mission-critical activities which would result in loss of important data and, in the extreme case, mission abort.

It is fairly obvious that a man's performance of technical tasks is directly dependent upon the technical skills that he possesses. This has been a major criterion in the selection and training of space crews and certainly should continue to be so. Not so obvious, however, is the influence of other behavioral factors such as crew morale or social-psychological factors on performance. Prior studies of small groups in confined spaces over long duration report that morale declined and interpersonal tension increased (Reference 3-30). The question for long-term space missions is: How can in-flight degeneration of morale be detected and, having done so, what remedial action can be taken?

Psychological tests of the paper and pencil variety are usually used when information relative to morale or social-emotional factors is desired. This often results in a reaction to the test itself. Subjects may resist providing information which is felt to be private. Or, when a subject is aware of being evaluated, there may be a tendency to select answer alternatives that will place him in the "best" light rather than those that truly represent actual feelings, thought, or opinions. Thus, the measurement technique itself alters the object being measured giving a false reading. In addition, there is an accompanying history of negative reactions to such tests, especially when given repeatedly. One way of avoiding the inaccuracy of these tests, as well as the negative reactions to them, is to collect data from the subjects without requiring their active participation.

The goal of the NIPA study was to develop methods of obtaining morale data from crewmen on the 90-day SSS test by visually and aurally observing behavior. The program was conceived to be non-interfering rather than unobtrusive; i. e., cooperation of the crewmen was not required or desired to obtain data. Unobtrusive observation was not entirely possible because of the test program policy of briefing the crewmen about all aspects of the program. Although they would be aware that cameras and microphones were installed in the SSS, crewmen would be able to carry on their programmed tasks (and other behavior) without interference by the NIPA staff. The crew would also receive a number of intrusive paper-and-pencil tests to augment the NIPA data with classically obtained information. The ultimate objective was to develop an observational methodology which would eliminate the need for intrusive testing methods where morale data are desired in operational situations. The immediate objective was to test a particular set of observational techniques which would provide preliminary avenues for further research in the area. The methodology as it might be ultimately developed is envisioned as a means for providing to ground support personnel real-time data on which to take remedial action in the event of significant decrement in the morale of operational space crews.

3.9.1 Experimental Method

The approach was to observe behavior through use of a closed-circuit video system and live microphones. Anticipated behavior of the crew was identified, defined, categorized, and quantified. A data analysis program was developed to correlate behavioral observations with the more traditional measures of behavior available to the experimenters. These measures included: paper-and-pencil psychological tests, biochemical stress indices, and work performance records.

The approach was based on previous findings of undesirable psychological-social effects of confinement and assumed that crew behavior would reflect these effects as they occurred during the test. It was expected that as test duration increased there would be evidence of decreased interactions among crew members, degraded work performance, irritability, hostility toward support personnel, psychosomatic complaints, degraded sleep behavior, impaired intellectual performance, and lowered motivation. Thus the entire NIPA program was oriented toward observing behavior which might be indicative of these changes and statistically relating behavioral changes to "objective" or criterion measures. Criterion measures are discussed separately.

The first step in the reasoning process dealt with defining and establishing quantitative values for the behavior to be observed. The next steps involved training observers to reliably collect observational data and developing the data analysis protocol.

3.9.1.1 Definition of NIPA Variables

A committee composed of NASA personnel, MDAC personnel, and a consultant to NASA from UCLA laid the ground work for the NIPA variables that were to be defined. The major premise underlying the selection of all variables was that this study would yield information about the crew, as a crew. Thus, the concepts and associated variables came from social psychology and past experience with crews in similar situations.

Based on prior studies in this field (References 3-31 through 3-35), including the Tektite and Sea Lab projects, three major categories of crew data were established for NIPA: (1) verbal interaction, (2) crew member location and activity, and (3) other behavior. A detailed description of each of these categories follows.

Verbal Interaction

It was assumed that an important source of data for crew morale lies in the extent of emotional affect in crew members' verbal conversations with each other. Consideration was given to use of the Bales (Reference 3-36) interaction process method, a widely known technique in social psychology which has had extensive use and has been experimentally assessed as being reliable. In the Bales scheme, 12 categories of verbal interaction are used. Three of these are identified as Social-emotional, positive and three others as Social-emotional, negative. The remaining six categories are divided into expressions of giving and asking of various types of information. These latter six categories are considered neutral with respect to emotional content. It was felt that because NIPA was an exploratory study with many unanswered questions regarding the ability of observers to acquire data, the 12 categories should be reduced to enhance observer reliability and to reduce the observational workload. Therefore, a four-category design was established collapsing the Bales categories into the following schematic representation:

ASK	+
GIVE	-

This four-cell scheme consists of statements which requested or offered information and were relatively devoid of emotional content (give; ask), statements expected to result in a favorable or pleasant response (positive or +) on the part of the crew member recipient, or statements resulting in an unfavorable or unpleasant response (negative or -) on the part of the recipient. All observed verbal interactions were thus categorized by the observers.

The NIPA observers were to monitor both intercom conversations and "overheard" verbal interactions. However, background noise in the chamber made the live microphones ineffective in picking up what the crewmen were saying. Installation of audio filters and other circuit modifications was attempted outside the chamber. After a crewman lowered the microphone hanging over the table used for eating/recreation, it was concluded that satisfactory pickup of crew conversations could occur there. For the remainder of the test, NIPA observers limited their observations of verbal data to that area and to the intercom conversations.

Crew Member Location and Activity

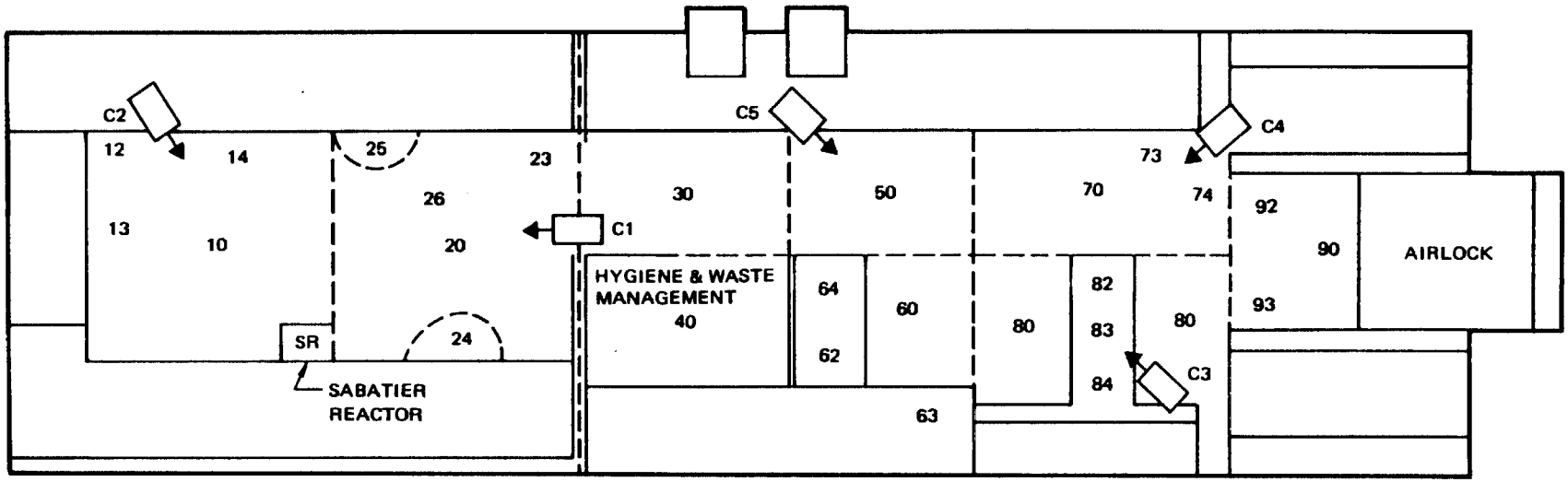
The category of crew member location and activity was chosen to provide an indication of crew cohesion and general morale. Closed-circuit television was used to gather data for this category. The simulator was conceptually divided into areas and the location of each crewman was recorded every 2-1/2 minutes by observer inputs to a teletypewriter, producing a paper tape. Observer coding was assisted by numbers affixed to the face of the five CRT's which showed the scenes captured by the five cameras in the SSS. Figure 3-76 shows that each area in the SSS was assigned a general number, for example, 10, 20, 30 up to 90; and within each area there were numerically subdefined areas which could be occupied by a crewman. Each crew member location and activity entry consisted of four teletypewriter strokes. The first stroke identified the crewman involved, the second and third strokes identified the area in which the crewman was occupied, and the last stroke identified the nature of the crew activity. For example, if the observer wished to record crewman 1 preparing food, he would punch a Q for crewman 1, a 64 for food preparation area, and a 1 for task activity (preparing food). Appendix F shows an example printout of a raw data tape in which physical space mobility/activity entries are encoded.

Other Behavior

Other crewman behavior included (1) observer judgment of the difficulty of the crew tasks on a seven-point scale called "Task Press," (2) verbal expressions of psychosomatic complaints, and (3) problem-solving and creative/innovative behavior. These categories, with accompanying instructions to the NIPA observer are shown in Table 3-36. This table also shows two additional kinds of behavior initially thought to be important; namely, whether the bulkhead door separating the equipment compartment from the crew compartment was open or closed and emotionally based bodily contact (i. e., a demonstration of affection or closeness).

The entire class of other behavior included less than 10 percent of all the data entries made. Only the "Task-Press" recordings provided sufficient data to be included in this report. The remaining categories of other behavior occurred too infrequently to be considered significant.

Acquisition of the three major categories of data just described (verbal interaction, crew member location and activity, and other behavior) requires a NIPA observer "on-line" who visually and aurally monitors behavior. For convenience these data are referenced later in this report as "on-line NIPA



IN AREA 10

12 LANGLEY COMPLEX COORDINATOR
13 LIFE SUPPORT MONITOR
14 TV MONITOR

IN AREA 20

23 RATER
24 RADIOACTIVITY AREA
25 RADIOACTIVITY AREA
26 ERGOMETER

IN AREA 60

62 ELECTRIC OVEN
63 MICROWAVE OVEN
64 PREPARING FOOD

IN AREA 70

73 CRITICAL TASK TESTER
74 PHONE OUTSIDE MDAC PREMISES

82 TABLE
83 ENTERTAINMENT SPEAKER
84 ENTERTAINMENT TV

IN AREA 90

92 BUNK - OPEN
93 BUNK - CLOSED
98 DON'T KNOW

NATURE OF ACTIVITY

1 TASK ACTIVITIES
2 SLEEPING
3 RECREATION
4 UNSCHEDULED PHYSICAL EXERCISE
5 EATING
6 MONITORED CONVERSATION
7 NON-MONITORED CONVERSATION
8 OTHER
9 DON'T KNOW

Figure 3-76. Space Station Simulator Floor Plan Labeled for NIPA Observations

Table 3-36

OTHER OBSERVER JUDGMENTS

Typewriter Key	Category	Recording[1]	How Often[2]
O	Task-press/workload	7 scale	1 per shift
P	Bulkhead door, open or closed	2 scale	Concurrently
B	Complains of headache	3 scale	1 per shift
N	Complains of stomach upset	3 scale	1 per shift
M	Complains of fatigue	3 scale	1 per shift
,	Complains of depression	3 scale	1 per shift
.	Other complaints	3 scale	1 per shift
V	Problem-solving and creative/ innovative behavior		Concurrently
J	Touch equipment		Concurrently
K	Touch persons		Concurrently

NOTE 1: Recording scale as follows:

7 Scale		3 Scale	
1	Overwhelming - cannot be done	1	Not mentioned
2	Extremely heavy - can be done	2	Mentioned
3	Moderately heavy - can be done	3	Severe
4	Average		
5	Moderately light		2 Scale
6	Very light	1	Open
7	No task requirement	2	Closed

(This judgment is made from the crewman's viewpoint.)

NOTE 2: The requirement of one per shift is minimal. Additional recordings should be made as needed.

data" to distinguish them from other data utilized by the NIPA program which were collected by the mission analysis observer, the communications monitor, and the engineering monitor.

Table 3-37 summarizes the NIPA measures that were defined for data collection. Also included are the paper-and-pencil tests that were administered, and are described in detail in Section 3.4.

Table 3-37

PAPER-AND-PENCIL TESTS AND NIPA MEASURES USED DURING THE STUDY

Paper-and-Pencil Tests	NIPA Measures
Hostility Scale	1. Privacy (PVCY)
• Hostility toward outside crew (Hostility O CRW)	2. Psychological Dispersion (PDSPN)
• Hostility toward inside crew (Hostility I CRS)	3. Physical Dispersion (DSPN)
• Hostility toward equipment compartment (Hostility EQCP)	4. Psychological Distance Per Move (PD/MVE)
• Hostility toward crew compartment (Hostility CRW CP)	5. Physical Distance Per Move (D/MVE)
Primary Affect Scale	6. Psychological Distance Per Unit Time (PD/TME)
• Primary affect - Happy	7. Physical Distance Per Unit Time (D/TME)
• Primary affect - Angry	8. Non-Affect Ratio (O AFF)
• Primary affect - Fear	9. Receive-Initiate Ratio (RC-INT0
• Primary affect - Depression	10. Positive Affect Ratio (+ AFF)
Sociometric Questionnaire	11. Negative Affect Ratio (- AFF)
• Sociometry A - Leader choice	12. Task Press (TASKPR)
• Sociometry B - Member choice	

Table 3-37 (Continued)

Subjective Stress Scale

Descriptive Sentence Test

Group Confinement Inventory*

- GCI -
- GCI +

Isolation Symptomatology Questionnaire*

- ISQ +
- ISQ -

Habitability Questionnaire

- Habitability - Crew Quarters
- Habitability - Equipment Quarters
- Habitability - Hygiene
- Habitability - Miscellaneous
- Habitability - Average

*The original subgroupings for the ISQ and the GCI were not used. For purposes of comparison with NIPA measures, all items were examined and data were used only for those items judged by two judges to contain positive affect or negative affect.

3.9.1.2 Data Collection

From the NIPA observer's viewpoint there were two modalities of data to be recorded; that which could be seen and that which could be heard. Recordings of these data were limited to the periods when all crewmen were scheduled to be up. A gross subjective judgment by NIPA observers indicates that about 70 percent of the onboard verbal interactions during this period were understood and recorded. All of the monitored intercom conversations were heard clearly. Medical interviews and personal phone calls were not monitored. Figure 3-77 shows this data collection procedure in schematic form and provides an overview of the entire data reduction and analysis effort. Data reduction and analysis are separately discussed in Sections 3.9.1.3 and 3.9.1.4.

There were two NIPA recording stations. One was located in the SSS control room and used the communication console and its TV monitoring capability. A second remote station, developed primarily to disengage NIPA observations from support staff interactions, was located on the second floor of the SSS laboratory facility. Each station had five CRT's which displayed the scenes of the five cameras inside the SSS and a teletypewriter for observer's entries. The positioning of the five cameras is shown in Figure 3-76. After test day 31, observations were made only at the second station.

A timing circuit presented a light every 2-1/2 minutes which signaled the observer to enter location and activity data for each crewman, then extinguish the light by pressing a button. The observer also could make audio recordings of the conversations among the crewmen and communications between the crew and support personnel. This facility was provided to record any verbal interaction that might prove to be of special interest later. All verbal interactions were monitored except those of confidential nature (private telephone calls, medical interviews, and conversations with staff psychologists). All of the recordings were labeled and stored for later analysis. The schedule of observers was arranged to assure observation of all periods of interest. From test day 31 to 60, observation was carried out almost throughout the 24-hour period, but from day 61 to 90, only the periods when all four crewmen were awake were observed.

Typically, throughout the run, each observer was on duty 4 hours at a time. Some observers, in the initial days of the run, were on duty continuously for 8 hours. It was soon found that this length of time was much too fatiguing and that the entries deteriorated as time progressed. After day 31, no observer exceeded the 4-hour observation period.

Each observer followed the same procedure for signing on and signing off the teletypewriter. First, using an I comment, the observer entered his name. He then punched the calendar date followed by the time of day to the nearest minute. An example of this sign-on procedure can be seen in Appendix F. Then the observer began entering coded data. The sign-off procedure was similar to the sign-on procedure except that four "periods" preceded the observer's name, the calendar date, and the time of day.

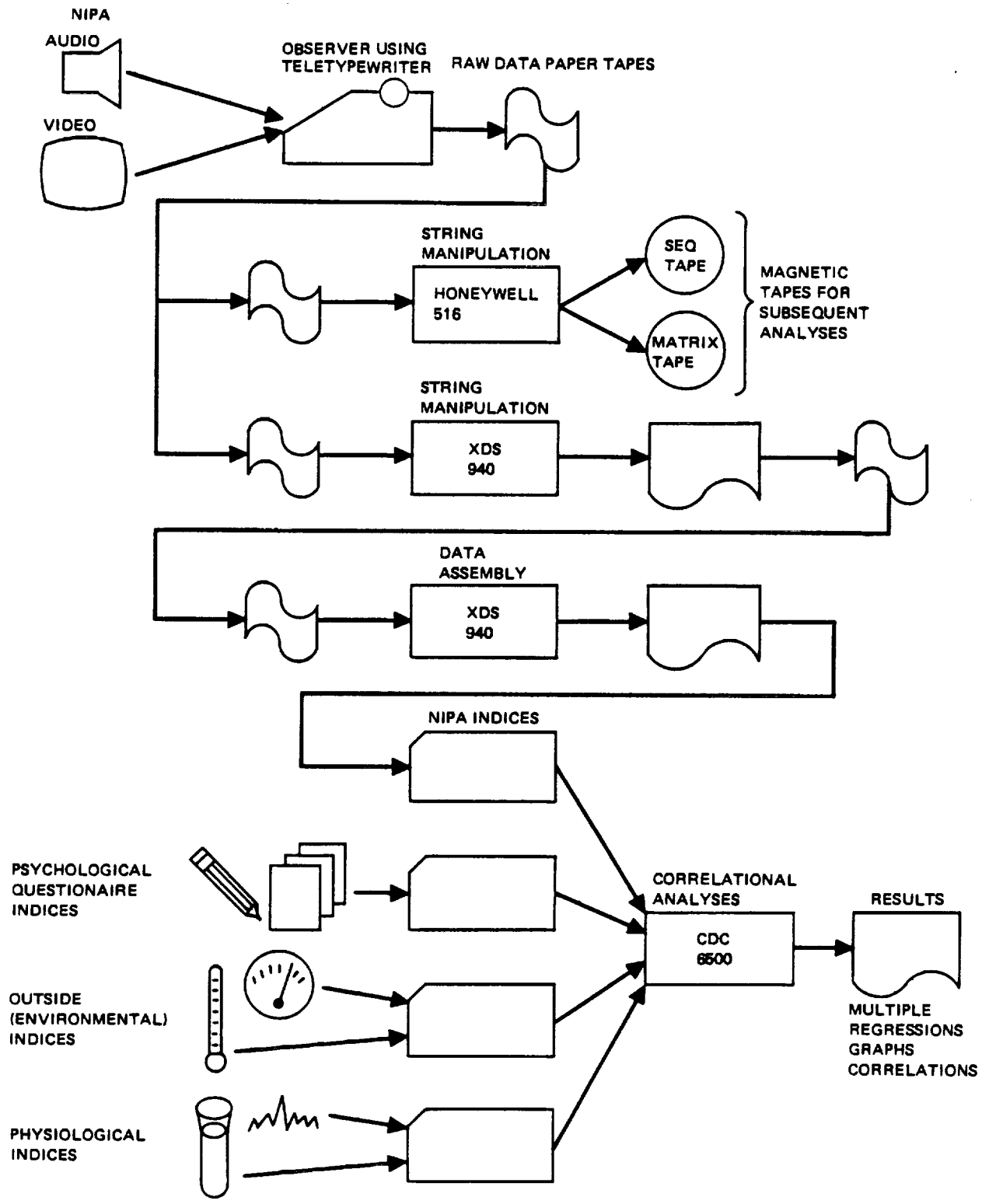


Figure 3-77. Flow Diagram of Data Collection, Reduction, and Analysis

3.9.1.3 Data Reduction

In the data reduction phase, recorded data from the punched tapes were developed into indices which could then be used for correlational purposes. The data reduction effort involved three major phases (see Figure 3-77). The first phase developed magnetic tapes to be used for further analysis. These tapes were produced to facilitate later analyses by avoiding the necessity of using raw data.

In the next phase, an XDS 940 Computer was used to produce a summary of each raw data tape. This summary assumed the form of the matrices discussed in Appendix G. Each matrix contained tallies, in appropriate element positions, based on the entries made by the observer on the paper tape. In the third phase, these tallies were then combined in predefined ways to produce 25 of the 66 indices defined in Appendix H, that is, the 25 NIPA indices.

The data reduction, string-manipulation program produced a summary for one paper tape only (e.g., one 4-hour shift). Several paper tapes produced on the same day were then combined into one set of indices. Indices represented all raw data observations (teletypewriter entries) combined for each crewman per day. Indices, in turn, were considered as data points for correlational analyses. Thus each "data point" represents all entries made for each crew member each day. This function was performed by the data assembly program. The output of the data assembly program was punched onto cards and then used as an input for the correlational analysis program. The requirements of data collection necessitated using the entire teletypewriter keyboard, both numerical and alpha characters. To unscramble the alpha characters, the string manipulation language was required. The computer language "Superbasic" was chosen because of its ability to compare alphas, to concatenate strings (join them together), deconcatenate strings, and to easily find numeric equivalence of alpha characters. Furthermore, since Superbasic is a time-sharing language, this data reduction was simplified by the use of computer time-sharing.

Appendix G shows the detailed matrix design in which tallies are inserted during the reduction of the raw data. Flow charts are included in the appendix to illustrate the general procedure for making the entries into the frequency matrices.

3.9.1.4 Data Analysis

Data were analyzed in two ways: (1) correlational analysis and (2) trend analysis through graphical plotting of data.

Correlational Analysis

After data were reduced to the form of the indices desired for correlational analysis, they were entered into an MDAC computer program known as the Stepwise Regression program. This program computes a sequence of multiple linear regression equations relating a dependent variable to a number of independent variables. An index is added or deleted on the basis of its potency (i.e., the amount by which it reduces the residual sum of squares).

An option to force or temporarily force any of the independent variables into the regression provides flexibility for constructing the sequence of equations and, in fact, makes it possible to operate in a "breakdown" instead of the normal "stepwise buildup" mode.

Three separate computer analyses were completed, differentiated by the schedule on which data were initially collected. On-line NIPA data were collected daily. These were compared with (1) other data collected daily including "outside indices" data and sleep questionnaire data, (2) psychological questionnaire data, and (3) physiological data. The latter two categories of data were collected on a scheduled interval varying from 3 days to 3 weeks.

For the first analysis, the sleep questionnaire items were separately designated as dependent variables and the stepwise regression was computed for each. Five runs were made, one for each crewman and one for the entire crew. The second analysis required 30 computer runs, 6 for each crewman and 6 for the entire crew while the third analysis required 10 runs, 2 for each of the 4 crewmen and two for the total crew.

A computer printout from these analyses included a matrix showing correlations for all indices entered. In addition, a step-by-step regression is shown indicating the equation at each step and those indices that are added or deleted at each step. Inspection of the contribution to sums of squares, F ratio, confidence level, and partial correlation at each step of the process makes it possible to determine the best-fitting equation.

Graphical Plotting of Data

Two classes of graphs were prepared; the first were mainly computer-generated outputs that present data for indices collected on a daily basis and the second were manually plotted data of selected indices showing trends in terms of 5-day averages.

3.9.2 Results

Figures 3-78 through 3-97 present computer-generated graphical plots for five of the NIPA measures (positive affect ratio, number of positive statements, psychological dispersion, physical dispersion, and psychological distance per unit time) which are typical of the data collected. Each graph gives data for an individual crewman and shows the trend for the specific measure for the 15th to 90th day. Valid data points were not available for the first 15 days. It can be seen that the positive affect ratios, as well as the absolute number of positive statements, show a dip during the period from days 60 to 70. This corresponds to the period of morale decline when interpersonal problems existed among the crew. It is thus evident that this measure detected a period of crew stress.

3.9.3 Discussion

The objectives of the NIPA program were to evaluate feasibility of measuring onboard crew behavior on a non-interference basis and to develop specific methods for obtaining morale data for crewmen on the 90-day SSS test by

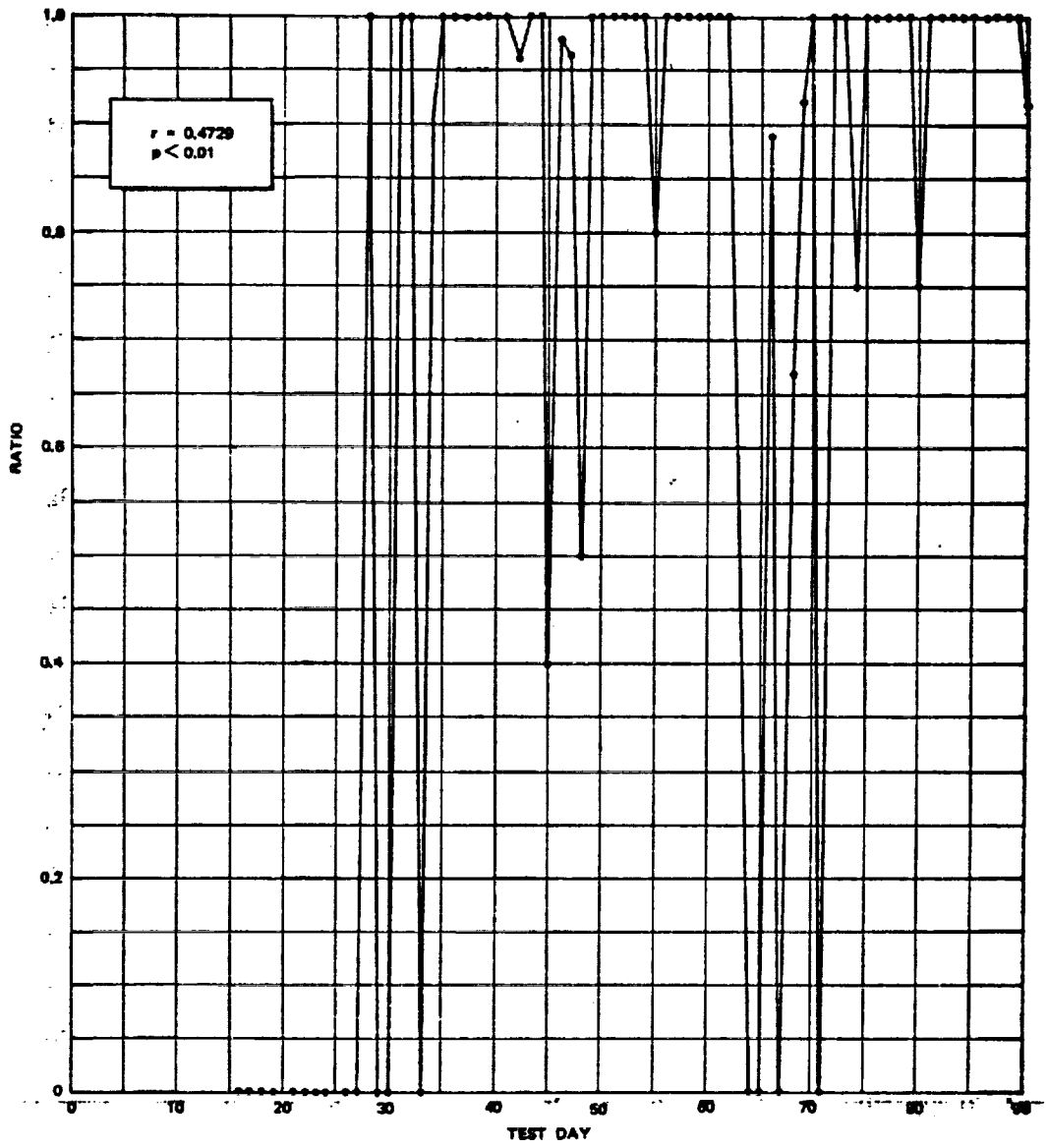


Figure 3-78. Positive Affect Ratio for Crewman 1

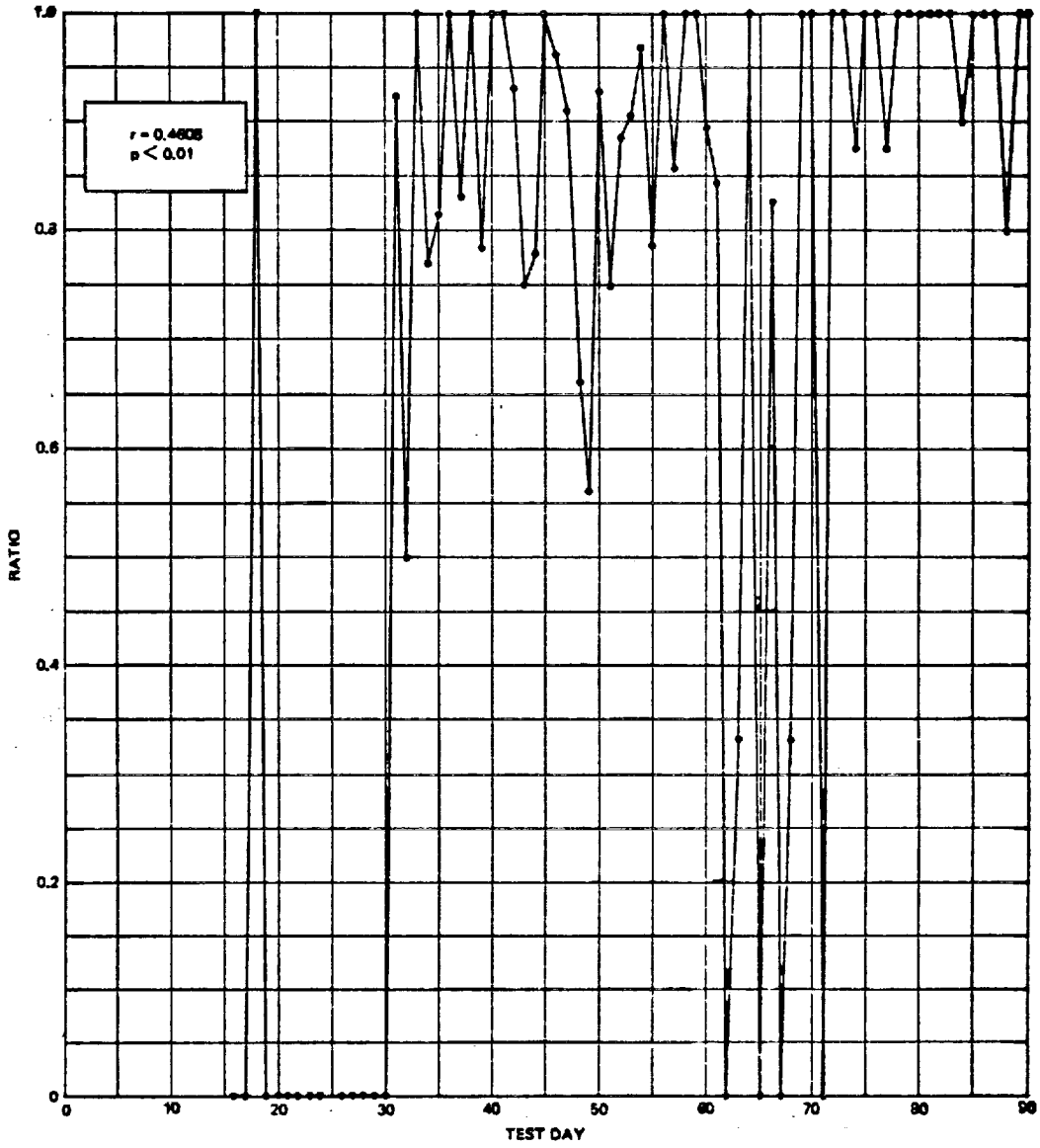


Figure 3-79. Positive Affect Ratio for Crewman 2

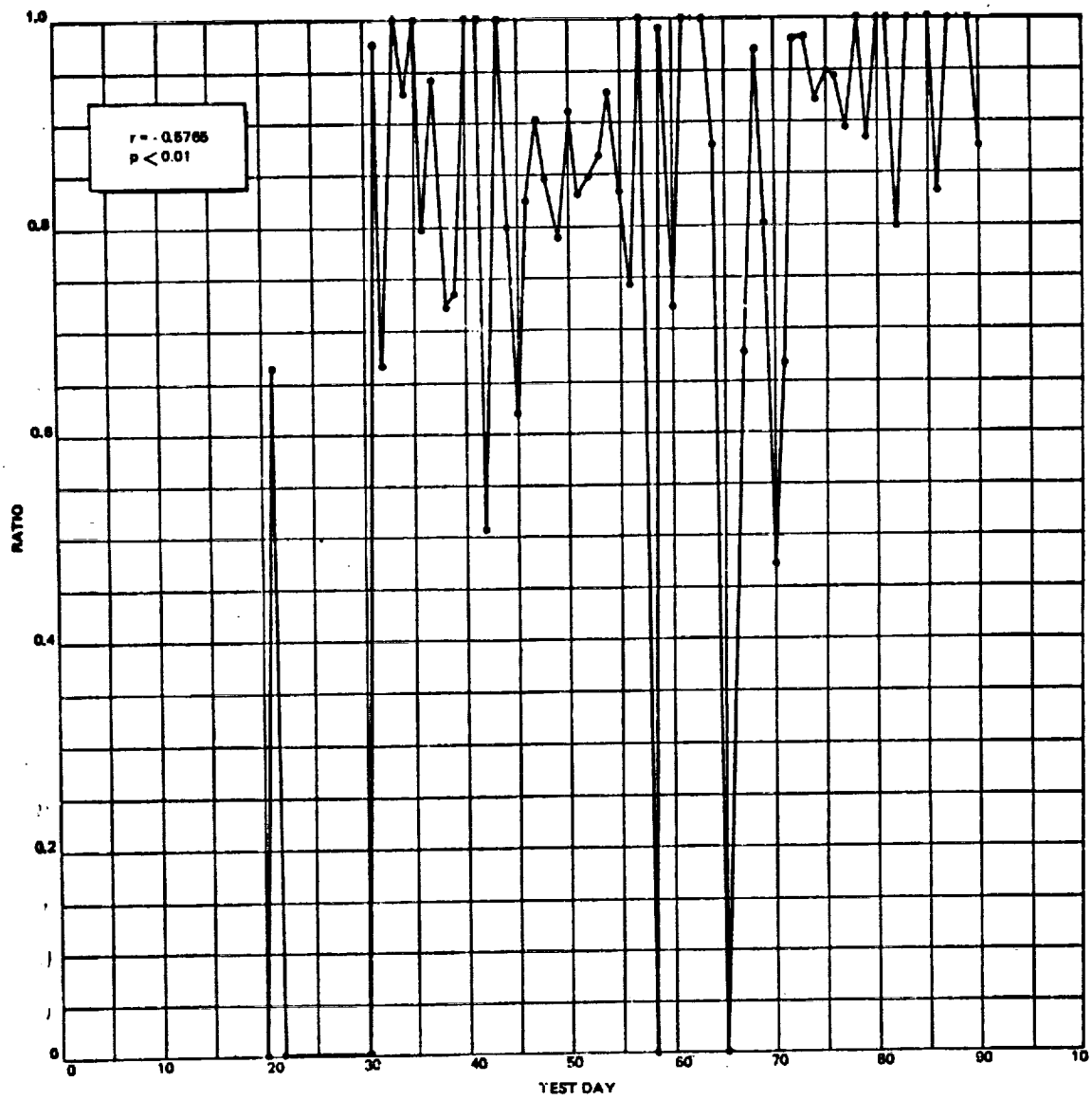


Figure 3-80. Positive Affect Ratio for Crewman 3

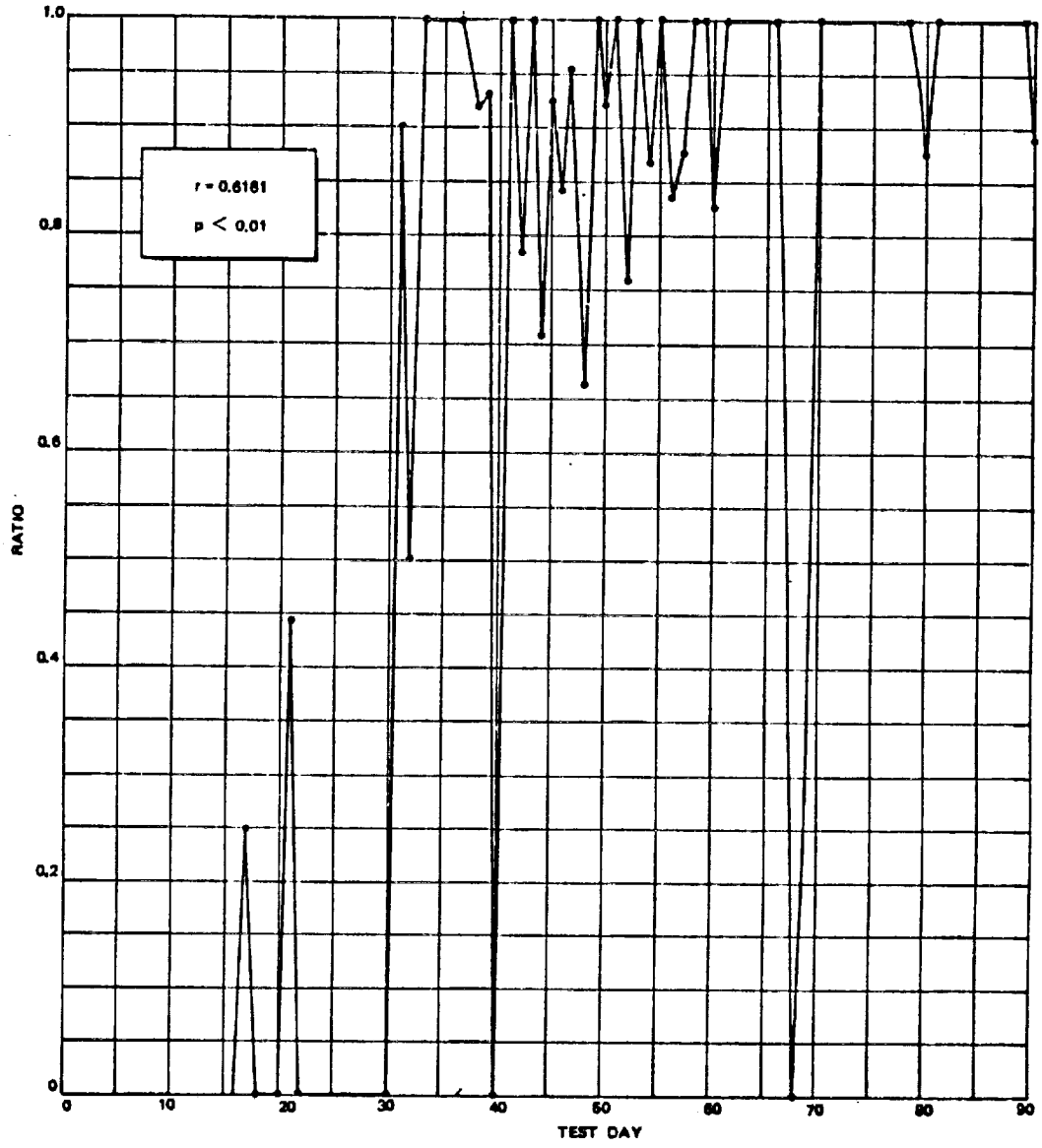


Figure 3-81. Positive Affect Ratio for Crewman 4

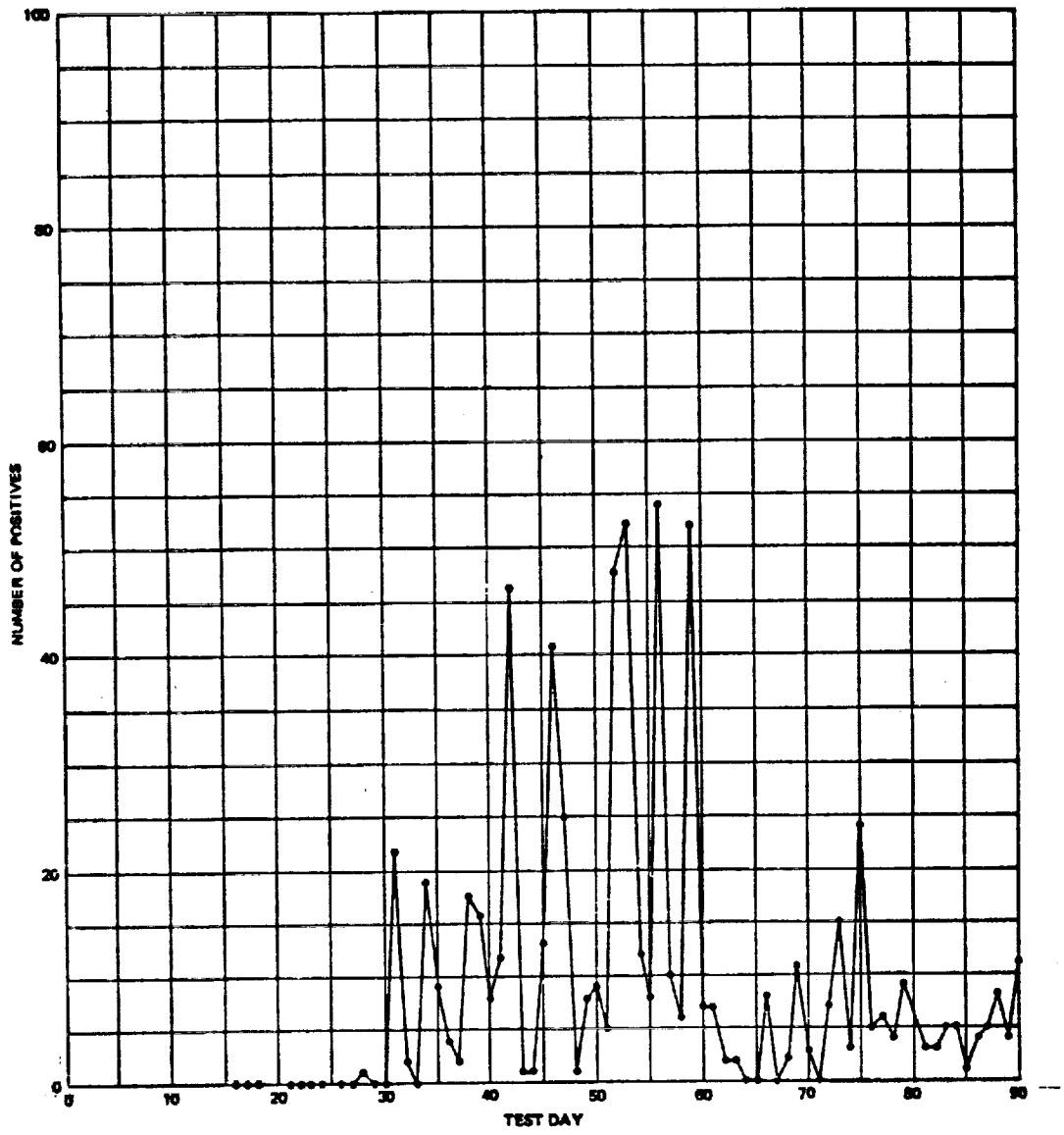


Figure 3-82. Number of Positive Statements by Crewman 1

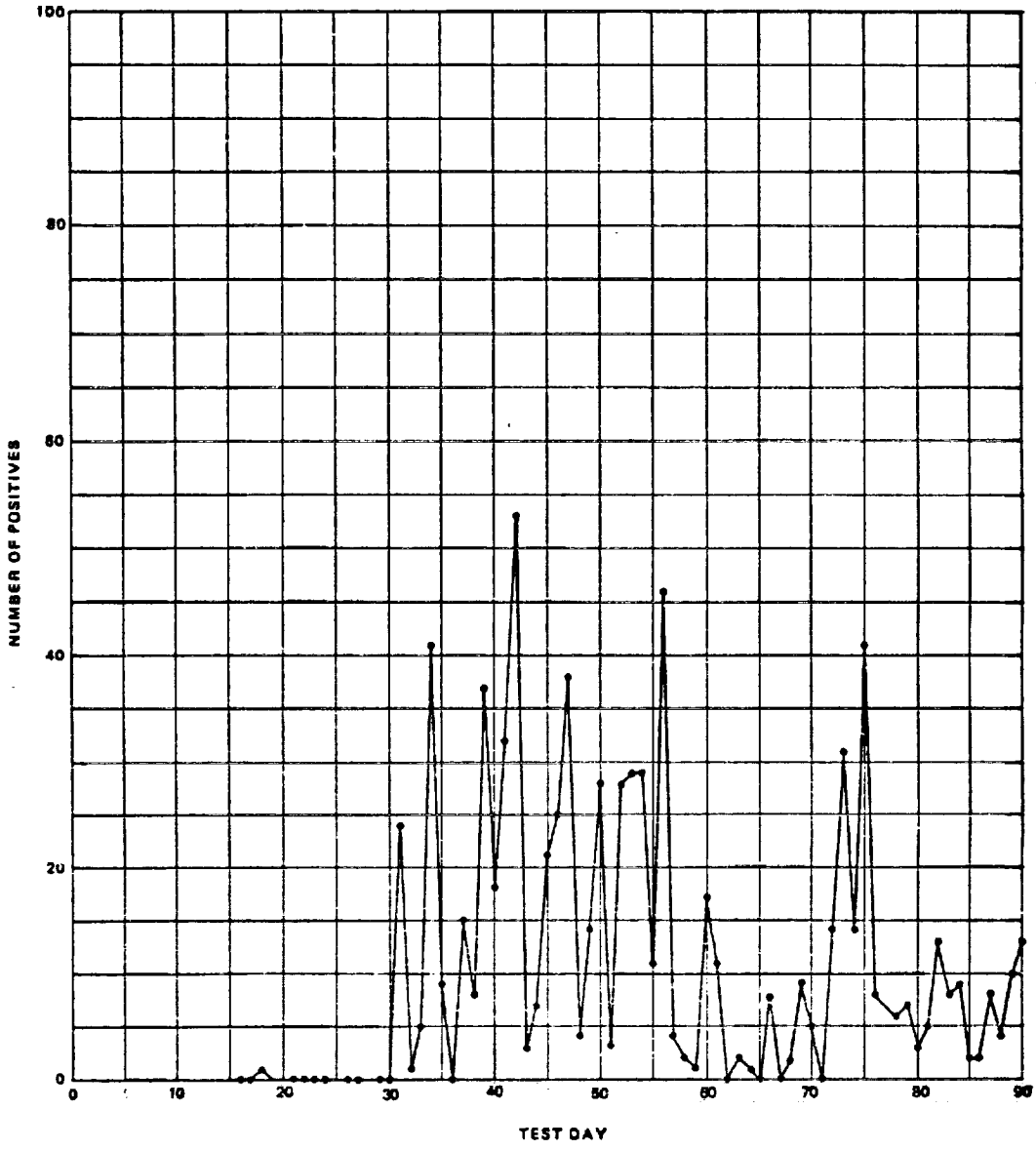


Figure 3-83. Number of Positive Statements by Crewman 2

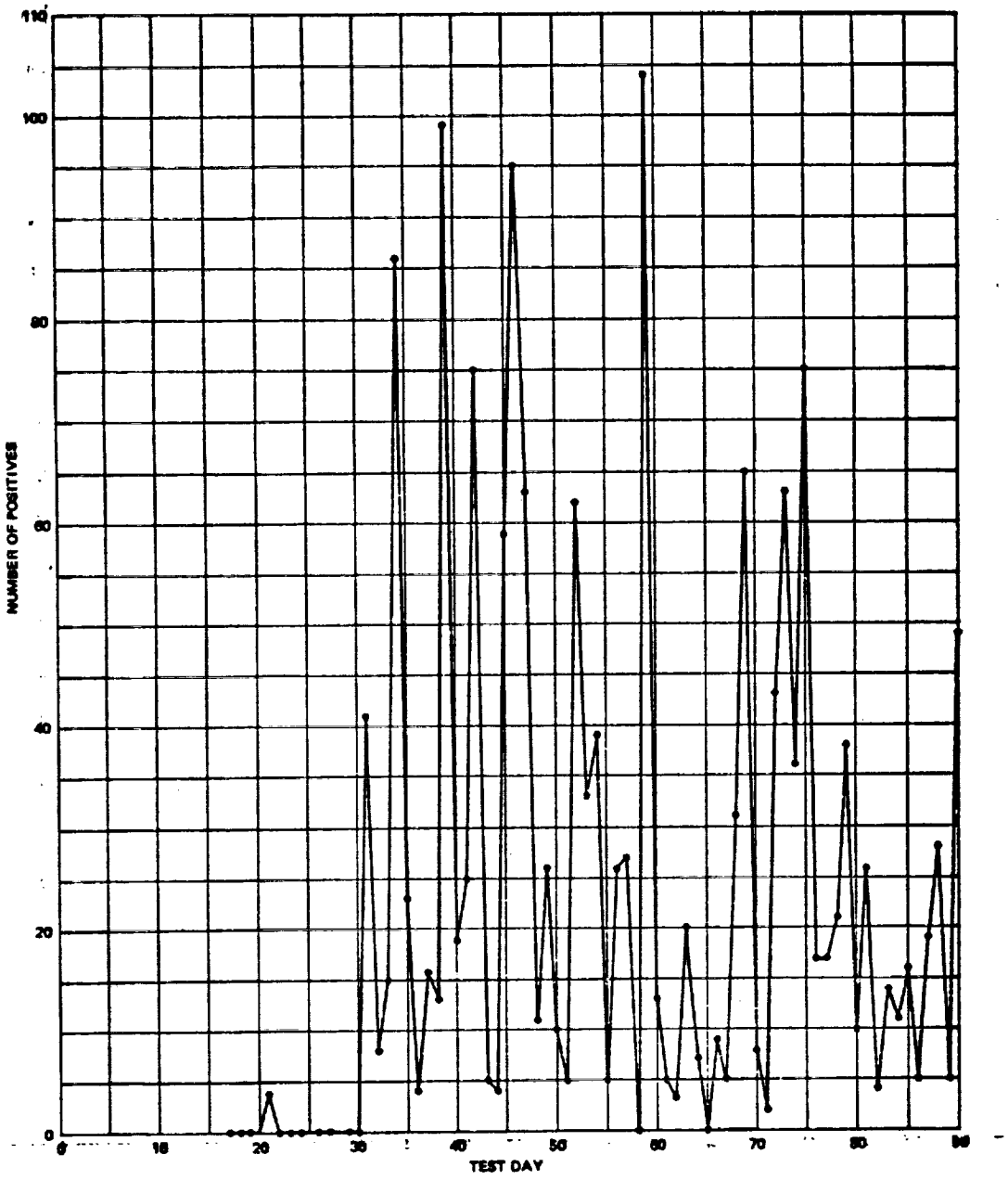


Figure 3-84. Number of Positive Statements by Crewman 3

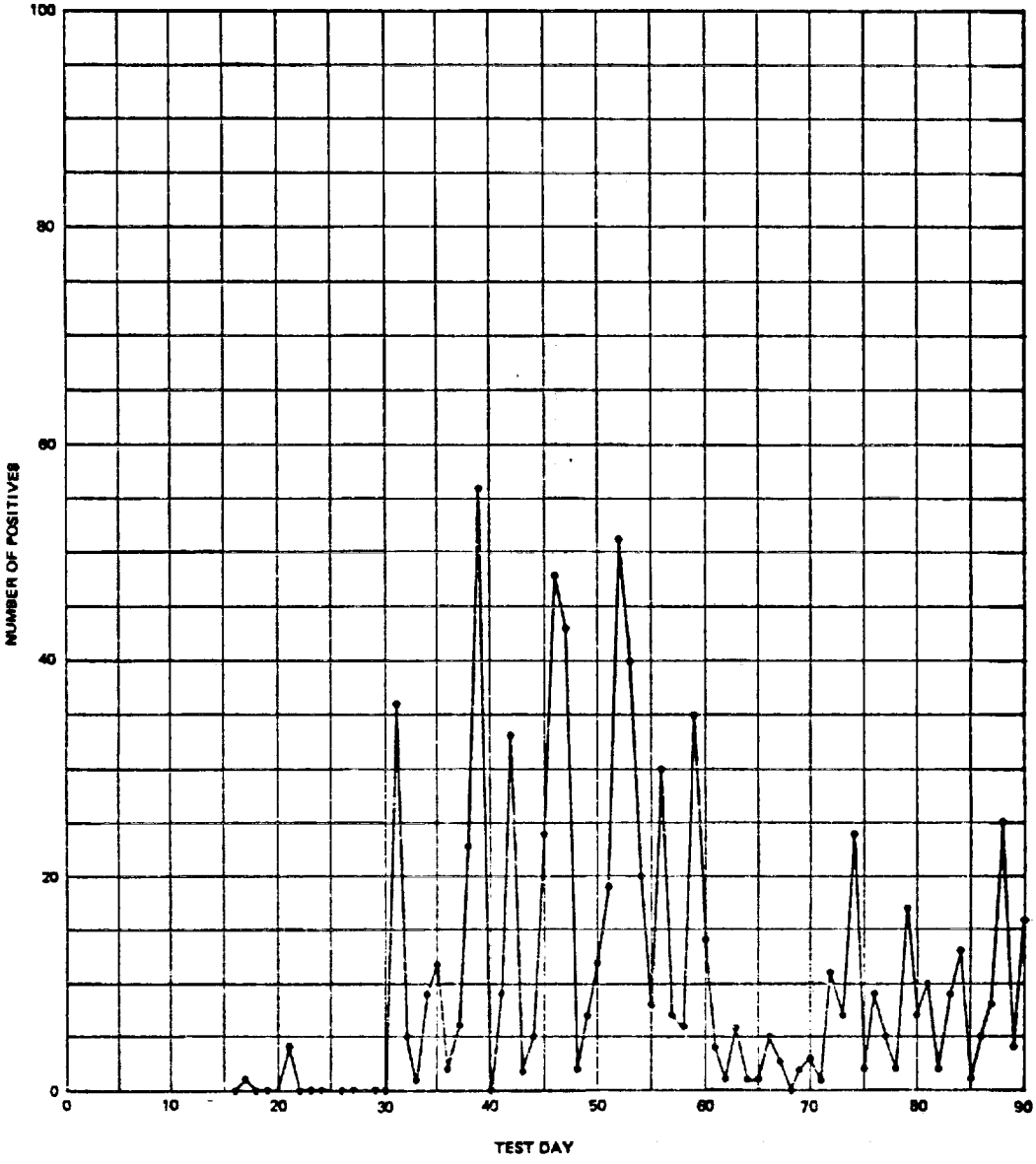


Figure 3-85. Number of Positives Statements by Crewman 4

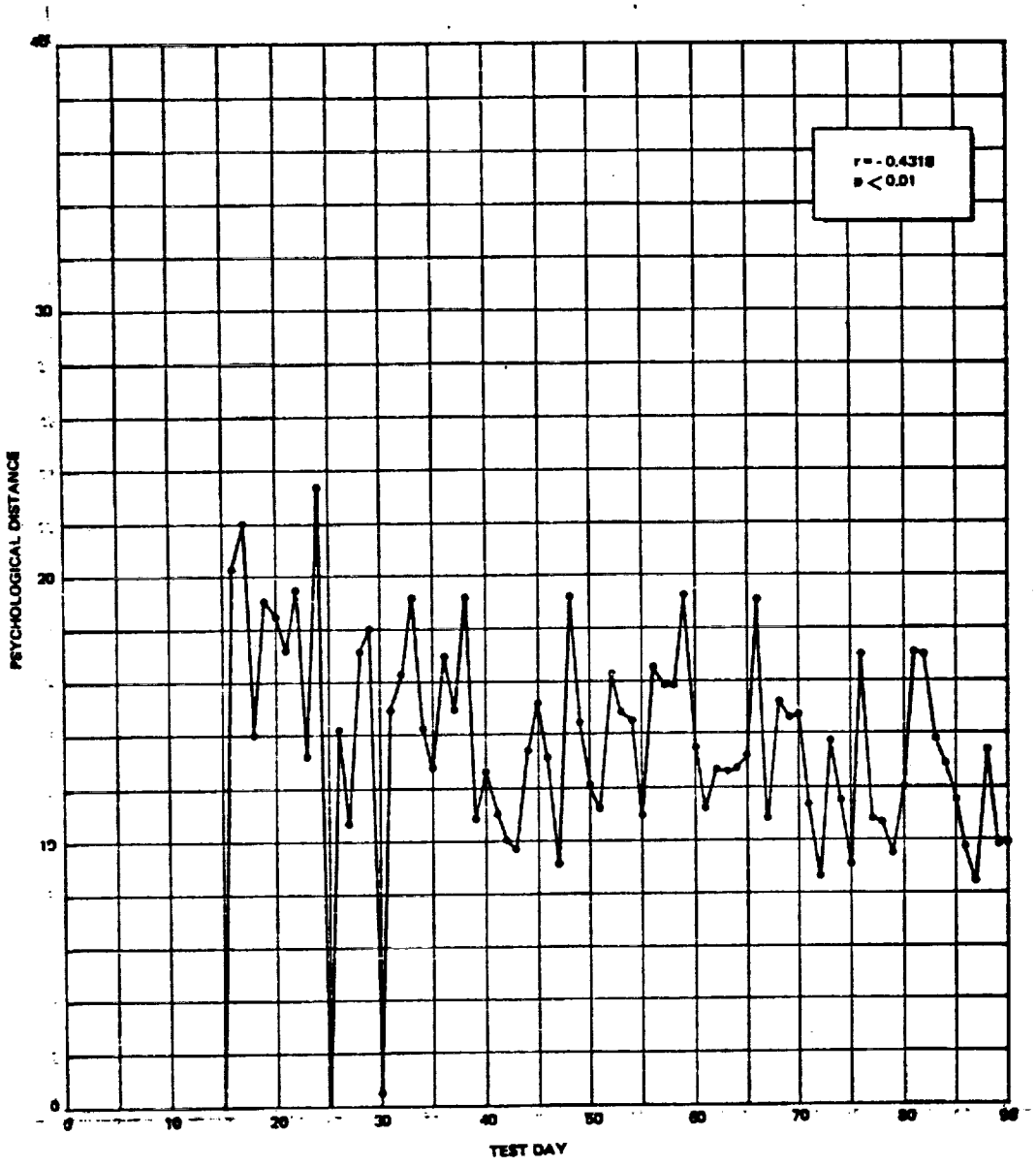


Figure 3-86. Psychological Dispersion from Others for Crewman 1

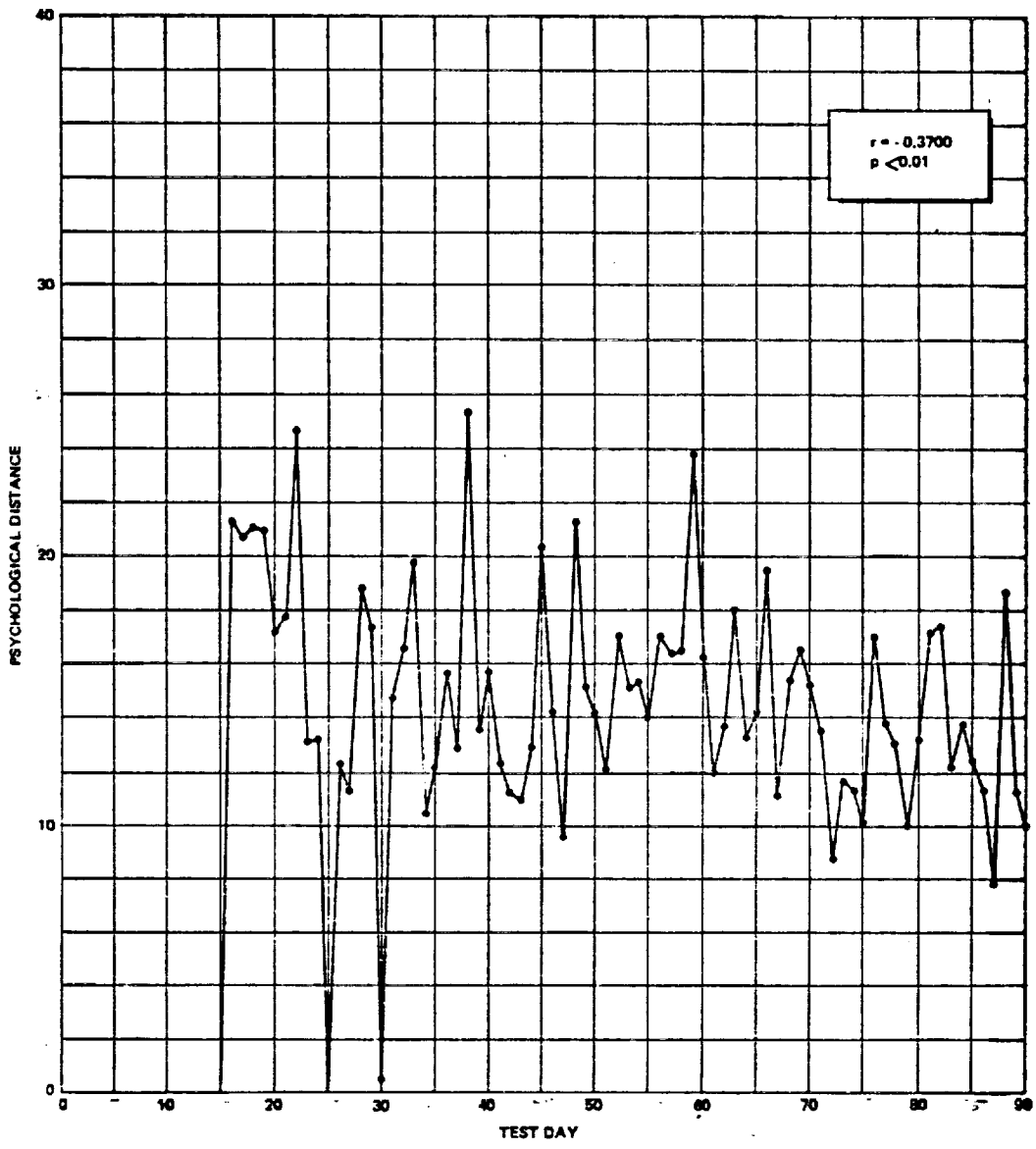


Figure 3-87. Psychological Dispersion from Others for Crewman 2

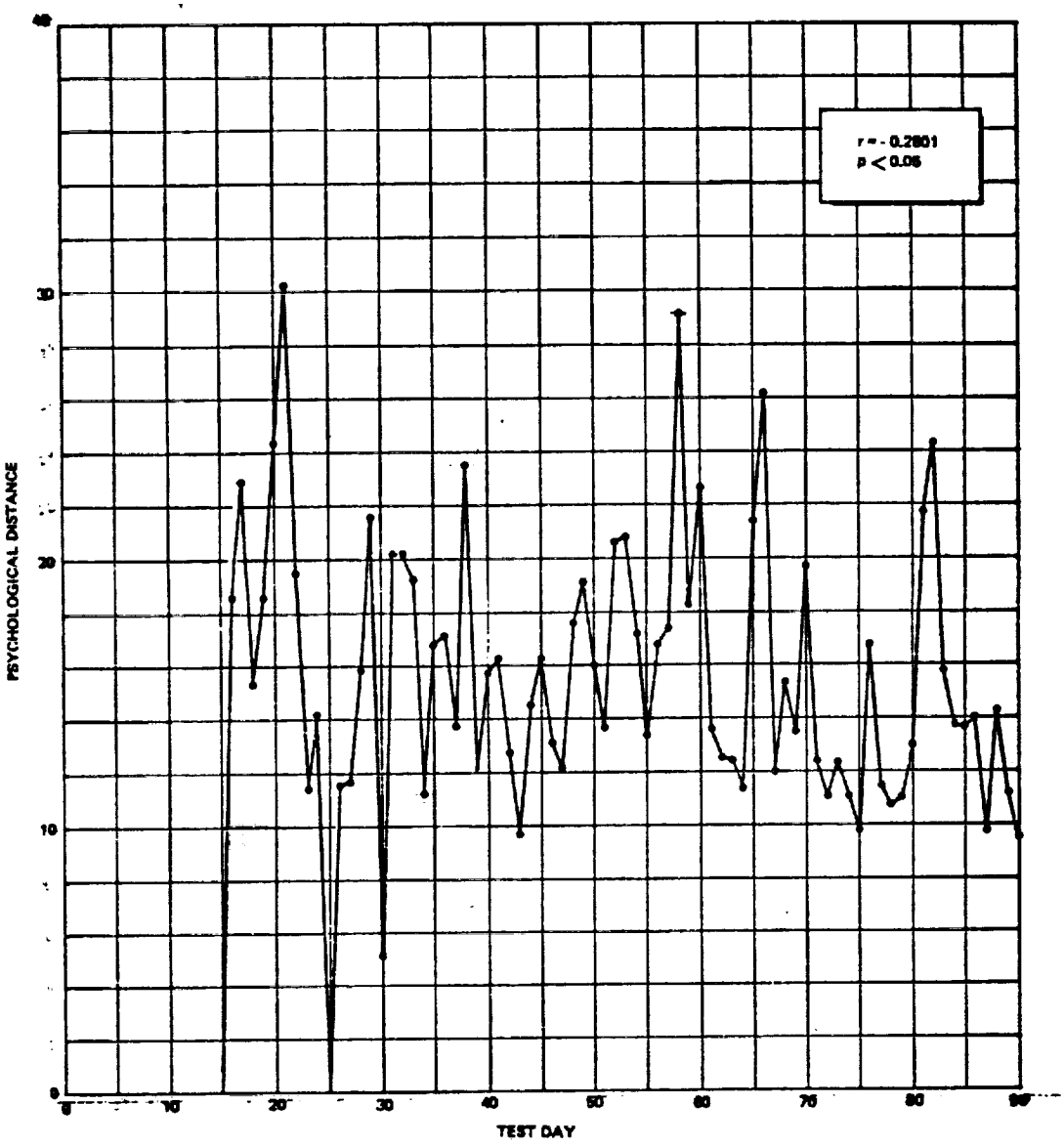


Figure 3-88. Psychological Dispersion from Others for Crewman 3

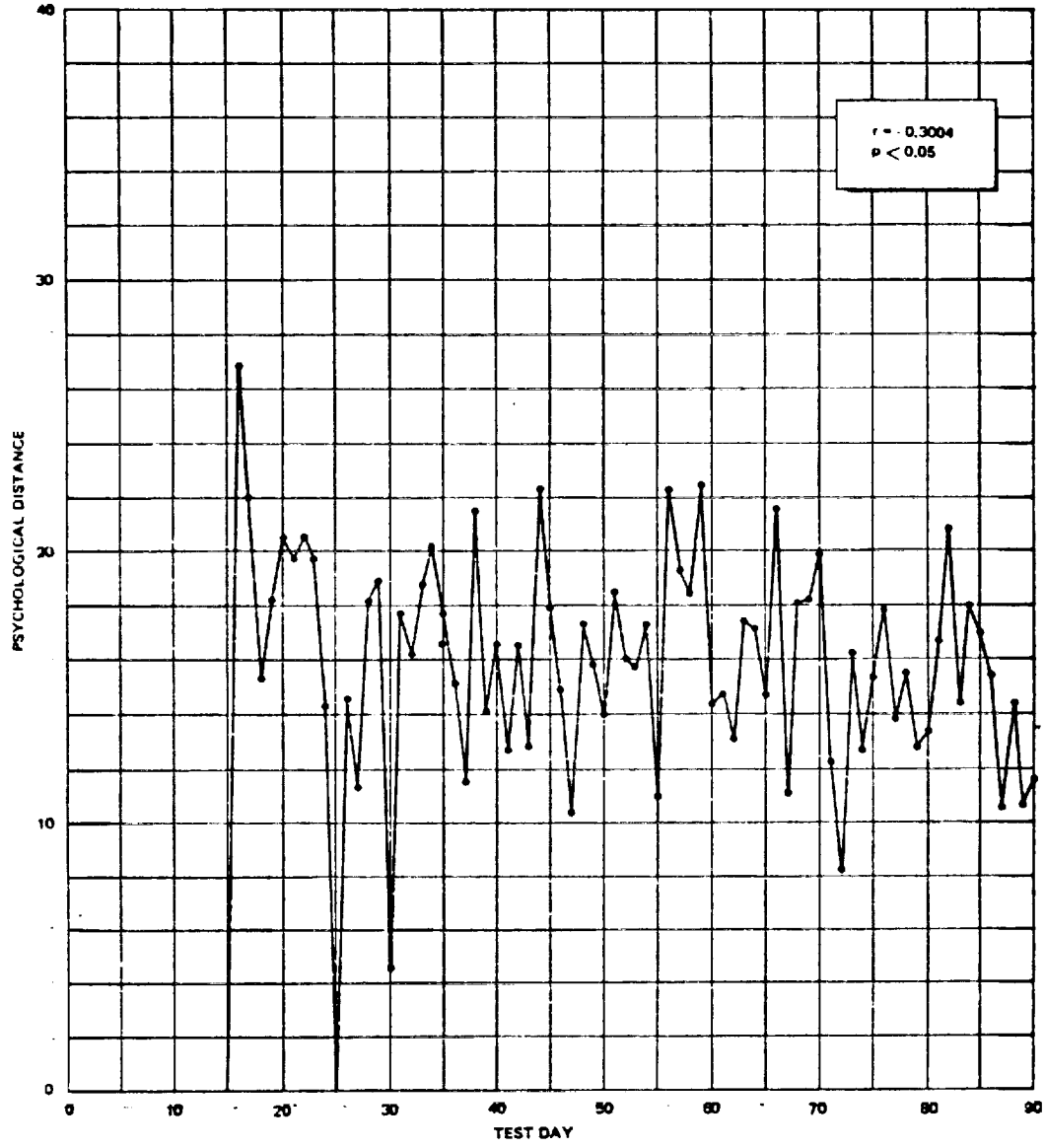


Figure 3-89. Psychological Dispersion from Others for Crewman 4

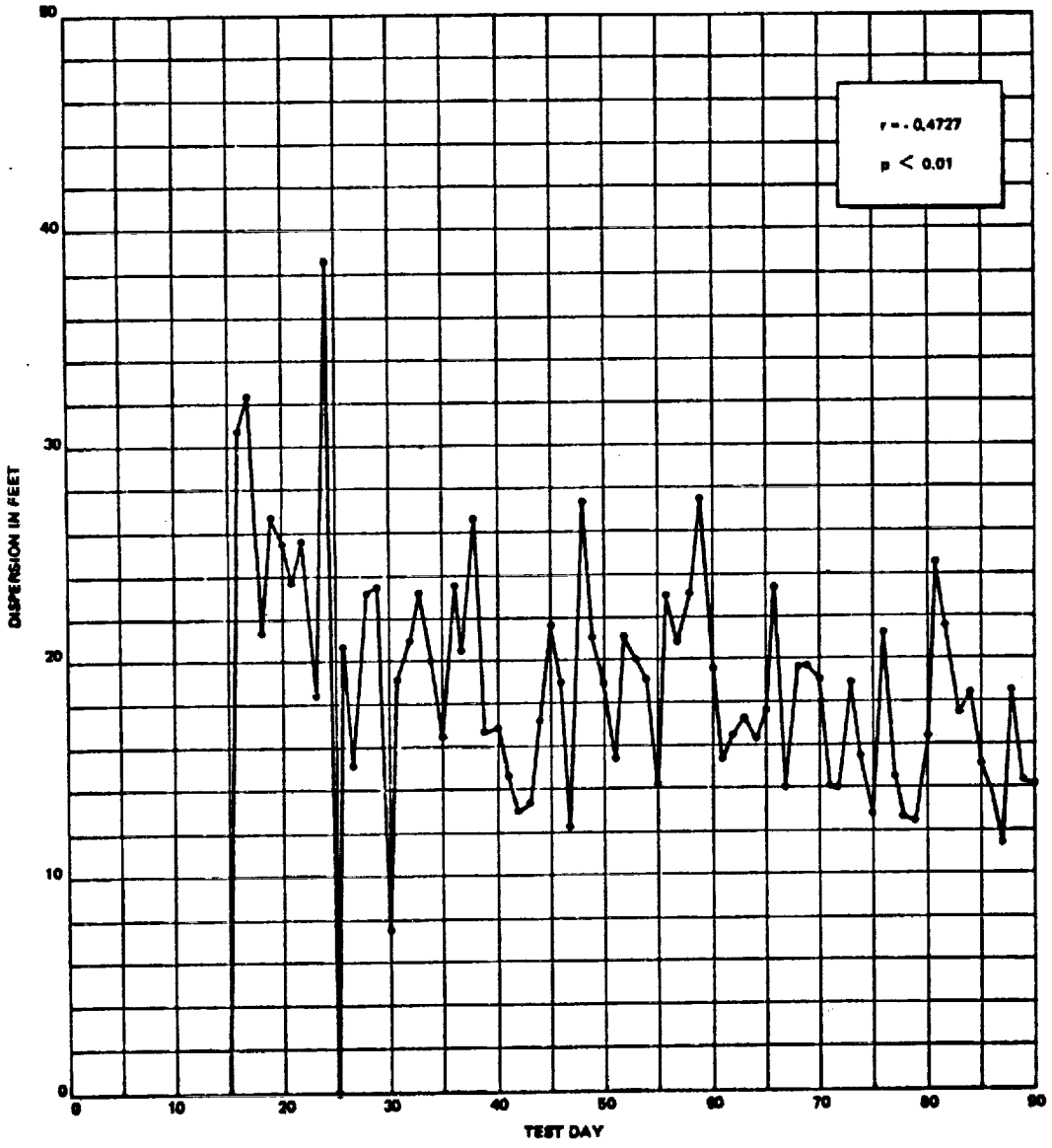


Figure 3-90. Physical Dispersion from Others for Crewman 1

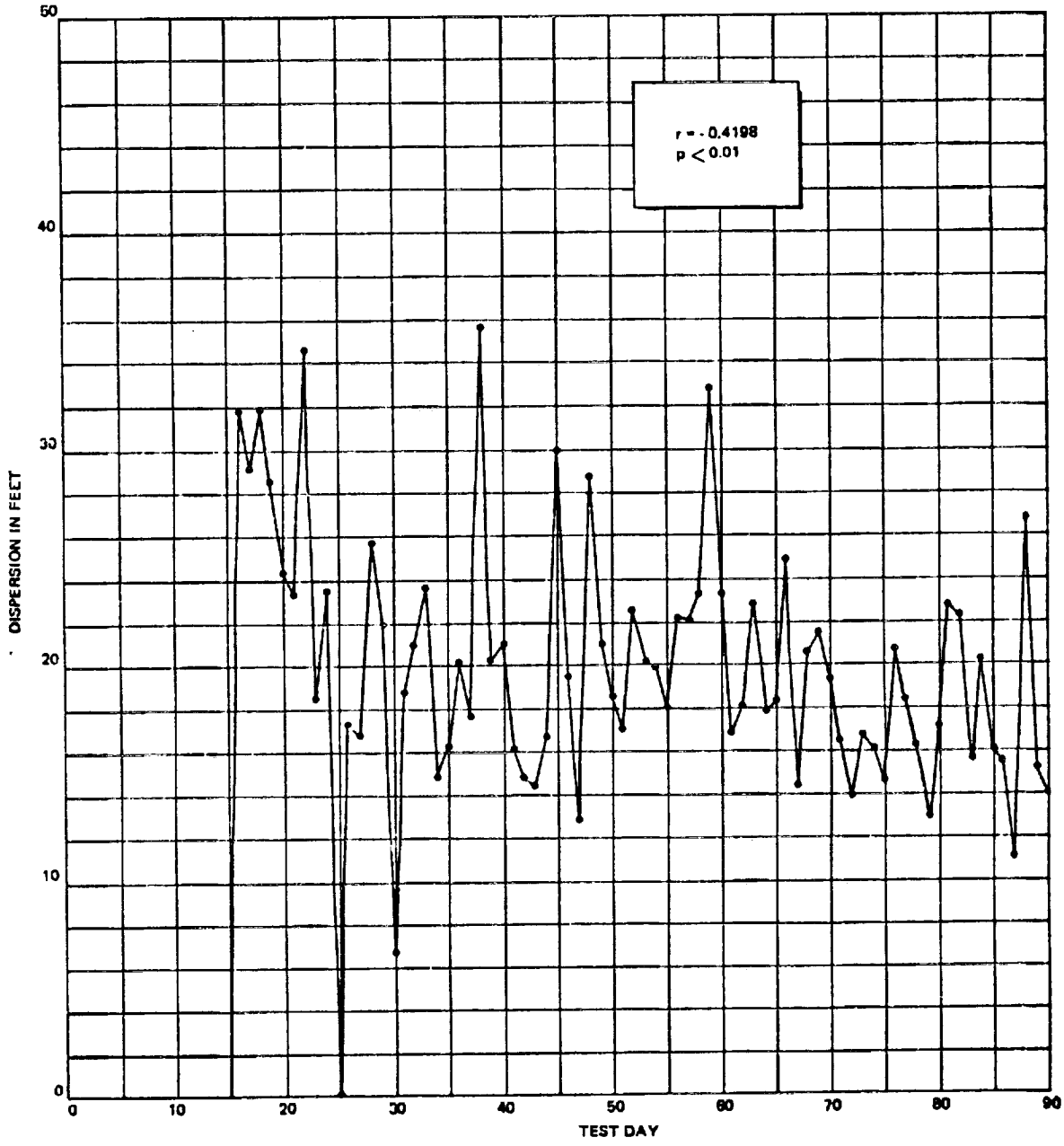


Figure 3-91. Physical Dispersion from Others for Crewman 2

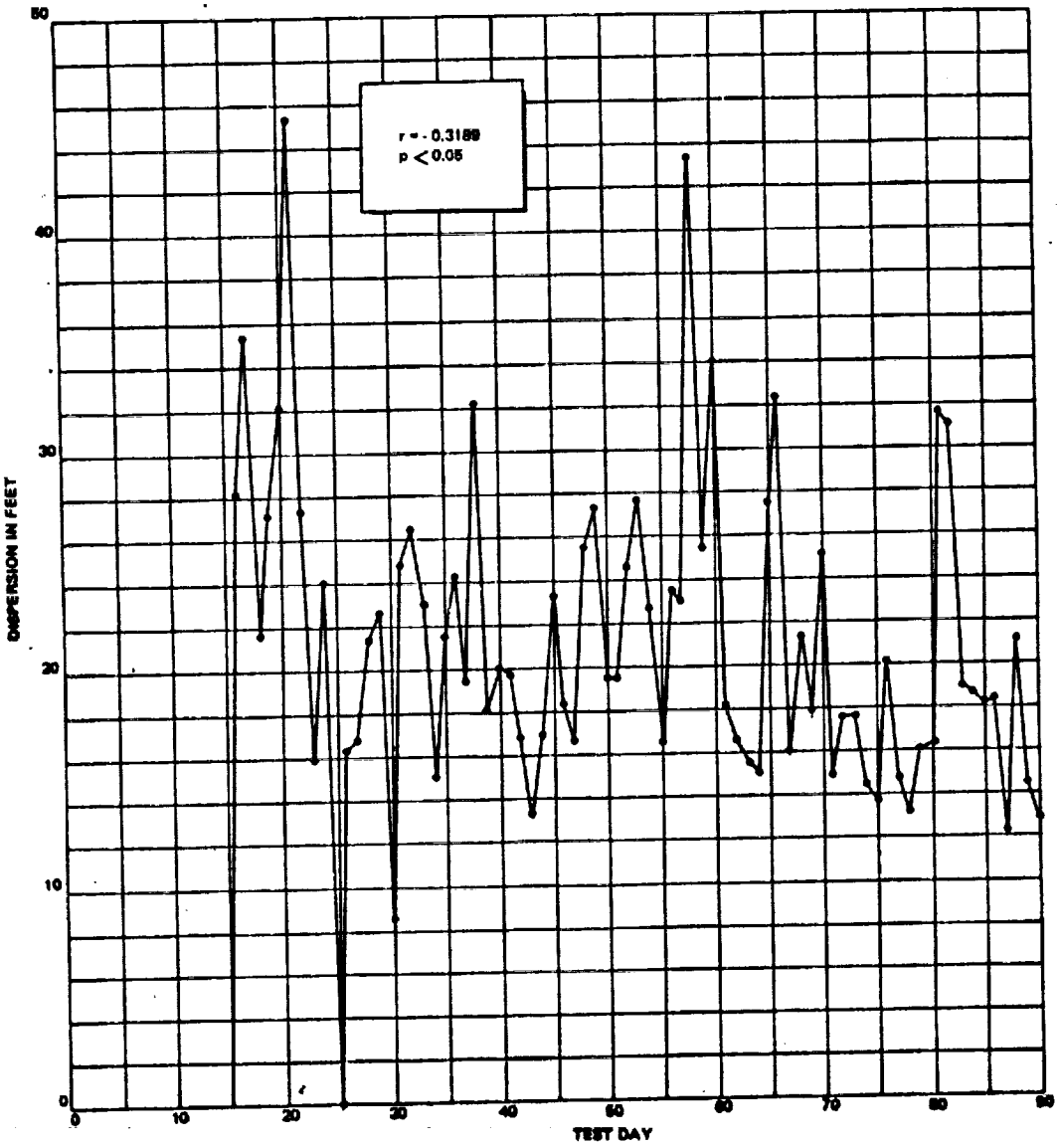


Figure 3-92. Physical Dispersion from Others for Crewman 3

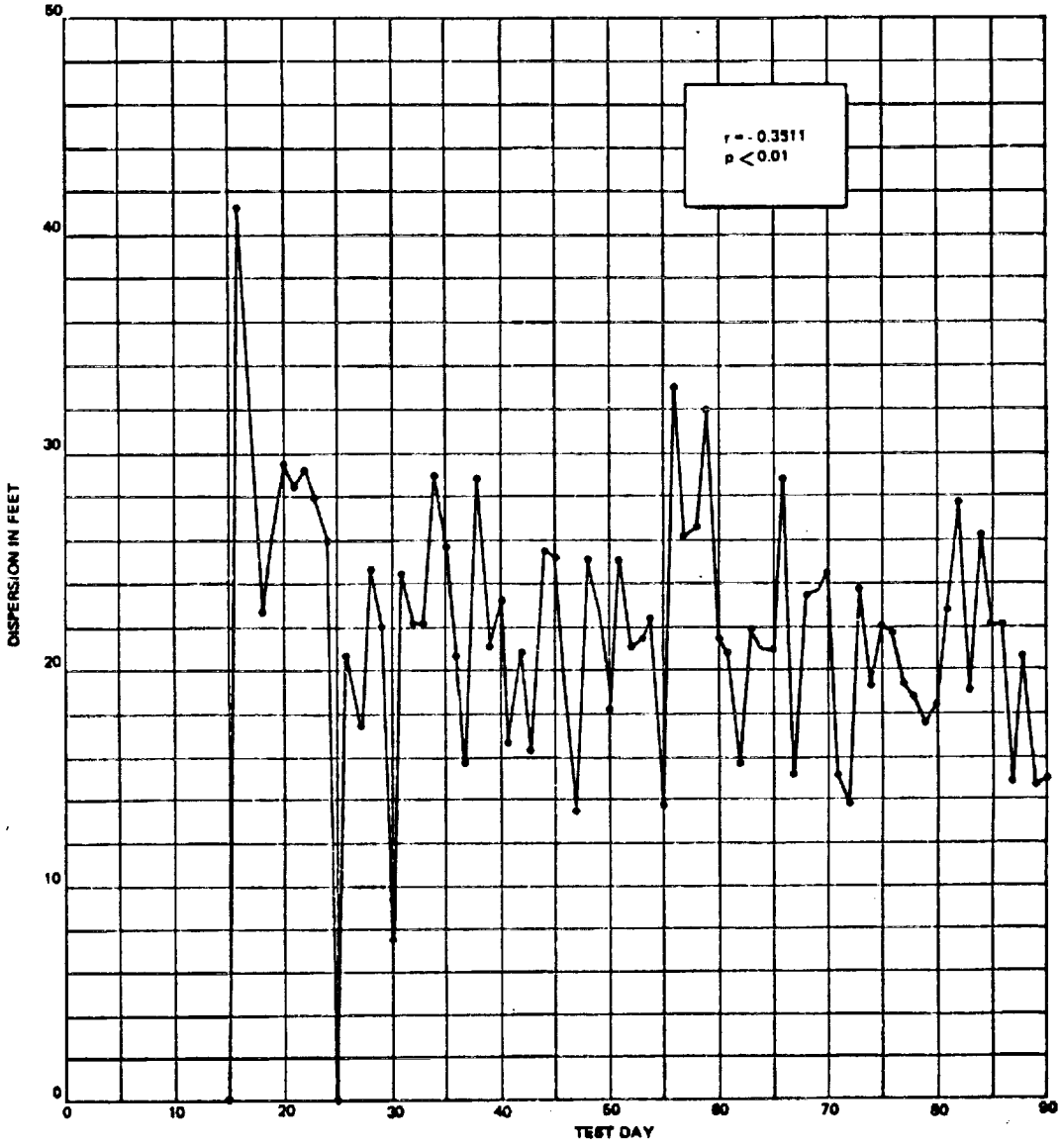


Figure 3-93. Physical Dispersion from Others for Crewman 4

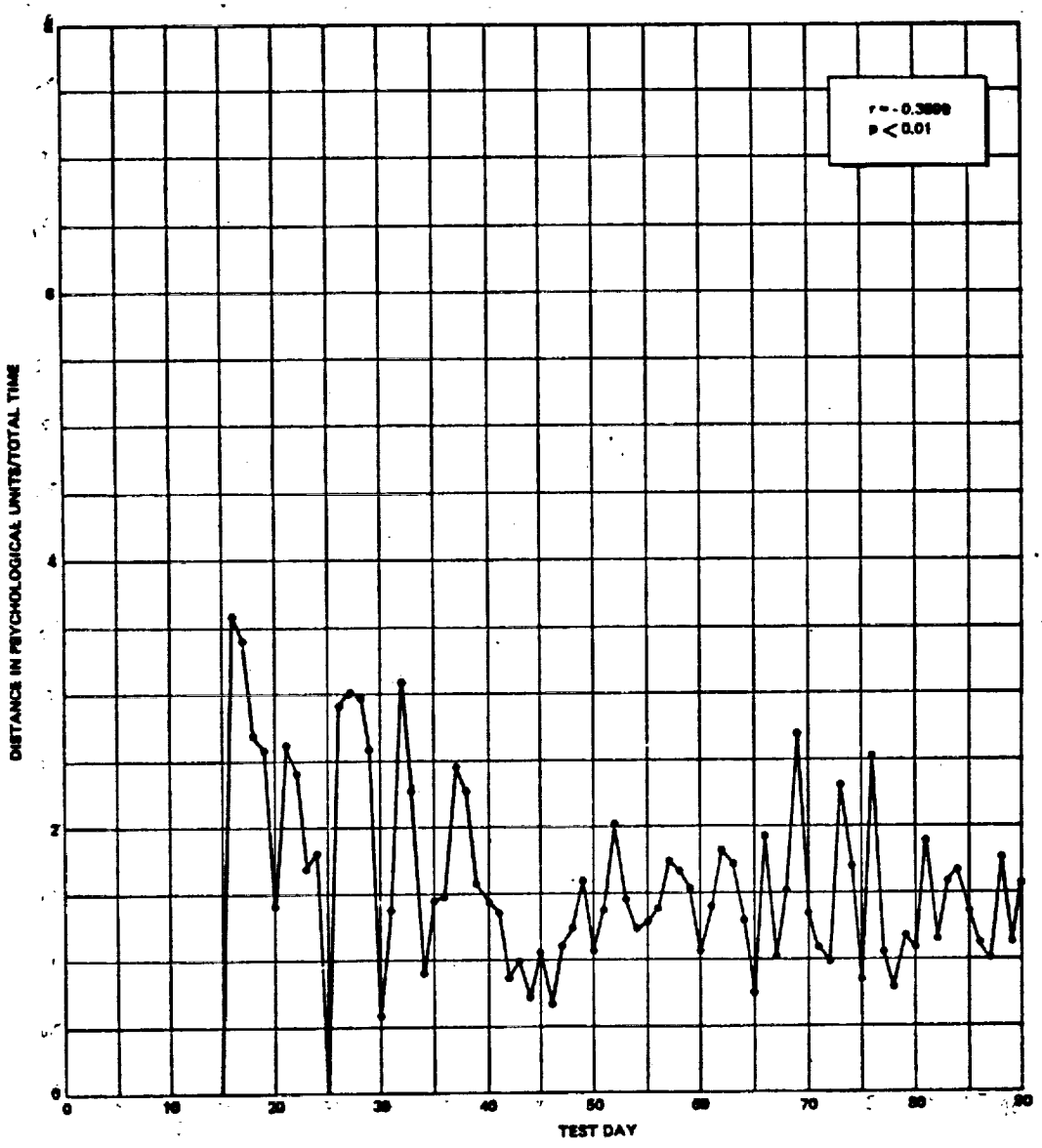


Figure 3-94. Psychological Distance per Unit Time for Crewman 1

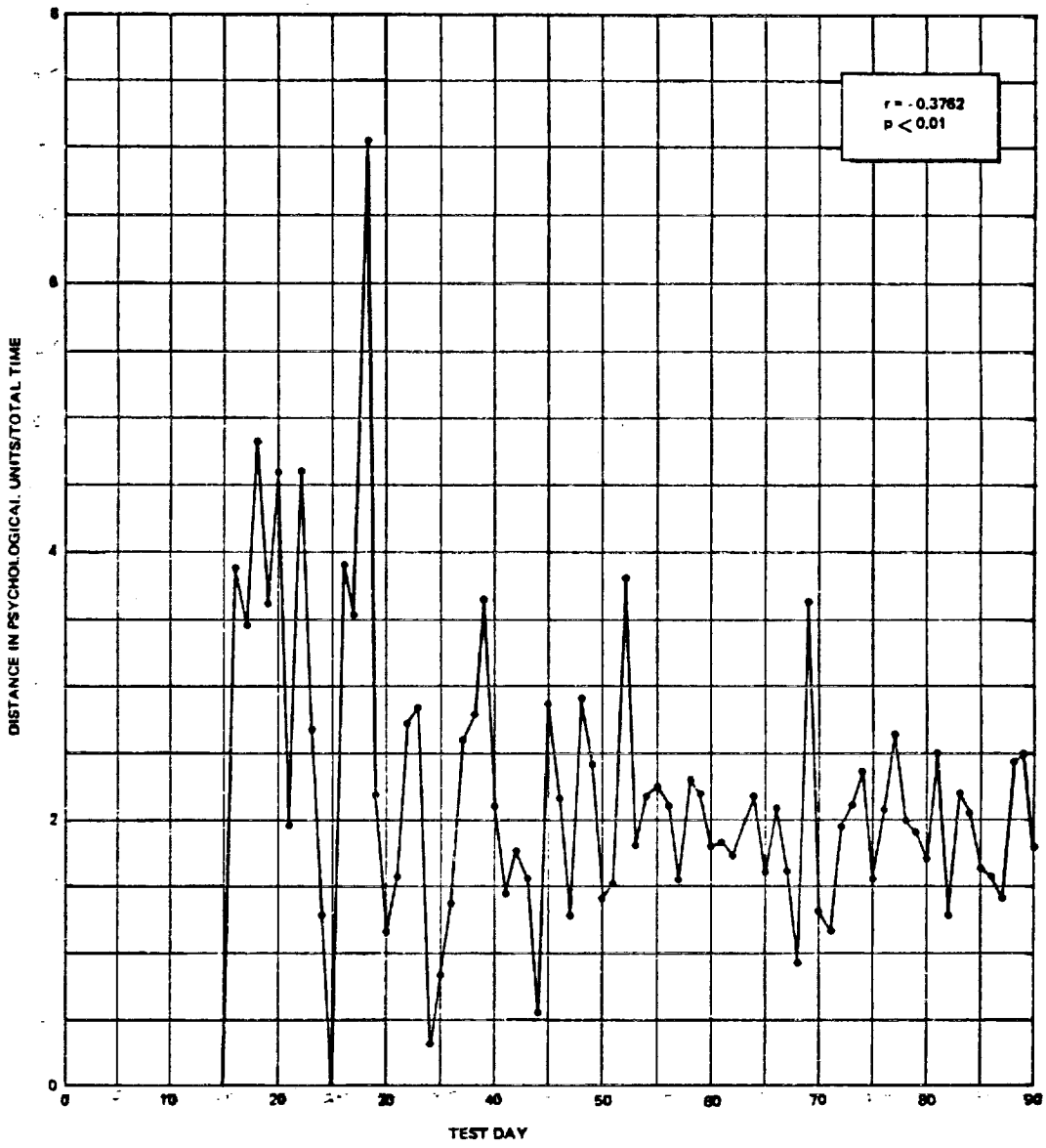


Figure 3-95. Psychological Distance per Unit Time for Crewman 2

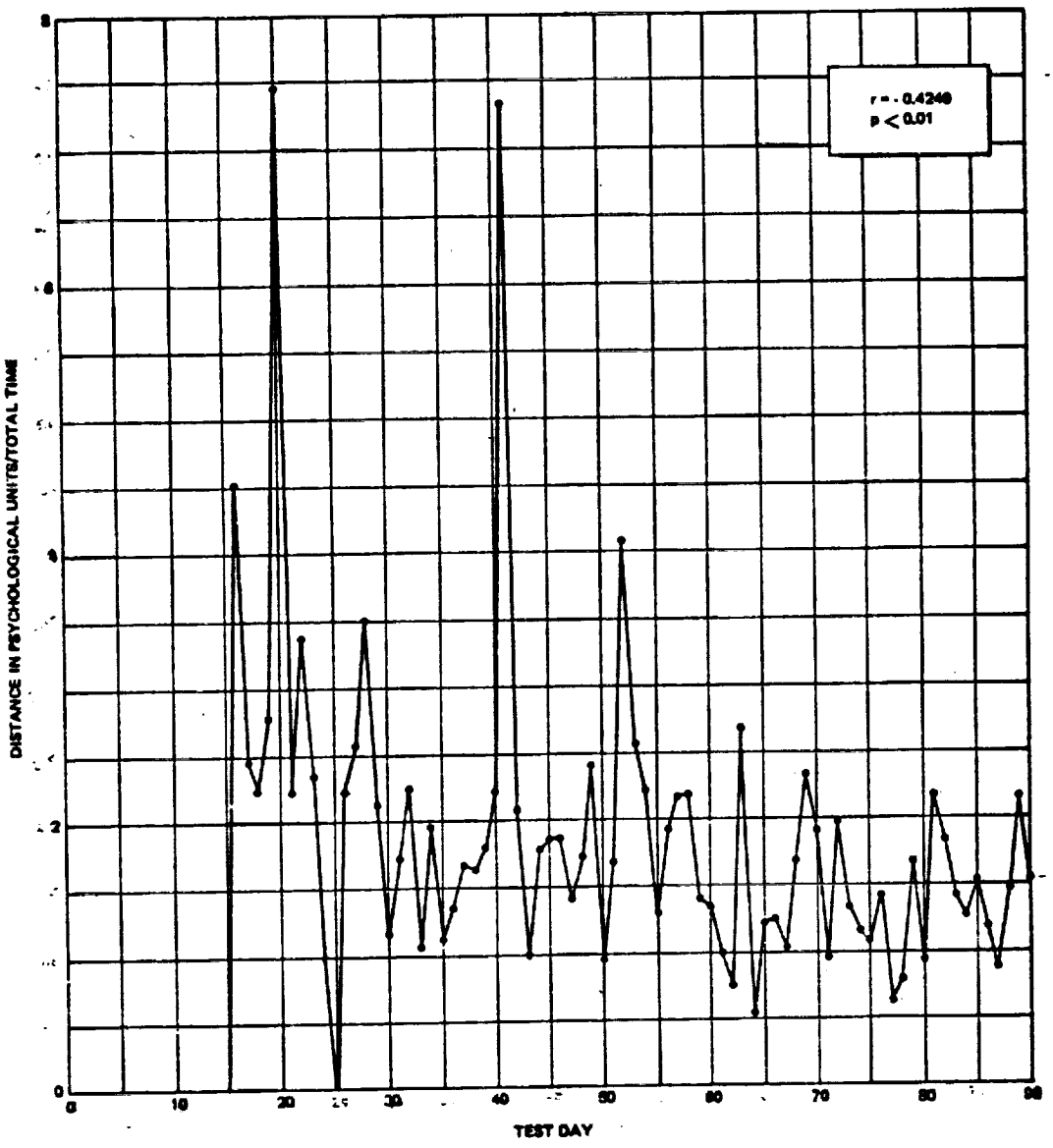


Figure 3-96. Psychological Distance per Unit Time for Crewman 3

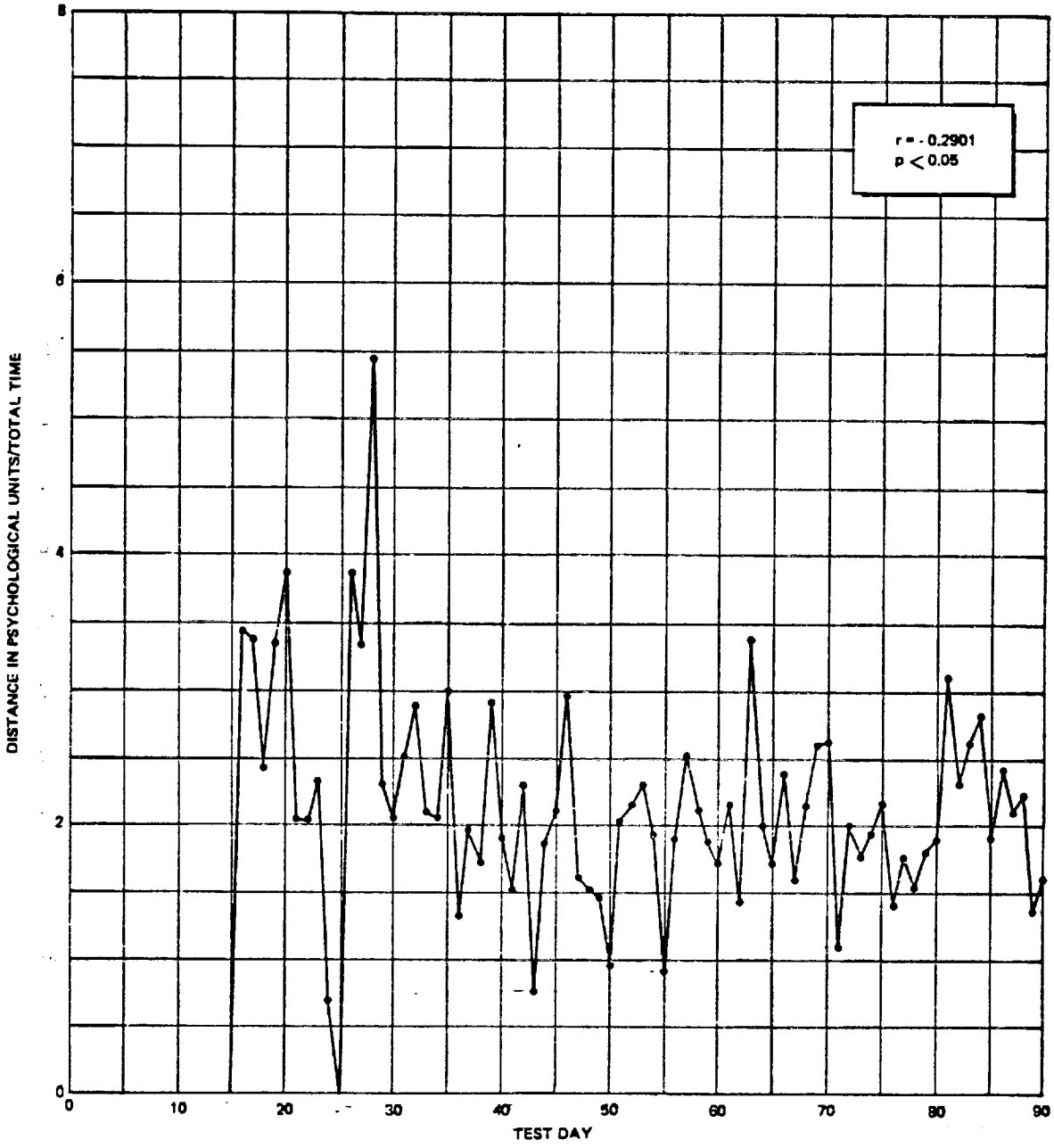


Figure 3-97. Psychological Distance per Unit Time for Crewman 4

visual and audio observation. Evaluation of how well these goals have been met must consider to what extent the NIPA measures correlate with each other and with other measures of human performance (paper and pencil tests) and to what extent these dependent variables (NIPA and other performance measures) correlate with independent variables, such as time in the chamber and task time. Finally, to assess the reliability, validity, and operational feasibility of the technique, consideration must be given to observer reliability criterion measures, and utilization under operational conditions. These considerations are covered in the discussion which follows.

3.9.3.1 Correlation of NIPA Measures

Table 3-38 presents correlations at or beyond the 0.01 level of significance obtained among various on-line NIPA measures. It may be seen that 14 correlations are significant for at least 3 of the 4 crewmen. These relationships are presented schematically in Figure 3-98. The heavy-lined rectangles represent verbal indices while the remaining rectangles represent distance indices. The implications of these correlations are discussed below. Table 3-39 presents definitions of selected NIPA indices.

Some of the correlations shown in Table 3-38 are artifacts of the way distance measures were collected. For example, there are three sets of indices which are differentiated by the variables psychological distance and physical distance: (1) PDSPN-DSPN, (2) PD/MVE-D/MVE, and (3) PD/TME-D/TME. The observed strong correlation between these pairs of measures results from the time sample involved; that is, the data were collected only during periods when four men were up. Therefore, the computer program included data for these indices only when a search during a particular 2-1/2-minute time segment showed that none of the crewmen were in the bunk area. It turns out that the most significant weighting for the variable psychological distance occurs when a man is in the bunk area relative to any other area in the chamber. Since observers were instructed not to collect data when one or more men was in the bunk area, the result was that the psychological distance value became very close to the physical distance value and a high correlation is to be expected. Strong correlations would be expected between these three pairs of indices. These limitations must be considered in interpreting the discussion which follows.

Inspection of Table 3-38 shows a strong correlation between privacy and psychological dispersion for all four crewmen. These results are not only statistically significant, but they satisfy the psychological prediction that a man who increases his privacy seeking will tend to be farther away from the other crewmen. The correlations do not appear to be an artifact of measurement. Privacy also correlates with Physical Dispersion which is an artifact as described above.

Psychological dispersion and physical dispersion correlate with each other for all four crewmen and with Indices 6 and 7 which are distance measures per unit of time (or distance traveled). These correlations occurred as a function of measurement as described above. Dispersion also correlates

Table 3-38

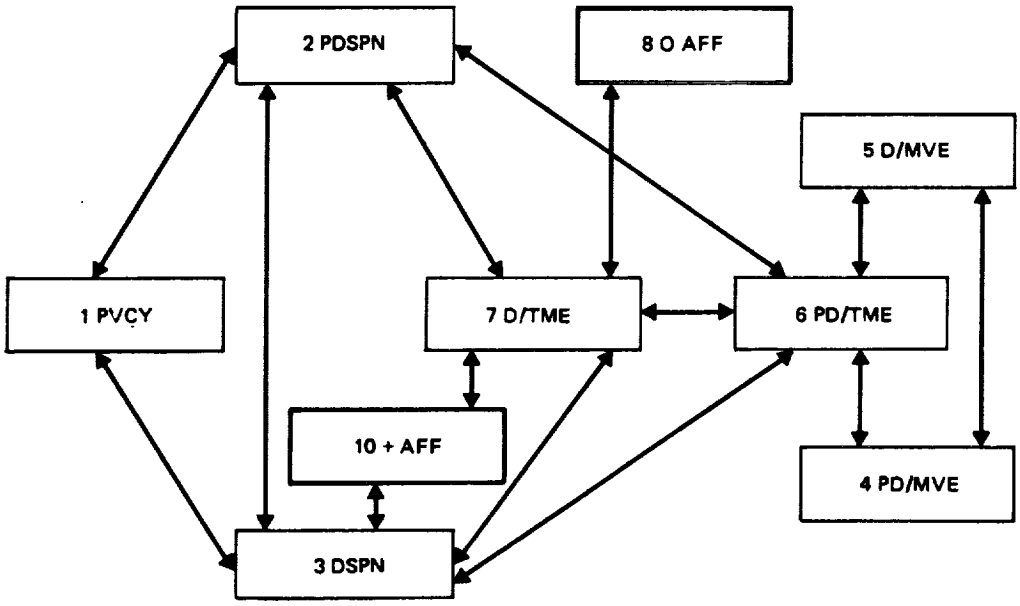
OBSERVED CORRELATIONS AMONG ON-LINE NIPA MEASURES SIGNIFICANT AT THE ONE PERCENT LEVEL

C* M		1	2	3	4	5	6	7	8	9	10	12
1 2 3 4	1 PVCY											
1 2 3 4	2 PDSPN	0.7218 0.6858 0.7347 0.5968										
1 2 3 4	3 DSPN	0.6843 0.6132 0.6519 0.5103	0.9616 0.9652 0.9587 0.9422									
1 2 3 4	4 PD/MVE	0.3326 -- -- --	0.4588 -- -- 0.4655	0.4838 -- -- 0.3893								
1 2 3 4	5 D/MVE	-- -- -- --	0.4680 -- -- 0.3776	0.5237 -- -- 0.3744	0.8455 0.8701 0.4191 0.9052							
1 2 3 4	6 PD/TME	0.5563 0.4960 -- --	0.6218 0.5773 0.3491 0.3952	0.6052 0.6204 0.3273 0.4123	0.6491 -- 0.5989 0.4511	0.6655 -- 0.3330 0.3981						
1 2 3 4	7 D/TME	0.5337 0.4855 -- --	0.5999 0.5888 0.4162 0.3276	0.5960 0.6394 0.4551 0.3923	0.5477 -- -- 0.3280	0.6908 -- -- 0.3869	0.9703 0.9867 0.7846 0.9601					
1 2 3 4	8 O AFF	-- -- -- --	-- -- -- --	-- -- -- --	-- -- 0.3883 --	-- -- -- --	-- -0.3531 -0.4135	-- -0.3692 -0.4588 -0.4585				
1 2 3 4	9 RC-INT	-- -- -- --	-- -- -- --	-- -- -- --	-- -- -- --	-- -- -- --	-- -- -- --	-- -- -- --	0.3325 -- -- 0.4227			
1 2 3 4	10 + AFF	-0.3669 -- -- --	-0.4095 -- -- -0.3285	-0.4408 -- -0.3121 -0.3849	-- -0.3106 -- --	-0.3534 -- -0.3415 --	-0.3747 -- -- -0.3823	-0.4062 -- -0.4059 -0.4017	-- -- -- --	-- -- -- --		
1 2 3 4	12 TASK PRESS	-- -- -- 0.3642	-- -- -- --	-- -- -- --	-- -0.4742 -- --	-0.3661 -0.4538 -- --	-- -- -- --	-- -- -- --	-- -- -- --	-- -- -- --	-- -- -- --	

NOTE 1: Index 11-AFF is the arithmetical complement of index 10 and automatically gives identical values in the opposite direction, so is not shown

NOTE 2: Significance of the correlations is based on the following N of data points: CM 1-67, CM 2-70, CM 3-68, CM 4-72

*CM = Crewman. All other abbreviations in this and the following tables are defined under glossary of indices, Appendix H



NOTE: SEE TABLE 3-39 FOR DEFINITION OF THE NIPA INDICES PORTRAYED ABOVE

Figure 3-98. Statistical Correlation of NIPA Measures

with Index 10, positive affect, for 3 out of the four crewmen. The correlations are in the predicted direction, i. e., we would hypothesize that as positive affect increases dispersion decreases. (The one correlation for crewman 2 that does not meet the level of confidence for reporting is - 0.2180; in the correct direction.) Thus, a correlation was found between these two measures; one a verbal measure, the other a distance measure.

Index 4, psychological distance per move, and 5, physical distance per move, correlate highly with each other and with index 6, psychological distance per unit time, for all four crewmen. Again the measurement method accounts for this relationship.

Index 6, psychological distance per unit time, correlates strongly for all four crewmen with index 7, physical distance per unit time. Again this appears to be a function of measurement. Index 7 also significantly correlates negatively with two verbal measures, Index 8, the non-affect ratio, and Index 10, the positive affect ratio, for three out of the four crewmen.

Index, the receive-initiate ratio, does not significantly correlate with any other NIPA measure. The same can be said for Index 12, task press.

Table 3-39

DEFINITIONS OF SELECTED NIPA INDICES

1. Privacy Seeking (PVCY): A ratio composed of the number of times a crewman is alone in a numbered chamber area divided by the number of observations made on the crewman.

2. Psychological Dispersion (PDSPN): A ratio composed of the sum distances of an individual crewman, in psychological units*, from the other three crewmen divided by the number of observations.

3. Physical Dispersion (DSPN): A ratio composed of the sum distances of individual crewmen, in actual feet, from the other three crewmen divided by the number of observations.

4. Psychological Distance/Move (PD/MVE): A mean distance that an individual crewman moved, in psychological units*, for every move the crewman made.

5. Physical Distance/Move (D/MVE): The mean distance moved by an individual crewman, in actual feet, for each move made by the crewman.

6. Psychological Distance/Time Period (PD/TME): The mean distance moved by an individual crewman, in psychological units*, per time period.

7. Physical Distance/Time Period (D/TME): The mean distance moved by an individual crewman, in actual feet, per time period.

8. Non-Affect Ratio (0 AFF): The ratio of the neutral affect – asking information, plus the neutral affect – giving information, divided by positive affect plus negative affect plus neutral affect--asking information plus neutral affect giving information.

10. Positive Affect Ratio (+ AFF): A ratio composed of the frequency of positive affect divided by the sum of the frequency of negative affect plus the frequency of positive affect. This ratio is the inverse of the negative affect ratio.

*Psychological units are defined by a matrix providing numerical weights to the distances between any of nine prescribed areas in the chamber.

In summary, Table 3-38 shows that among NIPA measures we find a significant correlation in the appropriate direction between verbal and distance measures for the following indices:

Index 3, physical dispersion and Index 10, positive affect ratio

Index 7, physical distance per unit time and Index 10, positive affect ratio

Index 7, physical distance per unit time and Index 8, non-affect ratio

The implications of these results are extremely important for the internal consistency of the NIPA method. If, indeed, a true correlation exists between verbal measures and distance measures then there is future promise for obtaining the type of data ordinarily acquired through verbal content by measuring distances. However, the data reported in Table 3-37 are simple linear correlations of pairs of indices which will show significant correlations if each of the indices also correlates with a third independent variable, such as time in the chamber. As shown in a later discussion, significant correlations are shown between run day and

A. Index 10, positive affect ratio, for all four crewmen

B. Index 3, physical dispersion, for all four crewmen

C. Index 7, physical distance per unit time, for all four crewmen.

However, non-affect ratio does not correlate with run day.

The question arises as to whether the three pairs of significant correlations found in Table 3-38 between the verbal and distance measures are simply because each is associated with run day or whether they are correlated independently of run day. To answer this question, a stepwise multiple regression analysis was performed with positive affect ratio as the dependent variable. From this, confidence levels and partial correlations were obtained for the indices in question and are reported in Table 3-40. This table shows that Index 3 and Index 7 are significantly correlated with Index 10 for crewman 1 and approach significance in the proper direction for crewman 4. Crewman 3 shows correlations in the correct direction, but not at statistically significant levels. Only the data for crewman 2 are not in any way correlated. Thus, it seems reasonable to conclude that there are, in fact, true correlations shown in Table 3-38 between positive affect, on the one hand, and physical dispersion and physical distance per unit time, on the other.

Because no significant correlation has been shown between non-affect ratio and run day, it is reasonable to conclude that the correlation shown in Table 3-38 between Index 8 and Index 7 is a true one.

3.9.3.2 Correlations Between Paper-and-Pencil Tests and NIPA Measures

Table 3-41 shows the actual correlations obtained between the NIPA measures and the paper-and-pencil tests results. In the case of the habitability inventory, correlations were performed using group data only. Significant correlations shown in Table 3-41 appear to reflect a relationship between activity levels

Table 3-40

PARTIAL CORRELATIONS OF SELECTED INDICES WITH POSITIVE AFFECT TO SHOW THEIR INDEPENDENCE OF RUN DAY

Crewman	Physical Dispersion (Index 3)		Physical Distance Per Unit Time (Index 7)	
	Confidence	Partial Correlation	Confidence	Partial Correlation
1	0.97832852	-0.2799668	0.97195520	-0.2679813
2	0.20899983	-0.0305288	0.34022612	0.0545926
3	0.82312265	-0.1656673	0.88144710	-0.1904502
4	0.9402460	-0.2219177	0.9756474	-0.2647465

dictated by task requirements and NIPA measures. These are considered to be spurious insofar as they represent a relationship which bears no resemblance to an index of reaction to the acceptability of various habitat features.

Table 3-41 shows no clearcut trend and, in some cases, shows relationships with very poor face validity. Except for the habitability questionnaire which provides only grouped crew data, there is not a single paper-and-pencil measure that correlates with a NIPA measure for more than two crewmen. In fact, there are only five instances when a significant correlation repeats for the same pair of measures. In addition to this absence of correlations the following relationships of questionable face validity are shown:

A. For crewman 1, as hostility toward the equipment compartment increases, positive affect increases.

B. For crewmen 1 and 3, as hostility toward the crew compartment increases, positive affect increases.

The correlations shown between habitability-equipment quarters and the few NIPA movement measures require more refined data before an adequate interpretation can be made.

One explanation of the lack of correlation between psychological questionnaires and NIPA measures is that an insufficient number of data points were available from the paper-and-pencil data to perform meaningful statistical

Table 3-41

CORRELATIONS BETWEEN PAPER-AND-PENCIL TESTS AND NIPA MEASURES

Paper-and-Pencil Test	Correlations with NIPA Measures			
	Crewman 1	Crewman 2	Crewman 3	Crewman 4
Hostility O CRW	No significant correlations	No significant correlations	No significant correlations	No significant correlations
Hostility I CRW	No significant correlations	PD/MVE 0.8220 p<0.01 D/MVE 0.8509 p<0.01 + AFF -0.9705 p<0.01 PCM1 0.8305 p<0.01 PCM2 0.8549 p<0.01	D/MVE 0.7908 p<0.01 PD/TME 0.8730 p<0.01 D/TME 0.9098 p<0.01 + AFF -0.8254 p<0.01 TASK TI 0.8205 p<0.01	No significant correlations
Hostility EQ CP	+ AFF 0.8136 p<0.01	No significant correlations	PDSPN -0.8516 p<0.01 D/MVE -0.8130 p<0.01 PD/TME -0.9190 p<0.01 D/TME -0.8482 p<0.01 UTASK -0.8988 p<0.01	OS CALL -0.7951 p<0.01
Hostility CRW CP	PDSPN -0.7827 p<0.01 DSPN -0.9006 p 0.01 D/MVE -0.8984 p<0.01 + AFF 0.8946 p<0.01 PCM2 -0.8159 p<0.01 PCM3 -0.7904 p<0.01 UTASK -0.8662 p<0.01	No significant correlations	DSPN -0.7880 p<0.01 D/MVE -0.8060 p<0.01 D/TME -0.7878 p<0.01 + AFF 0.8412 p<0.01 TASK TI -0.8092 p<0.01 HS OCRW 0.8124 p<0.01 HS ICRW -0.8054 p<0.01	No significant correlations
Primary Affect - Happy	No significant correlations	No significant correlations	PCM3 -0.8653 p<0.01 TM2ZZZ 0.9440 p<0.01	No significant correlations
Primary Affect - Angry	No significant correlations	No significant correlations	No significant correlations	No significant correlations
Primary Affect - Fear	No significant correlations	PA HAPPY 0.8082 p<0.01	No significant correlations	No significant correlations
Primary Affect - Depression	DIARY 0.7746 p<0.01	PVCY -0.7668 p<0.01 PD/MVE 0.9116 p<0.01 D/MVE 0.9390 p<0.01 TEMP -0.8000 p<0.01 TASK PR -0.9388 p<0.01	0 AFF -0.8107 p<0.01 + AFF -0.7742 p<0.01 PCM2 -0.7821 p<0.01	PA HAPPY -0.8161

* NOTE: A glossary of terms used for NIPA indices is given in Appendix H.

Table 3-41 (Continued)

Paper-and-Pencil Test	Correlations with NIPE Measures			
	Crewman 1	Crewman 2	Crewman 3	Crewman 4
Sociometry A - Leader Choice	No significant correlations	No significant correlations	No significant correlations	No significant correlations
Sociometry B - Member Choice	No significant correlations	No significant correlations	D/TME 0.9980 p<0.01	No significant correlations
Isolation Symptomatology Ques +	No correlation--constant scores	No significant correlations	OS CALL 1.000 Z FEEL 1.000	No significant correlations
Isolation Symptomatology Ques -	No significant correlations	No significant correlations	No significant correlations	No significant correlations
Group Confinement Inventory +	No significant correlations	No significant correlations	PD/TME 1.000 XTEMP 1.000 UTASK 0.9999 IMPOS 1.000 OS CALL -1.000	No correlations--constant scores
Group Confinement Inventory -	No significant Correlations	No significant correlations	O AFF -1.000	XTEMP -1.000
Subjective Stress Scale	No significant correlations	No correlations--scores constant	RETIRE 0.9258 p<0.01 DUR -0.8822 p<0.01 TM2ZZZ 0.9582 p<0.01	PCM3 -0.8026 p<0.01 RETIRE 0.7631 p<0.01
Descriptive Sentence Test	No significant correlations	No significant correlations	No significant correlations	PD/MVE -0.9698 p<0.01

*NOTE: A glossary of terms used for NIPA indices is given in Appendix H.

Table 3-41 (Continued)

Paper-and-Pencil Test	Correlations with NIPA Measures (Only crew data available for Habitability)
Habitability Crew Quarters	No significant correlations
Habitability Equipment Quarters	PDSPN 0.9334 $p<0.01$ DSPN 0.9245 $p<0.01$ DSA 2-3 0.9453 $p<0.01$
Habitability Hygiene	No significant correlations
Habitability Miscellaneous	PD/MVE -0.9861 $p<0.01$ D/MVE -0.9862 $p<0.01$
Habitability Average	No significant correlations

*NOTE: A glossary of terms used for NIPA indices is given in Appendix H.

correlations. The following shows the number of data points actually used in performing the correlations:

Hostility scale	10
Primary affect scale	10
Sociometric questionnaire	4
Group confinement inventory	3
Subjective stress scale	11
Descriptive sentence test	5

Correlations were performed with NIPA data only for the days on which the above questionnaires were administered. It is perhaps more meaningful to compare graphic presentations of test device and NIPA trends to discern consonance or dissonance. Trend plots for the questionnaires are given in Section 3.4.2.

3.9.3.3 Correlation of Independent and Dependent Variables

In order to make a comparison between the abilities of the intrusive and NIPA measures to acquire meaningful data, computations were made treating both measures as dependent variables in relation to four selected independent variables: Time in Chamber, Time on Tasks, Unscheduled Task Time, and Outside Requests. Only those data obtained by intrusive measures during the period of NIPA observations have been included in order to make the comparisons valid. This generally includes approximately the last 75 days of the test. Thus, early changes reflected in paper-and-pencil and other intrusive measures are not evaluated here.

A large number of statistical correlations were computed to identify the relationship between the four independent variables mentioned above and the dependent measures. Table 3-42 shows that seven NIPA indices correlate significantly with the independent variable, time in chamber. Five NIPA indices also are shown to be significantly correlated with Time On Tasks and Unscheduled Task Time. A question arises as to whether the correlations with the latter two independent variables represent an artifact of time in the chamber.

The independent variable, Increased Time in Chamber (run day), correlates significantly with Positive Affect for all four crewmen. Run day also correlates inversely with both psychological dispersion and physical dispersion. Thus, an overall increase of dispersion is consistent with the underlying rationale which assumes that with increased positive affect the crew members would tend to be closer together physically. However, it was originally predicted that positive affect would decrease over time. This assumption was made on the basis of empirical evidence, since prior studies of groups in confinement have shown a degradation of morale over time. The 90-day crew may have been qualitatively different, in terms of social/psychological variables, than other crews that have been studied. However, examination of the detail data shown on Figures 3-78 through 3-85 shows an initial period of zero values, rather high values during the middle 30-day segment, and generally intermediate values for the last 30 days. The overall correlation with run day

Table 3-42

CORRELATION OF NIPA MEASURES WITH SELECTED INDEPENDENT VARIABLES

Hypothesis	Crewman ($p <$ number shown) 1	2	3	4
As time in SSS increases:				
Positive affect ratio will increase	0.01	0.01	0.01	0.01
Negative affect ratio will decrease	0.01	0.01	0.01	0.01
Privacy seeking will decrease	0.05	NS	NS	NS
Psychological dispersion will decrease	0.01	0.01	0.05	0.05
Physical dispersion will decrease	0.01	0.01	0.05	0.01
Psychological distance/unit time will decrease	0.01	0.01	0.01	0.05
Physical distance/unit time will decrease	0.01	0.01	0.01	NS
Psychological distance/move will decrease	0.01	0.01	NS	NS
Physical distance/move will decrease	0.01	0.01	NS	0.05
Receive/initiate ratio will decrease	NS	NS	NS	NS
Task press will decrease	NS	NS	NS	NS
Task time will decrease	0.01	0.01	NS	0.05
Outside calls will increase	NS	NS	NS	NS
Non-affect ratio will increase	NS	0.05	NS	NS
As time on tasks increases:				
Privacy seeking will increase	0.01	0.01	NS	NS
Psychological dispersion will increase	0.01	0.01	0.01	NS
Physical dispersion will increase	0.01	0.01	0.01	NS
Psychological distance/move will decrease	NS	NS	NS	NS
Physical distance/move will increase	0.01	NS	NS	NS
Psychological distance/unit time will increase	0.01	0.01	NS	0.01
Physical distance/unit time will increase	0.01	0.01	0.01	0.01
Non-affect ratio will decrease	0.01	0.01	NS	0.01
Receive/initiate ratio will decrease	NS	0.01	NS	0.01
Positive affect ratio will decrease	0.01	NS	NS	0.01
Task press will decrease	0.01	NS	0.01	NS

Table 3-42 (Continued)

Hypothesis	Crewman ($p <$ number shown) 1	2	3	4
As unscheduled task time increases:				
Privacy seeking will decrease	NS	NS	NS	NS
Psychological dispersion will increase	0.01	0.01	0.01	NS
Physical dispersion will increase	0.01	0.01	0.01	NS
Psychological distance/move will increase	0.01	NS	NS	NS
Physical distance/move will increase	0.01	NS	NS	NS
Psychological distance/unit time will increase	0.01	0.01	NS	0.01
Physical distance/unit time will increase	0.01	0.01	0.01	0.01
Non-affect ratio will decrease	0.01	0.01	NS	0.01
Receive/initiate ratio will decrease	NS	NS	NS	NS
Positive affect ratio will decrease	NS	NS	NS	0.01
Task press will decrease	0.01	NS	NS	NS
As impositions increase:				
Positive affect ratio will increase	NS	0.01	NS	0.01

NOTE: NS means not significant.

appears to be biased by the initial low values and does not indicate the significance of the drop in positive affect which occurred following day 60, which will be discussed in more detail below. Run day is also shown to correlate significantly with psychological distance per unit time and physical distance per unit time. The explanation for these results is identical to that just described for dispersion.

The remaining significant correlation with run day was the NIPA variable task time. As time in the chamber increased, time on tasks decreased. This confirms the hypothesis that shakedown of the equipment and experience gained by the crewmen would result in decreased requirements for task activities.

The second independent variable, time on tasks, showed significant correlations for three out of the four crewmen with psychological dispersion and physical dispersion. The pretest hypothesis predicted a decrease in dispersion as

time on tasks increased, based on the assumption that as a man devoted more time to his task, he was required to remain longer in a particular area of the chamber with no freedom to increase distance from other crewmen. The data shows that in fact, distance was increased. This may indicate that attention to tasks actually prevented grouping of crewmen and may be a result of chamber layout.

Time on tasks also showed significant correlations with psychological distance per unit time and physical distance per unit time. The rationale for the hypothesis is identical to that given in the prior paragraph. The remaining significant correlations for the independent variable time on tasks is with non-affect ratio, in an inverse direction. This confirms the hypothesis, based on the common sense assumption, that there was less talking when a man was engaged in a task.

The third independent variable unscheduled task time was significantly correlated with psychological dispersion and physical dispersion. The hypothesis, based on the assumption that unscheduled tasks would require a greater distance of movement than regularly assigned tasks, was confirmed.

Unscheduled task time also correlated significantly for all four crewmen with psychological distance per unit time and physical distance per unit time. The rationale discussed in the immediately prior paragraph also applies here.

The remaining significant correlations for the independent variable unscheduled task time was with non-affect ratio. As with the independent variable time on tasks, the hypothesis, which was confirmed, was based on the assumption that there is less time for talking when a man is engaged in a task.

The fourth independent variable, imposition, was chosen for analysis because it was assumed that requests for actions (impositions) by the outside staff would produce psychologically detectable changes in mood. However, no significant correlations were obtained for this variable.

The obtained correlations between the four independent variables and the intrusive test results are listed in Table 3-43. As mentioned earlier, these correlations have been made only for the period during which NIPA data exists, and are determined from a limited number of samples (3 to 11 from each crewman in the case of paper-and-pencil tests).

Table 3-43 shows that the only statistically significant correlation for more than two crewmembers is the independent variable run day with psychomotor performance on the LRC-CC. Performance was improved significantly for all four crewmen over time, which is apparently because the LRC-CC measures complex learning process which continued throughout the test.

Averaged habitability questionnaire scores show a weak correlation with run day ($p < 0.05$) although individual scores do not. Correlations were found for two crewmembers between time to fall asleep and run day ($p < 0.05$), hostility scale scores toward crew compartment noise with task time, and positive scores of the group confinement inventory with unscheduled task time. These and occasionally significant correlations of a single crewman appear to be

Table 3-43

CORRELATION OF INTRUSIVE MEASURES WITH SELECTED INDEPENDENT VARIABLES

Hypothesis	Crewman ($p <$ number shown) 1	2	3	4
Primary affect scale: As time increases:				
Happiness will increase	NS	NS	0.05	NS
Anger will increase	NS	NS	NS	NS
Fear will increase	NS	NS	NS	NS
Depression will increase	NS	NS	NS	NS
Hostility scale score: As time increases:				
Toward outside personnel will decrease	NS	0.01	NS	NS
Toward inside crew will decrease	NS	0.05	NS	NS
Toward equipment compartment noise will increase	NS	NS	NS	NS
Toward crew compartment noise will increase	0.01	NS	NS	NS
Group confinement inventory scores: With time:				
Positive scores will increase	NS	NS	NS	NS
Negative scores will increase	NS	NS	NS	NS
Isolation symptomatology questionnaire: With time:				
Negative scores will increase	NS	NS	NS	NS
Positive scores will decrease	NS	NS	NS	NS
Subjective stress scale: With time:				
Overall score will increase	NS	NS	NS	0.05
Sociometric questionnaire: With time:				
Leader choices will decrease	NS	NS	NS	NS
Member choices will decrease	NS	NS	NS	NS
Sleep behavior questionnaire: With time:				
Sleep duration will increase	NS	NS	NS	0.01
Time to fall asleep will increase	0.05	NS	0.05	NS
Number of mid-sleep awakes will increase	NS	NS	NS	NS
Restfulness will increase	NS	NS	0.01	NS

Table 3-43 (Continued)

Hypothesis	Crewman ($p <$ number shown) 1	2	3	4
Free fatty acids - with time:				
Measured levels will increase	NS	NS	NS	NS
Sphyngomyelin - with time:				
Measured levels will decrease	NS	NS	0.05	NS
Sodium/potassium ratio - with time:				
Sodium/potassium levels will increase	NS	NS	NS	NS
Psychomotor performance (LRC-CC) - With time:				
Morning scores will decrease	0.01	0.01	0.01	0.01
Mid-day scores will decrease	0.01	0.01	0.01	0.01
Evening scores will decrease	0.01	0.01	0.01	0.01
Habitability questionnaire scores - With time:				
Crew quarters acceptance will increase	NS	NS	NS	NS
Equipment quarters acceptance will increase	NS	NS	NS	NS
Hygiene area acceptance will increase	NS	NS	NS	NS
Miscellaneous acceptance will increase	NS	NS	NS	NS
Average overall acceptance will increase	0.05			
Descriptive sentence test scores - With time:				
Cognitive performance will increase	NS	0.01	NS	NS
Primary affect scale - with task time:				
Happiness will decrease	NS	NS	NS	NS
Anger will increase	NS	NS	NS	NS
Fear will increase	NS	NS	NS	NS
Depression will increase	NS	NS	NS	NS
Hostility scale - with task time:				
Toward outside personnel will increase	NS	NS	0.05	NS
Toward inside crew will increase	NS	NS	0.01	NS
Toward equipment compartment noise will increase	NS	NS	NS	NS

Table 3-43 (Continued)

Hypothesis	Crewman ($p <$ number shown) 1	2	3	4
Hostility scale - with task time: (Cont)				
Toward crew compartment noise will increase	0.01	NS	0.05	NS
Group confinement inventory - with task time:				
Positive scores will decrease	NS	NS	NS	NS
Negative scores will increase	NS	NS	NS	NS
Isolation symptomatology questionnaire - with task time:				
Positive scores will decrease	NS	NS	NS	NS
Negative scores will increase	NS	NS	NS	NS
Subjective stress scale - with task time:				
Overall score will increase	NS	NS	NS	NS
Sociometric questionnaire - with task time:				
Leader choices will decrease	NS	NS	NS	NS
Member choices will decrease	NS	NS	NS	NS
Sleep behavior questionnaire - with task time:				
Sleep duration will decrease	NS	NS	NS	NS
Time to fall asleep increase	NS	NS	NS	NS
Number of midsleep awakes will increase	NS	NS	NS	NS
Restfulness will decrease	NS	NS	NS	NS
Free fatty acids - with task time:				
Measured levels will increase	NS	NS	NS	NS
Sphingomyelin - with task time:				
Measured levels will increase	NS	NS	NS	NS
Sodium/potassium ratio - with task time:				
Ratio will decrease	NS	NS	NS	NS

Table 3-43 (Continued)

Hypothesis	Crewman ($p <$ number shown) 1	2	3	4
Primary affect scale - with unscheduled task time:				
Happiness will increase	NS	NS	0.05	NS
Anger will increase	NS	NS	NS	NS
Fear will increase	NS	NS	NS	NS
Depression will increase	NS	NS	NS	NS
Hostility scale - with unscheduled task time:				
Toward outside personnel will increase	NS	NS	NS	NS
Toward inside crew will increase	NS	NS	NS	NS
Toward equipment compartment noise will decrease	NS	NS	0.01	NS
Toward crew compartment noise will decrease	0.01	NS	NS	NS
Group confinement inventory - with unscheduled task time:				
Positive scores will decrease	NS	NS	0.01	NS
Negative scores will increase	NS	NS	NS	NS
Isolation symptomatology questionnaire - with unscheduled task time:				
Positive scores will decrease	NS	NS	NS	NS
Negative scores will increase	NS	NS	NS	NS
Subjective stress scale - with unscheduled task time:				
Overall score will increase	NS	NS	NS	NS
Sociometric questionnaire - with unscheduled task time:				
Leader choices will decrease	NS	NS	NS	NS
Member choices will decrease	NS	NS	NS	NS
Sleep behavior questionnaire - with unscheduled task time:				
Sleep duration will decrease	NS	NS	NS	NS
Time to fall asleep will increase	NS	NS	NS	NS
Number of mid-sleep awakes will increase	NS	NS	NS	NS
Restfulness will decrease	NS	NS	NS	NS

Table 3-43 (Continued)

Hypothesis	Crewman ($p <$ number shown) 1	2	3	4
Free fatty acids - with unscheduled task time:				
Measured levels will increase	NS	NS	NS	NS
Sphingomyelin - with unscheduled task time:				
Measured levels will increase	NS	NS	NS	NS
Sodium/potassium ratio - with unscheduled task time:				
Ratio will increase	NS	NS	NS	NS

NOTE: NS means not significant.

random effects. The general indication, again, is that intrusive measures used during the 90-day test were not adequate to measure the effects of the generally low stress levels that existed.

3.9.3.4 Observer Reliability

An obvious potential source of error in the NIPA data resides in observer reliability. In a separate analysis, data were accumulated in terms of the amount of positive affect detected by particular observers (see Figure 3-99). The only two female observers terminated their assignments on day 56 and it was of interest to determine the overall effect of their presence or absence. Overall, there was as much positive affect detected after day 56 as before.

Reviewing the data on an individual basis for all observers shows differences in total scores; however, these differences follow crew shift times in that the highest scores occur during times when all four crewmen were up. Some observers kept to the same daily observation period so their performance at different times is not known.

All observer's scores show great day-to-day variability, but high and low scores for all observers match quite well on a daily basis. The scores for affect are relative and the interest is in discernible high and low periods. No conclusions can be drawn about absolute levels of affect. The removal of any observer's scores changes the amplitude of the day to day curve, but not its general shape or period. The individual observer's effect on trends seen in the data was apparently insignificant. This effect can be further reduced by additional observer training, observer shift rotation, and obtaining baseline data for each observer.

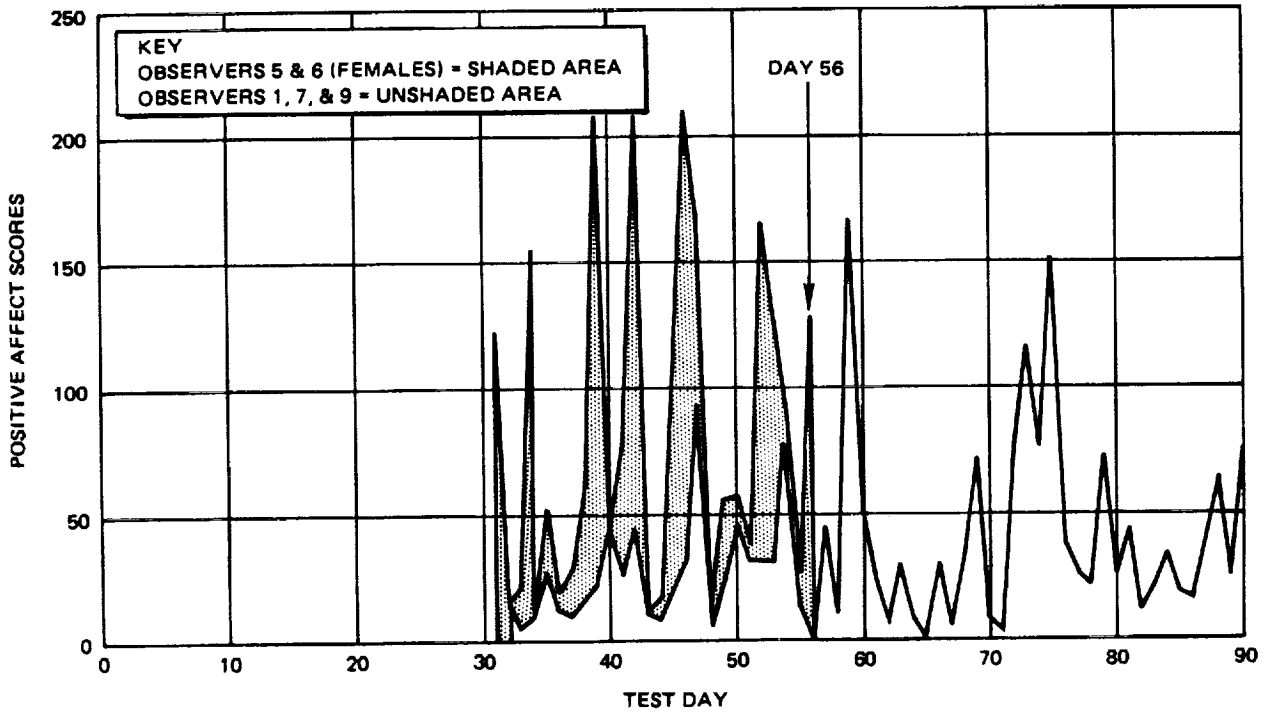


Figure 3-99. Comparison of Observers by Total Number of Positives Recorded

3.9.3.5 Criterion Measures

Validity of a measurement device or technique is a function of how well it measures what it purports to measure. The NIPA technique used in the 90-day test was designed to measure a specific aspect of crew behavior – changes in crew morale. Ultimately, of course, performance assessment is concerned with operational factors such as mission accomplishment, system and subsystem functioning, and crew safety. The assumption underlying the selection of morale as the dependent variable in this experiment is that degeneration of crew morale, if allowed to continue, will eventually affect the operational factors identified above.

To assess the validity of NIPA or any other measurement technique, an independent, uncontaminated criterion measure of the behavior of interest is required. Under operational conditions, and to a large extent in simulations such as the 90-day test, the selection of a criterion measure for human behavior is exceedingly difficult, due to operational constraints and the lack of validated behavioral measurements. In addressing the criterion problem for NIPA, three types of criterion measure were considered: (1) direct measures of morale in the form of paper and pencil tests, (2) indirect measures of morale such as physiological indicators of stress, and (3) measures of the assumed operational results of increased or decreased morale such as task performance. Additional and more subjective criterion measures were available in (1) self-reports by crewmen and their communications with outside support personnel, and (2) direct observations by communications monitors, medical monitors, and program staff.

The validity of paper-and-pencil tests as a direct criterion measure of morale was not substantiated. In general, no significant correlations were found between paper-and-pencil tests and NIPA measures nor were there significant correlations between paper-and-pencil tests and the four independent variables of time in chamber, time on tasks, unscheduled task time, and outside requests.

Indirect measures considered were (1) the biochemical indices of stress sphingomyelin count, urinary sodium-potassium ratio, and free fatty acids; (2) scapegoating behavior toward outside crew, and (3) performance on psychomotor devices such as the LRC-CC, ARC Rater, and the Critical Task Tester. Of the biochemical indices investigated only the urinary sodium-potassium ratio seems to correlate with morale changes. This ratio became depressed at about day 60, the point of observed morale decline, and accelerated to approximately previous levels following a round-table corrective discussion held by the crew. Scapegoating behavior on the part of the crew was never reported by the communication monitors so its value as a criterion measure is unresolved. Of the three psychomotor devices investigated, only the Critical Task Tester scores can be considered as even approximately independent criteria of morale state. As described in Section 3.10, weekly mean critical task scores on this device for all crew members exhibited a definite dip during week 9 (around day 60), even though all crewmen showed a consistent improvement trend over the entire 90-day period.

The measures of task performance investigated as potential criterion measures included the following:

A. Performance of scheduled mandatory vs. recommended tasks as observed and recorded by communications monitors.

B. Time Share Computer Link (TCSL) transmission errors as observed on computer printouts.

C. Handwriting changes as evidenced in detailed examination of crew diaries.

For this particular test, performance of scheduled tasks as a criterion measure proved infeasible since all tasks, both mandatory and recommended, were performed and generally as scheduled. TCSL transmission errors were a poor criterion measure insofar as some errors, when detected, were corrected by support personnel and it became impossible to clearly differentiate crew errors from system initiated errors. Analysis of handwriting changes over the last 60 days of the mission concentrated on 11 variables. Three of these variables (percentage of abbreviated words, percentage of incompleted letters, percentage of incomplete sentences) showed significant intercorrelations for each of the four crewmen, indicating that transcription quality may well reflect a non-intrusive assessment of intellectual, perceptual, and motor performance.

Unexpectedly these measures of handwriting quality also show a significant positive correlation with measures of task pressure, i.e., the crew was at its best when task load was heaviest. Since crew workload was low at the 60-day point of morale decline, it is reasonable to suggest handwriting quality as a potential criterion measure.

Subjective indicators of morale changes in the form of crew reports (both during and post-test) and observations of outside support personnel verified that a definite dip in morale occurred at the two-thirds point of the mission.

In summary, several independent indicators were effective in identifying one specific period of decreased morale, a period to which NIPA measures also responded. Sufficient data are not available, however, to judge any one of these as the criterion measure of choice for studies of this type.

3.9.3.6 Operational Aspects

Aside from the preceding material, attention must be given to the NIPA methodology and its potential operational use during prolonged manned flights of the future. The study demonstrated that NIPA is feasible as a technique to measure human behavior under ground simulation conditions. Furthermore, it has been shown that it can be used to provide virtually continuous information on crew and individual behavior patterns which are related to morale states and performance quality. With minor effort, NIPA data can provide operational support personnel with real-time information concerning crew morale levels. To do this, it is necessary to investigate techniques of presenting information to operational personnel in a manner that provides immediate information return. An example of how this can be done may be seen in the following material.

Data from certain behavioral measures were combined into 5-day group mean values. These were plotted and appear in Figure 3-100. The improvement in visual display was not considered adequate for operational use. Manipulation of the data from Figure 3-100 was then undertaken in the following manner. Five-day group means were tabulated cumulatively and treated with a mathematical constant as necessary to permit the use of one ordinal scale. Plotting of cumulative averages is shown in Figure 3-101. This display demonstrates that, although time on tasks remained at a relatively constant level, both positive affect and outside requests simultaneously deviated in the same direction during the period from day 55 through 60. Also shown is similarly plotted material on urinary Na^+/K^+ which has been employed as a biochemical index of psychological stress.

Using these graphs, a clearer picture of the events which transpired is apparent. These events are described below and derive corroboration from subjective impressions of the test, as well as reports by crew members during and after the confinement period.

Between days 55 and 60, support crew activities became less intense because of a reduction in unscheduled equipment maintenance requirements. Verbal contact (outside requests) between crews was reduced. Accompanying these changes in activity requirements was a dramatic change in the frequency of positive statements among crew members. The exact reason for this change in affect is unclear. A tentative hypothesis is that an increase in social isolation occurred as a result of fewer contacts with outside personnel — either because of fewer equipment malfunctions or because the onboard crew had reached a point of proficiency permitting greater independence. Regardless of the reason for such change, it is clear that a NIPA measure, positive affect (PA), was capable of quantitatively tracking changes in crew morale. It is

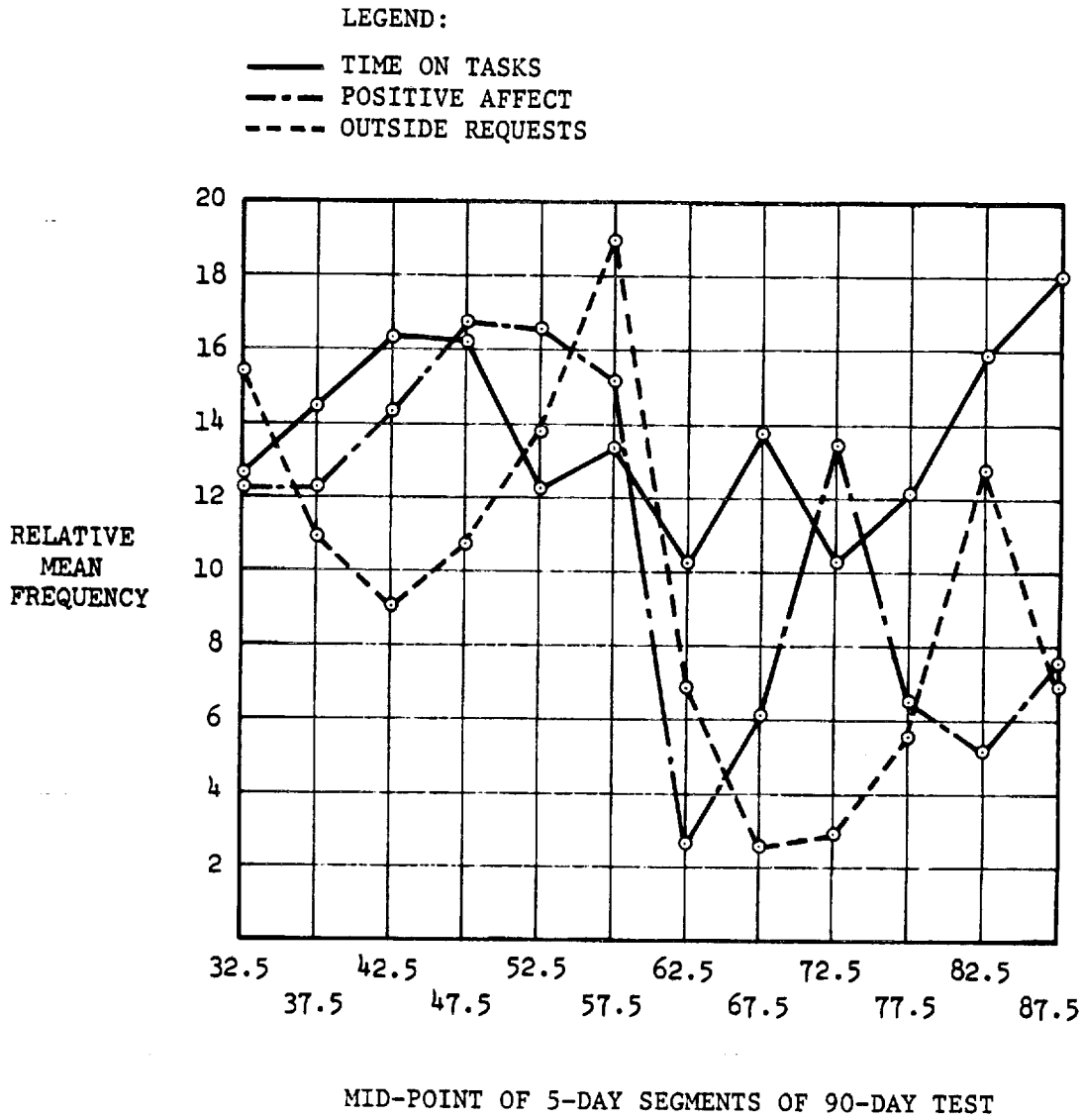


Figure 3-100. NIPA Results as Conventionally Plotted

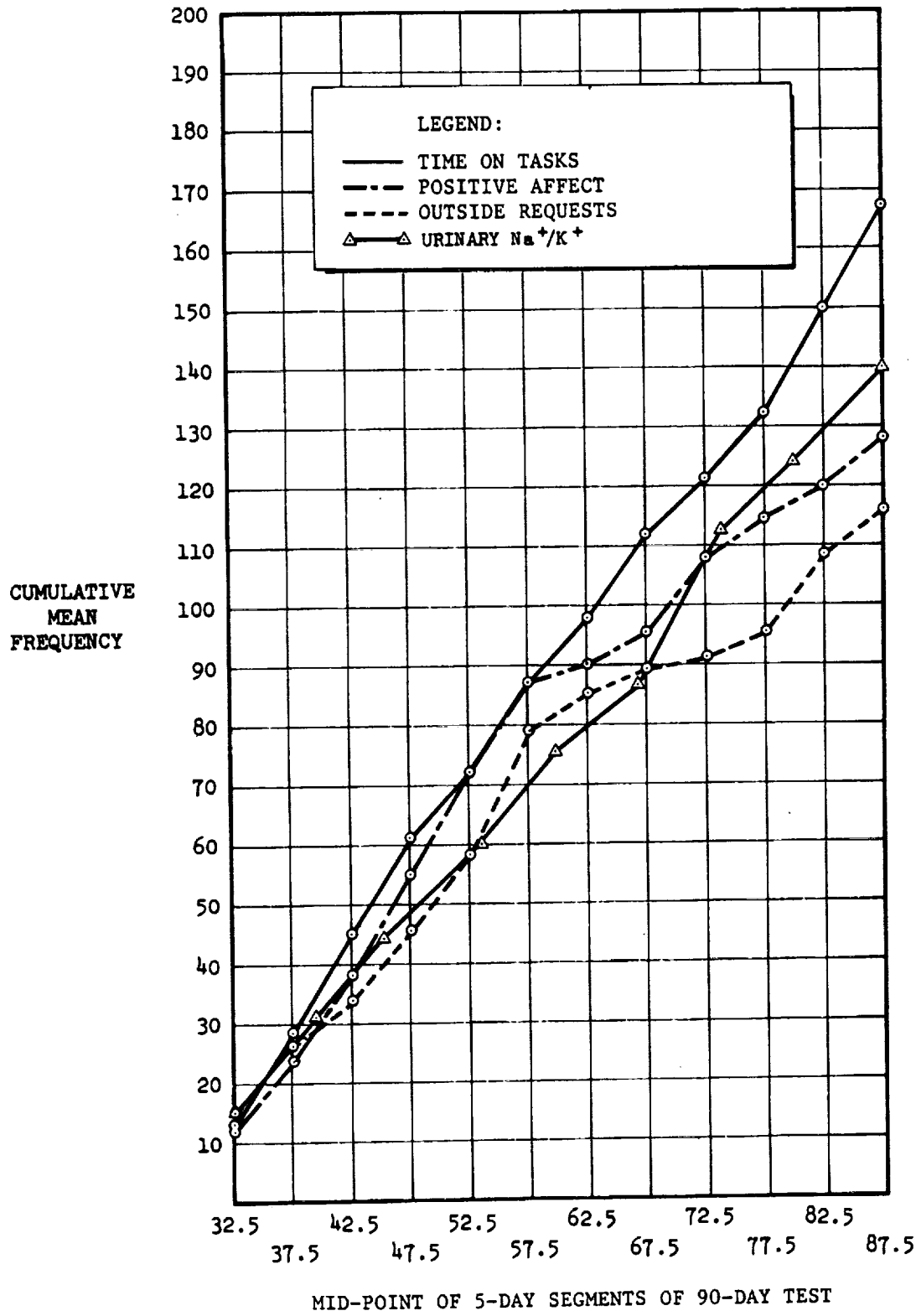


Figure 3-101. NIPA Results Cumulatively Plotted Showing Operational Utility

interesting to note that the slope change in PA seen between points 67.5 and 72.5 can be attributed to the effects of increased verbal contact with project management and a "gripe" session undertaken on day 69 by onboard crew members. Although an improvement in affect occurred, it did not persist beyond day 80. The remaining 10 days of the test were accomplished at a morale level (defined in terms of PA statements) below that established between days 31 and 50. The end spurt of anticipation expected on the part of the crew was thus inadequate to the task of elevating affect to the earlier baseline slope.

The cumulative curve of Na^+/K^+ shows deviations in excretion rates of these cations at approximately the same times as the behavioral measures. This correspondence provides further support to the notion that NIPA was capable of quantitatively tracking a period of psychosocial stress which has been named a morale decline. Further discussion of this psychophysiological relationship may be found in Reference 3-37 and Section 4.5.3.2 herein. If this graph had been available to program management during the test, it: (1) would have provided a real-time assessment of crew morale and performance, (2) would have helped in determining when to undertake remedial procedures, (3) could have been used to measure the effects of remedial procedures, and (4) would have provided a ready, quantitative answer to the hitherto unanswerable question, how is the crew doing?

This can thus be accomplished and can provide real-time information for operational scheduling of mission tasks by management personnel without imposing time and task requirements upon crew members and without the use of test devices which characteristically generate irritation among even the most dedicated personnel. That was, and remains, the goal of the NIPA methodology.

3.9.4 Conclusions and Recommendations

This study has demonstrated the methodological potential for developing a remote means of obtaining real-time social-emotional data from crews during future space missions. Despite some operational difficulties, there are definite indicators that the NIPA method can acquire meaningful data.

The verbal content categories were admittedly gross, yet the category identified as positive, detected a decrease in positive affect between days 60 and 70 that is known to have been a period of interpersonal stress. Thus, there is evidence that the monitoring of verbal content has potential. In addition, the analysis described in Section 3.9.3 shows significant correlations, in the predicted direction, between verbal content and distance measures. This opens the possibility for obtaining the type of data ordinarily acquired through verbal content by measuring distances and movements among crew members.

Two innovations in the method developed in the present study have distinct advantages over prior studies of this type, in terms of research efficiency. They are:

A. Indices, as opposed to raw data, were developed and effectively utilized in data analysis.

B. The data were distilled and put into a form for computer input at the point of data gathering. This saved a monumental task of later data reduction when one considers that, in the four-man-up period only, there were 130,000 verbal interactions requiring 1,200,000 calculations to reduce the data and 200,000 mobility and activity entries requiring 2,200,000 calculations.

Whether the NIPA method can be substituted for paper-and-pencil testing is still problematical because no statistically significant correlations resulted in comparing NIPA observations and onboard questionnaires. Interpretation of the data in terms of comparisons between paper-and-pencil tests and NIPA observations presents a logical dilemma. An unequivocal conclusion is not possible.

The following recommendations are made for future tests:

A. Establish the behavior criteria which are to be identified and determine remedial action.

B. Provide an extensive training program for the NIPA observers. This should include actual observations with the hardware planned for final use, in a mocked-up situation.

C. Provide the finally selected onboard crew members with cross-training as NIPA observers. Post-test debriefings with crew members of the present study suggest that this would be beneficial in terms of their acceptance of the project.

D. Obtain a "purer" measure of the psychological distance variable. In the present study task directed movement was included with non-task activity. The initial assumption underlying this variable was that the movement involved is voluntary. Thus, it makes a crucial difference whether a man goes into the equipment compartment to get away from his fellow crewmen as opposed to going there to make an equipment adjustment. In a later study it would be desirable to purify these measures by "subtracting out" those times when a task was being performed.

E. Prior to the run, obtain baseline behavior on the finally selected applicants. Thus, if a valid measure of "privacy seeking" is available for use during the run, it is desirable to collect behavioral data regarding "privacy seeking" prior to the run for comparative purposes.

F. Consider refinement of the verbal categories. In the present study, an angry statement and a statement indicating loneliness both received a "score" of negative. To what extent would additional categories provide better prediction of the criterion behavior?

G. Consider an automated means for collecting crew movement and location data.

H. Consider an automated method for on-going detection of emotional content in voices, perhaps through spectral analysis.

I. Determine the optimal observer schedule for human observation in terms of the behavior which has been selected for monitoring.

J. Determine the optimal number of observers per crew number and the observing strategy, i. e., man-on-man; division of observer labor by crewman function, etc.

K. Consider the development of a real-time or near real-time data display technique of selected observational and biochemical indices to provide information on crew condition during confinement.

3.10 CRITICAL TASK TESTER

The 90-day test provided a unique opportunity to evaluate certain psychomotor functions in a realistic space station environment (except for zero-gravity), under operational type work-rest cycles and ambient stresses. Among the more important of such psychomotor tasks are the broad class of tracking tasks: star tracking for navigation or astronomical purposes; telescope pointing for earth-resource or reconnaissance purposes; fine tuning of apparatus for research or communications purposes; and, last but not least, piloting tasks such as rendezvous in orbit and reentry into the earth's atmosphere.

To measure behavior appropriate to such tracking tasks, Systems Technology, Inc., under sponsorship by the NASA-ARC Man-Machine Integration Branch, provided a battery of tracking tasks to be performed during the 90-day mission. The objectives of this experiment were:

A. To obtain a simple "clinical" measure of the crew member's visual-motor dynamic performance on a routine basis using the critical instability task (reference 3-38).

B. To obtain comprehensive measures of the intrinsic dynamic response properties on a less frequent basis by means of advanced cross-correlation techniques, and to correlate this standard tracking-task data with the critical instability measure.

C. To present data obtained in this tracking experiment for correlation with medical, physiological and psychological data from other experiments run concurrently.

The tracking task test battery and associated apparatus employed in this experiment were developed under NASA sponsorship and are detailed in References 3-38 through 3-42. Systems Technology's role in the present experiment was to provide test specifications, experimental design and procedures; to participate in indoctrination and training; and to reduce and analyze the data. MDAC personnel were responsible for integrating the equipment and tests into the 90-day test and for administering the control task test sessions.

3.10.1 Control Tasks

The psychomotor tests used in this experiment are continuous, compensatory visual-motor tracking tasks. A general block diagram representation of these tasks and associated data measures and analysis is shown in Figure 3-102. A thorough description of these tasks is given in References 3-41 and 3-42. Basically, the subject is required to control the motion of a luminous horizontal CRT line with an isometric (force) control stick whose output controls a dynamically unstable controlled element [first-order: $Y_c = \lambda_1/s-\lambda_1$); second order: $Y_c = \lambda_2/s(s-\lambda_2)$]. If the subject provides the appropriate dynamic equalization behavior he will be able to not only stabilize the man-machine system, but to minimize CRT line motions away from the null point or reference line. Two variations of this unstable tracking task employed in the present experiment are described below:

A. Critical Instability Task — The subject is required to maintain stable control as the controlled element's instability is steadily increased. No external disturbance need be introduced in this task because "remnant" noise sources internal to the human operator (e. g., unsteadiness, tremor) provide ample excitation for the unstable element. In the face of the increasing instability the subject will lose control of the task at some point because the line diverges off the CRT more quickly than he can exert compensatory control action. The degree of instability, λ_c, at which the subject loses control is termed his "critical instability" score. It is roughly equal to the inverse of the operator's dynamic time delay as shown in References 3-38 and 3-39.

The control of simple first-order divergent dynamics is called the first-order critical task, and requires the operator to act as a simple gain (i. e., the operator's stick output looks like a scaled version of the system error signal including a time shift equal to the operator's dynamic time delay). Controlling a first-order divergence in series with a pure integrator is called the second-order critical task. In controlling these dynamics the operator must effectively cancel out the effect of the integrator by providing what we term first-order lead equalization to stabilize the control dynamics. (Lead equalization is equivalent to rate perception or error signal prediction.) Generation of this lead equalization requires additional mental processing time (Reference 3-43) which increases the operator's effective dynamic time delay. Thus for the second-order critical task the operator cannot achieve as high a critical instability score as with the first-order task.

The operator's basic effective time delay, as measured by the first-order critical task, is composed primarily of neural conduction time delays and neuromuscular dynamics of the arm. Thus performance on the first-order critical task is a measure of basic neuromuscular dynamics, while the second-order task measure includes a component due to higher center involvement.

The critical task is easily administered since it only requires about one minute per trial and a single number is recorded at the end of each trial. Therefore, the first- and second-order critical instability tasks were selected to be administered routinely during the 90-day test.

B. Steady "Subcritical" Tracking Tasks — For steady tracking tasks the instability level of the unstable dynamics is held constant at a value well below the typical subject's critical instability score. An unpredictable command input is introduced into the tracking loop as shown in Figure 3-102, and the subject is asked to maintain minimum tracking error during runs lasting approximately 2 min. Using special apparatus to be described later, the error signal is Fourier analyzed and performance data are computed during the run. These data are further reduced off-line, via a time-sharing computer program, to obtain the subject's open-loop describing function and task performance. The describing functions are fitted with a three-parameter dynamic response model, and the resulting loop closure properties are interpolated. Key parameters presented herein include:

Crossover frequency (ω_c), the unity-amplitude frequency of the open loop describing function, a measure of the subject's gain.

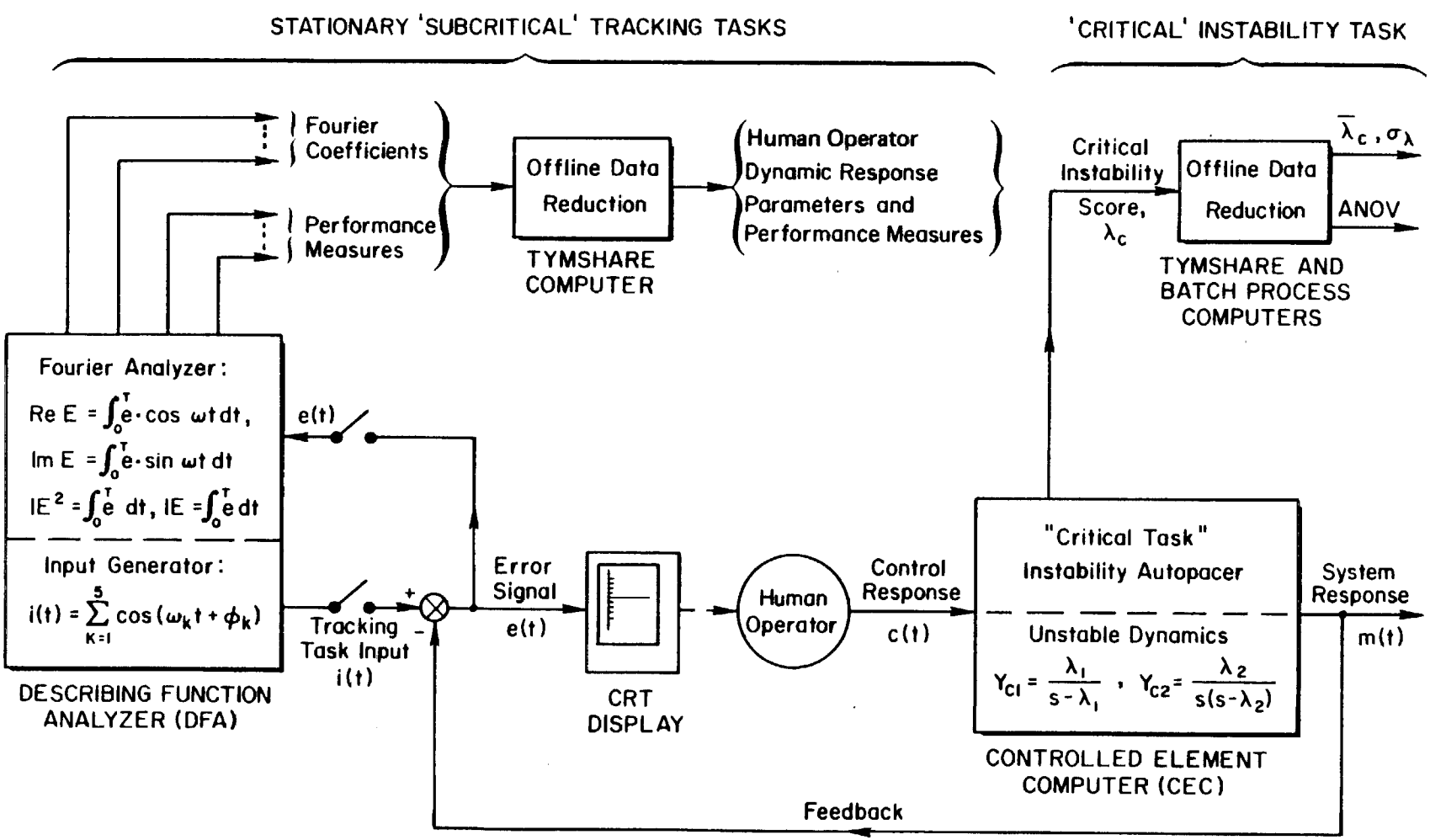


Figure 3-102. Tracking Tasks, Data Measurements, and Analysis

Phase margin (ϕ_M), a measure of system stability margin related to the closed-loop damping ratio.

Dynamic time delay (τ_e), the subject's visual-motor time delay in a continuous tracking task including neural and mental delays and neuromuscular lags.

The performance measures include:

Normalized error variance (σ_e^2/σ_i^2), the ratio of tracking error variance to the variance of the task input.

Error coherence (ρ_e^2), the percentage of total variance predicted by (correlated with) the describing function measurements. The remaining error power ($1 - \rho_e^2$) is due to the subject's internal noise (remnant).

For this experiment we chose to include both first- and second-order subcritical tracking tasks that are dynamically equivalent to the first- and second-order critical instability tasks. The first-order instability was set at $\lambda = 2$ rad/sec, and the second-order case was set at $\lambda = 1.25$ rad/sec. Although these tasks allow a detailed assessment of the subject's dynamic response and noise properties, they require longer trial durations and a large amount of on-line data collection and reduction. For this reason they were run less frequently than critical tasks during the 90-day test, and were employed to provide realistic tracking task data to correlate with the critical instability scores.

3.10.2 Test Setup and Equipment

The experimental layout and apparatus are shown in Figure 3-103. The test administrators conducted the experiment from the control room where the task computers were located. The Controlled Element Computer (CEC) provided the unstable dynamics for the tracking tasks, and automatically increased the instability during critical task runs as shown in Figure 3-102. The Describing Function Analyzer (DFA) provided the subcritical tracking task input, Fourier analyzed the tracking error signal, and measured various performance parameters.

The display and control stick, connected to the computers through a 100-ft cable, were located in the space chamber recreational area. The test administrator communicated with the crewmen through an intercom, and also via interconnected "ready" lights located on the subject's display and the controlled element computer.

3.10.3 Training

Crewmen began training on the first- and second-order critical tasks four months prior to commencing the 90-day confinement period. This training consisted of approximately 30 one-hour sessions spanning a five-week period. At each session the crewmen would track 2 three-trial blocks of the first-order critical task and 2 five-trial blocks of the second-order critical task. These λ_{c_1} and λ_{c_2} training scores are plotted in Figure 3-104a. It is evident

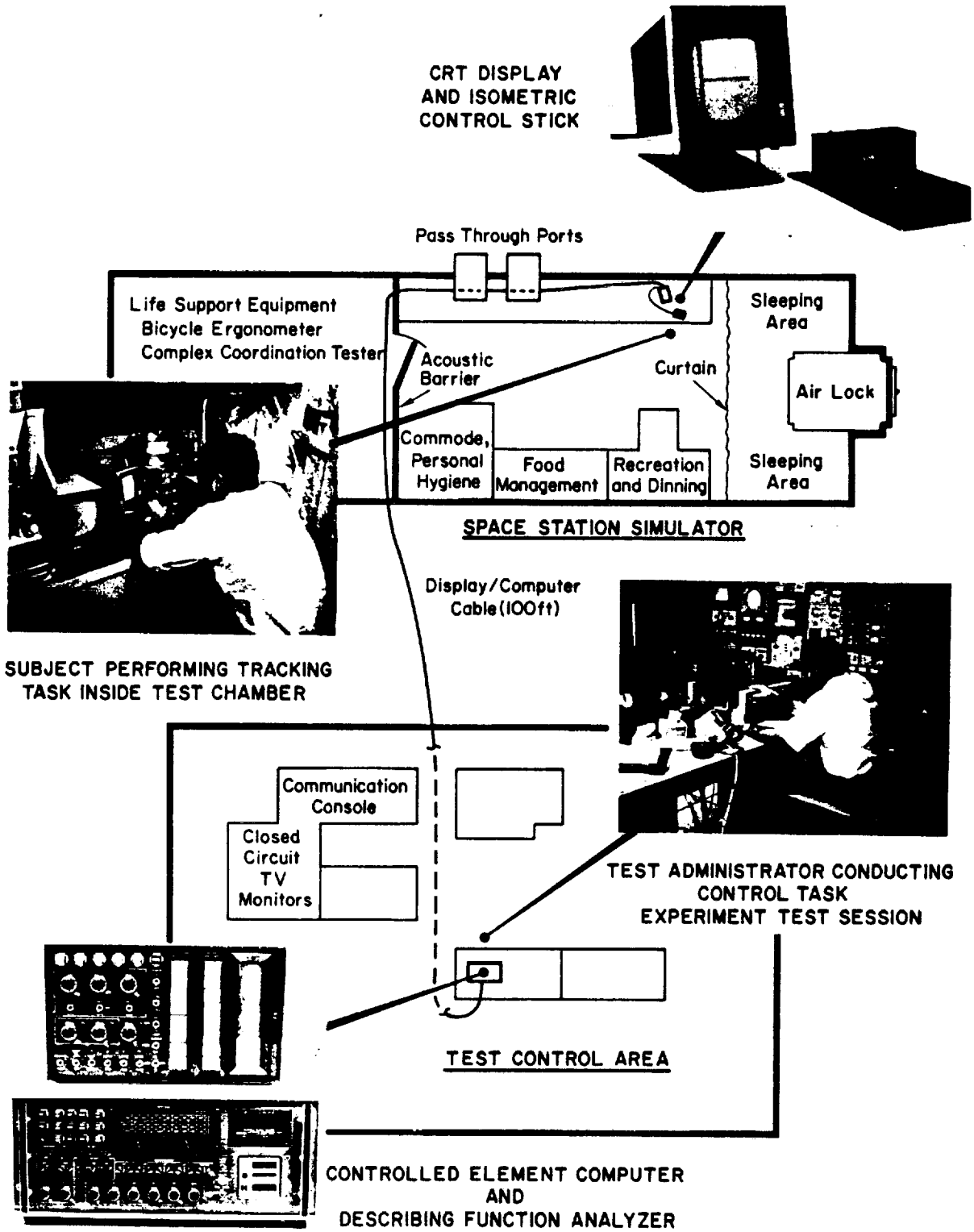


Figure 3-103. Control Task Apparatus and Experimental Setup for the 90-Day Confinement Study

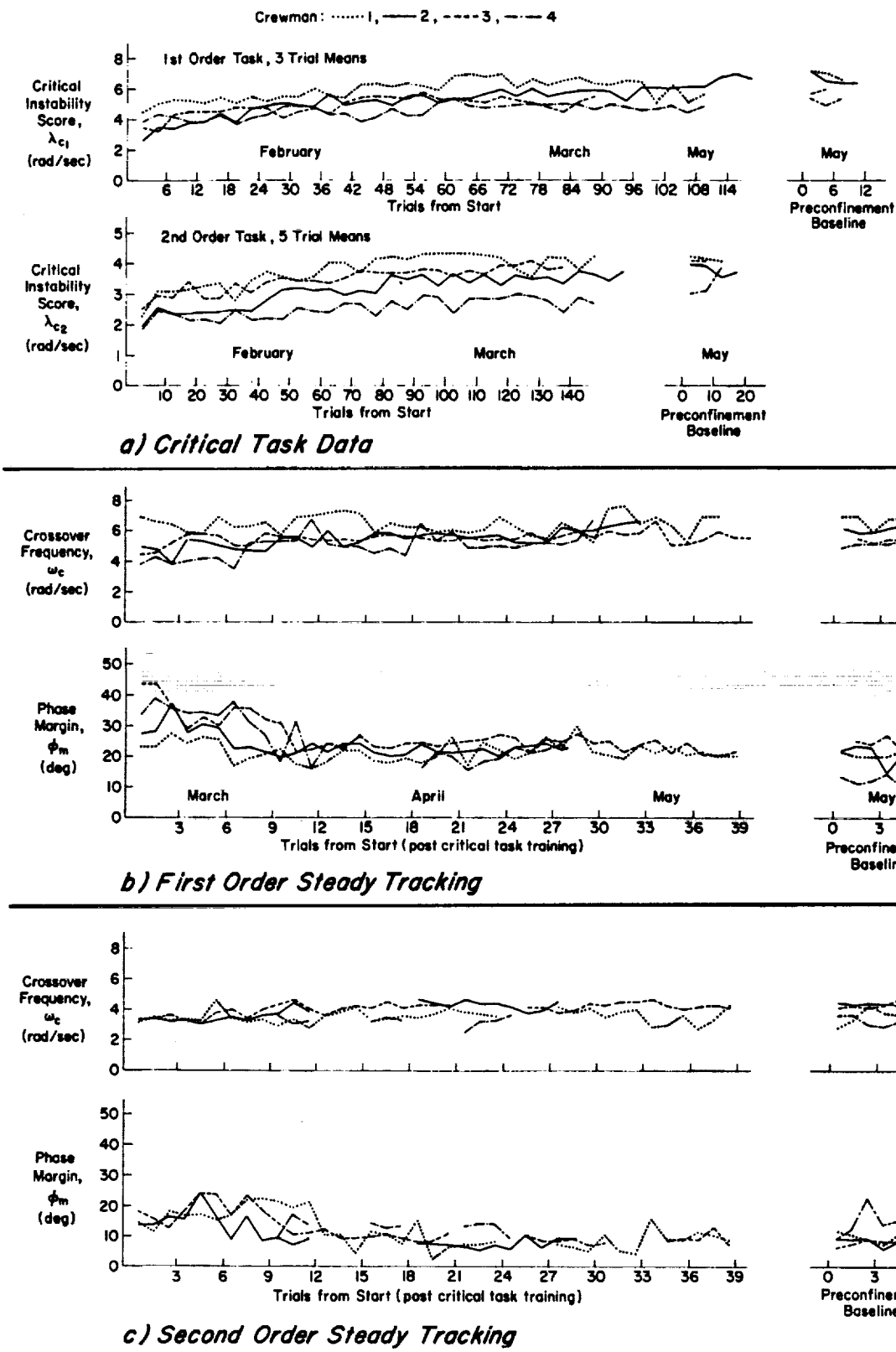


Figure 3-104. Training Data

that all crewmen reached stable levels of critical instability within about 100 trials of distributed practice.

Training of the steady tracking tasks was commenced immediately after critical task training. Because of the dynamic similarity between the critical and subcritical tasks, a favorable transfer of training is assured. The crewmen tracked three first-order and three second-order runs per session for approximately ten sessions spanning a 4-week period. Dynamic response data for the first- and second-order tasks is plotted in Figure 3-104b and 3-104c. From these figures the crossover gain, ω_c, shows a gradual increase with training, while the stability margin, ϕ_M, shows a concurrent decrease. Stable training levels were achieved in all cases except for crewman 4 on the second-order task. He had significantly less exposure to this task than the other crew members, and he later exhibited correspondingly larger learning effects during the confinement period.

3.10.4 General Protocol

During the confinement period, three trials of first-order and five trials of second-order critical instability task were administered routinely every Monday, Wednesday, and Friday following the midday meal. These data formed the core of our experimental design, and represent a base from which other tracking data can be compared and extrapolated. Steady tracking sessions were performed twice a week, one session for each order. These sessions began with the critical instability trials of the equivalent dynamics to provide a warmup and also to provide concurrent correlations between λ_c and the more comprehensive measures of steady tracking behavior.

The crewmen were split into two shifts, with crewmen 1 and 2 on a nominal day shift (0700 to 2300 hr) and crewman 3 and 4 on a graveyard shift (2100 to 1300 hr). Illumination was held constant inside the simulation chamber, and all indications are that crewmen 3 and 4 quickly adjusted to their abnormal work shift. Test sessions were conducted after the midshift meal (nominally 1300 hr for crewmen 1 and 2, and 0200 hr for crewmen 3 and 4). All test sessions began with a warmup critical instability trial.

3.10.5 Results

3.10.5.1 Critical Instability Task

Weekly mean critical task scores (averaged across the solely λ_c sessions for each week) are plotted in Figure 3-105. Generally, these scores were very reliable (low residual variance) and showed a consistent stratification among crewmen. Crewman 1 evidenced the most variable performance, with a definite dip in scores during the initial confinement period compared with his preconfinement baseline. This dip was followed by a return to performance levels significantly above his preconfinement baseline. There is one very consistent dip in performance for all crew members during week 9. As discussed in several other sections of this report, it was observed that a definite dip in morale occurred in this period.

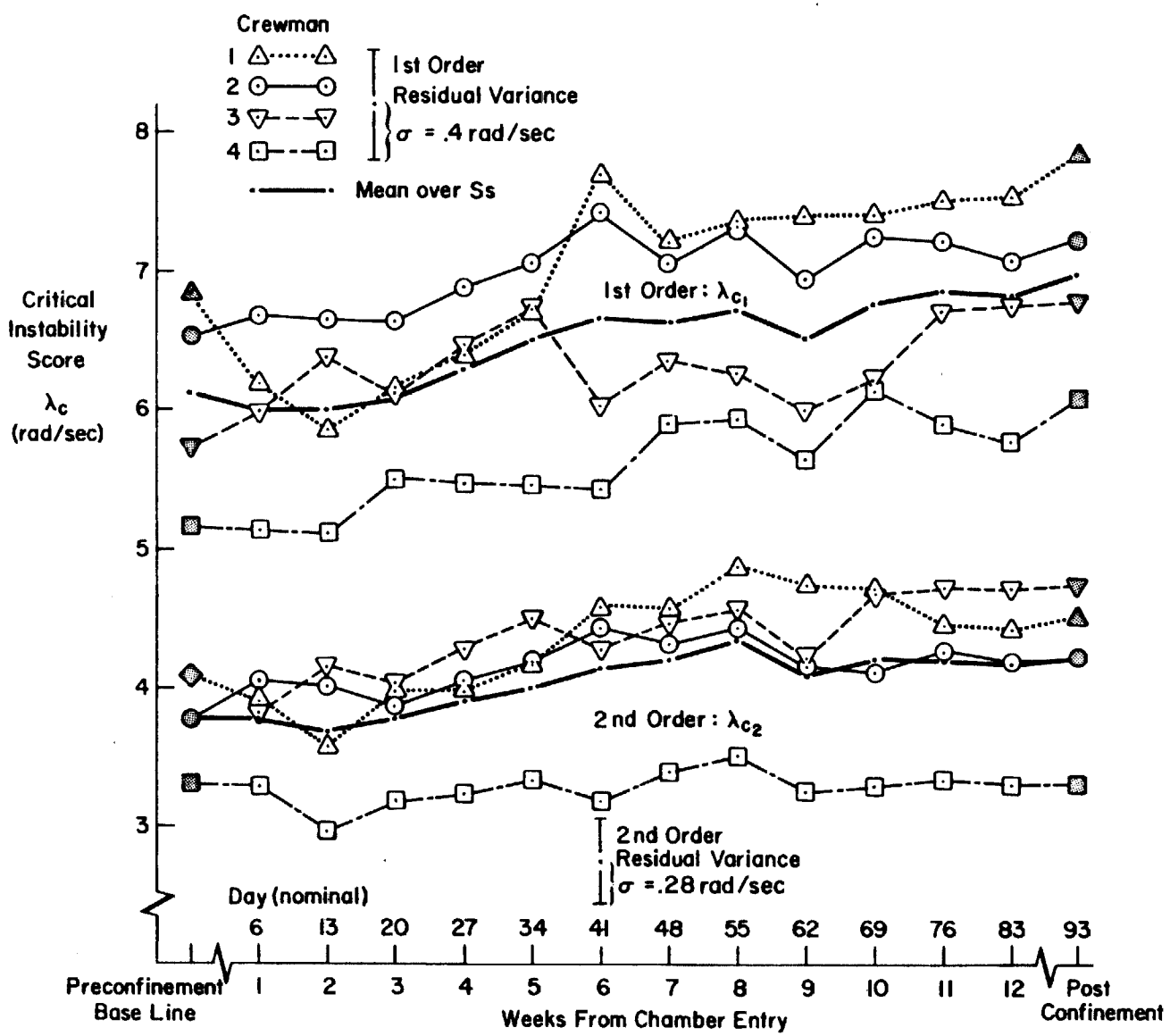


Figure 3-105. Weekly Mean Critical Instability Scores during the 90-Day Confinement Period

There is a consistent, albeit small, improvement trend apparent over the 90-day period in all cases except for crewman 3 on the second-order task. Experience suggests that this reflects a residual improvement in the neuromuscular system due to continuous practice beyond the initial training asymptote — much as in any athletic skill involving strength.

Analysis of variance procedures applied to the data showed subjects and weeks to be significant main effects. The subjects by weeks interaction was also statistically significant.

3.10.5.2 Steady Tracking Task

The steady tracking behavior and performance data are plotted in Figure 3-106. (The critical instability data shown here were obtained at the beginning of each subcritical tracking session, and were not included in Figure 3-105.) The steady tracking data are often missing because these sessions had a somewhat lower priority than the critical task sessions, and were not performed for a variety of reasons.

The dynamic response data (ω_c and ϕ_M) and critical task scores (λ_c) seem to remain fairly consistent and similar in level over the 90-day period. The normalized error and error coherence performance measures (σ_e^2/σ_i^2 and ρ_e^2) show considerable variations, however. Crewman 4's tracking errors are significantly higher than that of the other crew members. This result seems to be due primarily to an intrinsically higher remnant level as evidenced by his lower error coherence scores for both the first- and second-order tasks.

Crewmen 1 and 4 were still learning the second-order steady tracking task during the first half of the confinement period, as reflected in their normalized error scores. This result seems to be primarily due to dynamic response effects as both subjects show a corresponding increasing trend in crossover gain during the first half of the mission.

The comprehensive variety of measurements made during steady subcritical tracking will help in interpreting variations in tracking behavior and performance. A good understanding of the theoretical relationships among the above parameters exists (Reference 3-42) and this will be used to unravel the seemingly complex and anomalous variations exhibited in Figure 3-106.

3.10.5.3 Correlation Between Subcritical and Critical Task Results

One of the objectives of this experiment was to tie in the dynamic response measurements obtained during steady tracking tasks with the critical instability scores. Some correlation of critical and subcritical task data is shown in Figure 3-107. Effective dynamic time delays (τ_e) were derived from the dynamic response measurements obtained during subcritical tracking runs, and the inverse of τ_e should be directly related to critical task scores as discussed in Reference 3-38 and 3-39. The good correlation of τ_e^{-1} versus λ_c scores obtained during each subcritical tracking session ($R = 0.75$) is shown at the top of Figure 3-107 for both first- and second-order tasks. Because it is ultimately bonded by τ_e^{-1} and hence by λ_c, crossover frequency (ω_c) has also been shown to correlate with λ_c (References 3-38

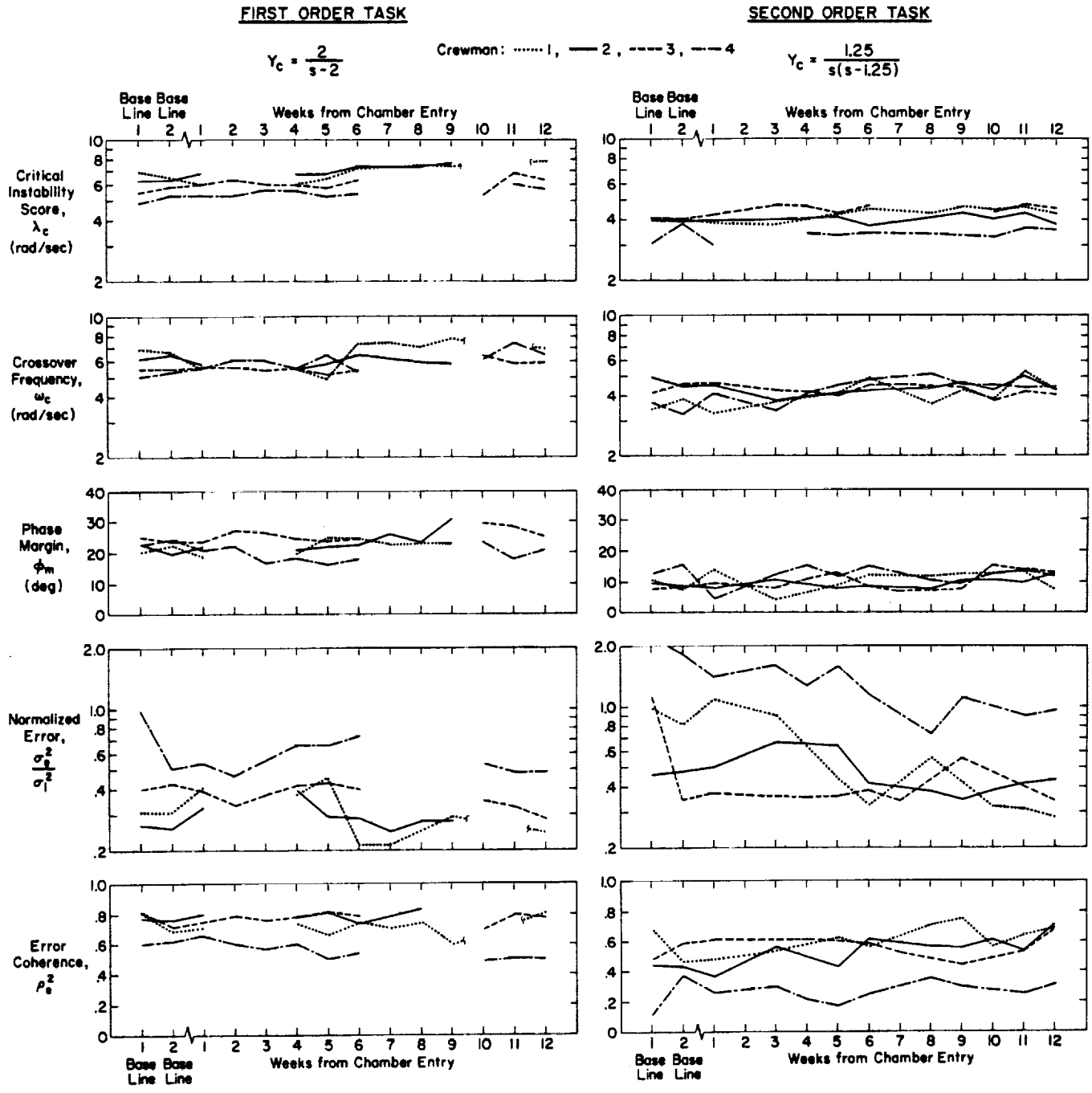


Figure 3-106. Comparison of Tracking-Session Data for the 90-Day Test

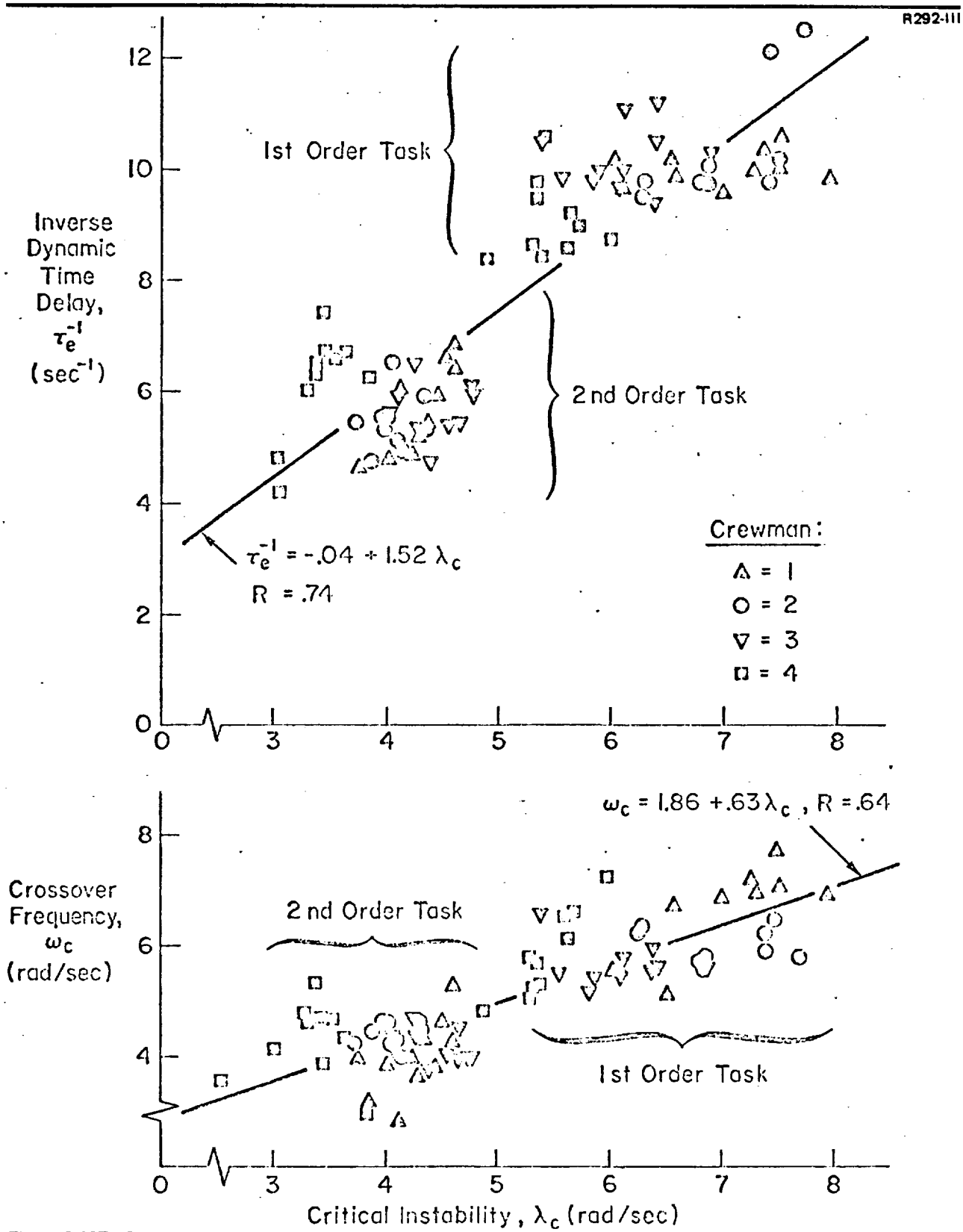


Figure 3-107. Correlation Between Critical Instability Score and Steady Tracking Data

and 3-39). The good correlation in this experiment (R = 0.64) is shown at the bottom of Figure 3-107. The present correlations, with initially naive subjects, are somewhat less than similar ones made in References 3-38 and 3-39 among professional pilots, but the trends and fitted lines are similar. The good tie-in of the present tracking behavior, performance, and critical instabilities with previous data constitute a strong validation for the generality of the models and interrelationships observed. Further analysis is now in order to compute the empirical factors via the theoretical models and the present data.

The absence of profound decrements in the performance data, tracking behavior, or critical instability scores should come as no surprise since the chamber environment was maintained in a generally satisfactory state.

3.10.6 Conclusions

Crewmen performance in this experiment agrees quite favorably with that of experienced pilots and test subjects tested previously (Reference 3-38 and 3-39). No serious degradations in performance were noted during the mission, and in fact there appeared to be a slight improvement trend throughout the 90-day period. Some dips in individual performance seem to correlate with subjective attitude and morale data not shown, so correlations of tracking data with other psychological measurements as well as with physiological and environmental data should be pursued.

A rich harvest of statistical data on manual control behavior has been obtained in this experiment. Its further analysis should tell us a great deal about the consistency and measurability of human dynamic response properties over an extended period of time under confined conditions.

The control task equipment functioned properly throughout the mission, even though the CRT display and control stick were subjected to the simulator sub-atmospheric pressure. In spite of the apparent complexity of the equipment and test protocols, both the crewmen and test administrators quickly became proficient in the experiment procedures. Test sessions for one subject typically required less than 15 min. Thus the simpler equipment and tests being planned for future orbital use by astronauts should meet with good acceptance and permit acquisition of in-depth information regarding the space environment's effect on human dynamic response properties.

10 ⊕

Section 4
BIOMEDICINE

The basic medical program for the 90-day manned test was directed primarily toward maintaining constant surveillance over crew health. The procedures were carefully selected to minimize instrusions into crew operations, for relevance to test conditions and for compatibility with the constraints of limited pass-out and the limitations in onboard crew capabilities. These basic procedures included constant medical attendance by licensed physicians, daily status checks, constant radiation exposure monitoring, biweekly clinical blood chemistries, and weekly electrocardiography and pulmonary spirometry. Continuous physiologic monitoring was not considered necessary or realistic in a simulation of a long-duration mission.

Certain low-level stresses were expected in 90 days of confinement in an artificial atmosphere. While these stresses were not expected to result in changes significant to crew health, changes might be significant with respect to future long-duration tests or space missions. Certain special studies were, therefore, added to the basic medical program and, because of the unique opportunities afforded by the complete crew isolation, an extensive microbiological sampling program was also carried out. An additional special study funded in part by MSFC through the airlock Project (MDAC-East) and in part by MDAC IRAD concerned the evaluation of the effects of long-term low-level carbon dioxide exposure on blood and urine biochemistry.

All routine and special procedures were explained in detail to the crew members before the test. It is noteworthy that, in contrast to other confinement studies, at no time before, during, or after the test did the crew members fail to perform scheduled biomedical tasks.

Results from the basic evaluation program reveal that the 90-day manned test was medically benign. Certain observations reveal sampling problems significant to future tests and to orbital missions. There were no apparent changes relevant to confinement, per se, but techniques in physical conditioning and in timely assessment of body fluid changes both require more study and improvement.

The special CO_2 study has produced preliminary results suggestive of biochemical trends developing from exposure to carbon dioxide. Results from this study are incomplete, but certain conclusions are made pending further study. The microbiology program is reported in detail in Section 4. 6.

4.1 PRETEST PROCEDURES AND BASELINE DATA

4.1.1 Physical Examination

Complete physical examinations, using the FAA Class I examination as a model, were part of the crew selection program (visual standards were waived for this test) and another brief examination was conducted immediately before confinement. These examinations revealed no significant medical findings and neither did the baseline clinical electrocardiograms (ECG). Extensive eye examinations, in support of the automated and visual sensitivity tester experiment, and clinical electroencephalography (EEG), in support of the sleep EEG study, were negative for pathology. Reports of the physical examinations are being held by the Test Medical Director as confidential medical information. Pertinent findings are summarized and compared with post-test findings in Section 4.3.1.

4.1.2 Clinical Chemistries

Clinical blood and urine analyses were initially performed on all candidate crew members as part of the crew selection and screening procedure. These analyses were performed by a commercial laboratory and included the following:

A. Blood

1. Complete blood count
2. RBC indices
3. Bleeding and clotting time
4. Alkaline phosphatase
5. Bilirubin, total
6. Fasting glucose
7. Glucose, 2 hours p-p
8. Blood urea nitrogen
9. Cholesterol
10. Serum calcium
11. Inorganic phosphorus
12. Uric acid
13. Total protein

14. Albumin

15. Glutamic oxaloacetic transaminase (SGOT)

16. Lactic dehydrogenase (LDH)

17. Protein bound iodine (PBI)

18. VDRL

B. Urine

1. Specific gravity

2. Glucose

3. Albumin

4. Microscopic examination of sediment

5. Occult blood

6. Acetone

7. Acid/base reaction

C. Stool — Microscopic examination for ova and parasites.

Standard bioanalytical techniques were used for all determinations. Blood tests 4 through 16 were performed on an autoanalyzer (Technicon Corporation SMA 12/60), using Hyland Laboratories control sera between each two samples.

These analyses revealed no significant medical findings except for a depressed PBI on one candidate and an elevated serum bilirubin on another. With additional testing, the low PBI was attributed to the candidate's low serum thyroxine (total T_4 = 2.2 micrograms percent, free T_4 = 1.0 nanogram percent) and extremely low thyroxine binding capacity (TBC = 3.5 micrograms percent). The candidate having the elevated serum bilirubin was diagnosed as expressing Gilberts syndrome. Neither finding was considered significant reason for disqualifying these candidates for the test. Screening test results are summarized in Table 4-1.

4.1.3 Radiological Health

The radiological safety program for the 90-day test of the SSS dealt with two distinct hazards. The most prominent hazard consisted of direct exposure of personnel to ionizing radiations emanating from radioisotope heat source capsules used in the urine recovery system (VD-VF). These included four capsules of approximately 70 to 75 watts thermal output and one of 45 to 50

Table 4-1

SCREENING TEST RESULTS, RAW DATA

Blood

Status	Crewman	Ca^{++} mg%	Inorganic P mg%	Glucose mg%	BUN mg%	Uric Acid mg%	Cholesterol mg%	Total Protein gm%	Albumin mg%	Total Bilirubin mg%	Alk. Phos. mU/mL	LDH mU/ml	SGOT mU/ml	Hemoglobin gm	Hematocrit Vol %	RBC $X10^6/mm^3$	WBC $X10^3/mm^3$	MCV μ^3	MCH μg	MCH %	Eosinophiles %	Segs. %	Lymphs. %	Monos. %	Bleeding Time min.	Clotting Time min.	PBI μg%	VDRL
Fasting	1	10.0	3.3	75	15.0	5.4	140	8.2	5.10	0.7	40	105	38	14.5	42.5	4.71	5.9	92	31.0	34.1	2	60	33	5	1'20"	4'10"	5.9	NR
	2	9.5	5.8	80	16.5	6.1	195	7.8	4.50	0.6	25	115	29	14.9	44.4	4.73	5.1	94	31.3	34.5	3	67	29	1	1'0"	3'20"	6.5	NR
	3	9.9	3.4	80	15.0	6.4	137	7.9	5.0	0.8	27	160	31	15.7	49.0	5.45	6.3	90	28.8	33.1	1	66	31	2	1'10"	4'45"	5.1	NR
	4	9.8	3.5	78	16.1	7.0	210	6.9	4.84	2.53	32	129	41	15.9	46.5	5.21	5.0	89	30.9	34.4	2	59	32	7	1'0"	5'30"	7.6	NR
	5	10.5	2.7	85	8.8	6.1	187	7.7	5.12	1.00	24	101	27	16.0	46.5	5.15	6.2	90	31.5	34.6	1	63	30	6	1'0"	5'30"	2.4	NR
	6	10.6	3.4	89	17.6	5.6	210	7.9	5.00	0.64	44	102	27	17.4	51.1	5.53	6.5	92	31.9	34.2	1	63	32	4	1'0"	5'30"	5.8	NR
2 Hr. Post-Prandial	1	9.8	4.6	59	16.0	5.3	130	7.8	4.9	0.6	35	105	35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	9.0	4.4	75	15.0	6.2	190	7.4	4.2	0.6	20	100	27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	9.8	3.4	105	17.0	6.5	228	7.4	4.4	0.5	25	170	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4	10.2	3.7	85	16.0	7.0	213	6.7	4.7	2.64	32	120	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	9.9	3.9	80	7.9	5.9	179	7.4	4.9	0.93	21	94	28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	6	10.0	3.3	101	15.6	5.5	203	7.6	4.8	0.63	41	94	27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fasting Normal Range		8.5-10.5	2.5-4.5	65-110	10-20	2.5-8.0	130-300	6.0-8.0	3.5-5.0	0.15-1.00	30-85	90-200	10-50	14-18	42-52	4.6-6.2	4.8-10.8	80-94	27-31	32-36	1-4	51-67	20-30	5-10	1-3	3-6	4-8	NR

Urine

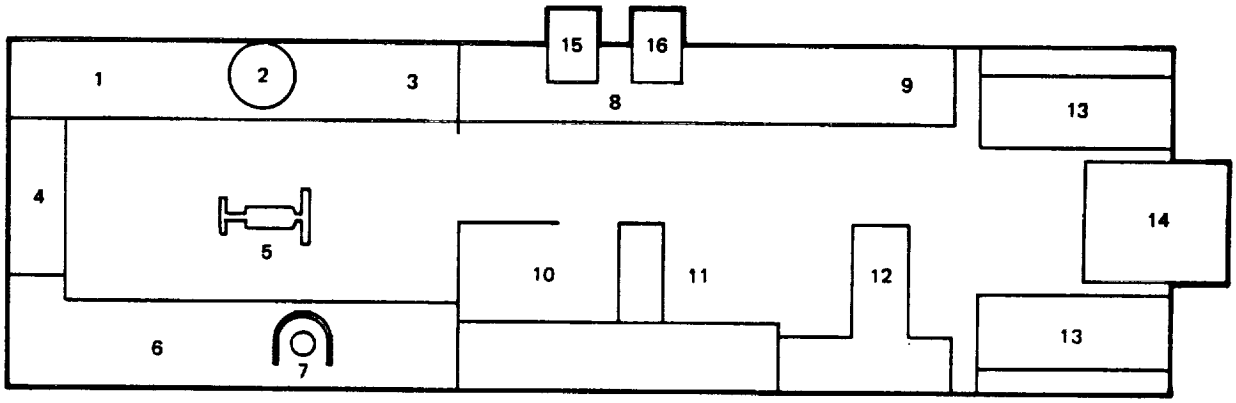
Crewman	Color	Charact.	Reaction	Albumin	Sugar	Acetone	WBC	RBC	Epithel. Cells	Amorph. Sed.	Casts	Crystals	Sp. Grav.	Remarks
1	Y	Clear	Neut.	0	0	0	0-2	0	Occ.	0	0	0	1.023	Many Mucous Threads
2	Y	Clear	Acid	0	0	0	0-2	0	Occ.	0	0	0	1.015	None
3	Y	Clear	Acid	0	0	0	0-1	0	Occ.	0	0	0	1.020	None
4	Y	Clear	Acid	0	0	0	0-2	0	Few	0	0	0	1.025	None
5	Y	Clear	Acid	0	0	0	0-1	0	Occ.	0	0	0	1.008	None
6	Y	Clear	Acid	0	0	0	0-1	0	Occ.	0	0	0	1.020	Many Mucous Threads

watts. The second hazard derived from the very remote possibility that a capsule might accidentally leak radioactive contamination. Trained personnel and special equipment, facilities, and procedures were employed to protect the health of the crewmen and to evaluate the significance of these radiological hazards so that similar radioisotope-fueled devices might be safely and confidently employed in a future Skylab or Space Station.

The external hazard posed by the radioisotope heat source capsules consisted of neutrons and gamma radiations. Neutrons, the most prevalent and hazardous radiation, emanated from spontaneous fission of ^{238}Pu and (α, n) reactions within the $^{238}PuO_2$. Gamma radiations resulted from the radioactive decay of daughter products and impurities, and contributed to about 10 percent of the dose. A 73-watt capsule produced a dose rate slightly greater than 5 mrem/hr at 1 meter and about 25 mrem/hr to the eyes and whole body at convenient handling distances. Such dose rates necessitated shielding the VD-VF unit, consideration of the location of the VD-VF unit and isotope storage container (chill box) within the SSS, and thorough analysis of handling operations.

The interior layout of the SSS with respect to the radiation areas is shown in Figure 4-1. As indicated, the VD-VF unit was located in the equipment and storage room. When the VD-VF unit was not in operation, the capsules were stored in water contained in a chill box located across the aisle from the VD-VF unit. The water was used to cool and shield the capsules.

R292-III



LEGEND

1. EXPERIMENTS/STORAGE
2. CHILL BOX
3. MAINTENANCE/SPARE PARTS
4. COMMAND STATION
5. ERGOMETER
6. LIFE SUPPORT EQUIPMENT
7. VD-VF UNIT
8. ONBOARD LAB/STORAGE
9. COUNTER/STORAGE
10. WASTE MANAGEMENT/ PERSONAL HYGIENE/STORAGE
11. FOOD PREPARATION/STORAGE
12. DINING/RECREATION
13. BUNKS
14. AIRLOCK
15. PASS-THROUGH AIRLOCK
16. PASS-THROUGH AIRLOCK (AUTOCLAVE)

Figure 4-1. Space Station Simulator, Simplified Interior Layout

A movable, U-shaped tank containing water was constructed to shadow-shield the VD-VF unit. Stationary water tanks above and below the unit were also a part of the shadow shield. Calculations indicated that a thickness of at least 0.25 meter (10 in.) of water in the shield would be required for uncontrolled access to the area (8-hour working day). Due to the volume occupied by the VD-VF unit and its thermal insulation, the mass and dimensions of such a shield would have been incompatible with easy access to the VD-VF unit, space available in the equipment and storage room, the actual time spent by the crew in the vicinity of the unit, and the general objectives of the program. As a compromise, shielding guidelines were established to prevent exposure of any major portion of the body to a dose rate in excess of 5 mrem/hr for the majority of activities and normal traffic within the equipment and storage room. Shielding was such that during normal operations of the VD-VF unit no area was accessible to personnel that would result in exposure of a major portion of the body to a dose rate in excess of 100 mrem/hr. When the layout of the equipment and storage room and the schedule of crew activities were examined, the usual activities and traffic were at distances greater than 1 meter from the outer surface of the shield. Calculations for this condition indicated that a 0.1-meter (4 in.) thickness of water plus the water always present in the VD-VF unit would shield to a dose rate of about 25 mrem/hr at the surface of the shield and 2.8 mrem/hr at 1 meter from the surface.

Before the shield was constructed, the conditions of exposure were analyzed to assure that no crewman would be knowingly exposed to an integral dose that would exceed the allowances given in the radiation protection guide (Table 4-2).

The dose rates were calculated for various locations within the SSS. Using these data, the maximum integral dose to a crewman was tabulated as shown in Table 4-3 according to the schedule of crew activities and the maximum dose rate for the location of that activity in the SSS. From Table 4-3 the integral dose for 90 days was expected to be less than 1.25 rem and well within the 3 rem that could be permitted for 3 months of radiation work.

Problems of control of radioactive contamination were not anticipated. First, the capsules were designed and tested to prevent release of any radioactive materials for all credible accidents during shipment of the capsules or testing of the VD-VF unit. Second, special procedures and equipment were used to prevent credible accidents. Third, the chemical and physical form of the $^{238}PuO_2$ microspheres minimized the danger to health and property from contamination in the unlikely event of capsule leakage or rupture. Nevertheless, a rigorous program of control was conducted in the event of accidental release of radioactive material from the capsules. The program emphasized the detection and containment of radioactivity and emergency procedures to minimize any contamination of personnel or property.

A preliminary accident analysis gave the following results. The total mass of ^{238}Pu was less than 10 percent of the minimun critical mass reflected. Further, the storage and utilization of the capsules in water lessened the

Table 4-2

FEDERAL RADIATION COUNCIL RADIATION PROTECTION GUIDE*

Type of Exposure	Condition	Dose (rem)
Radiation worker:		
(A) Whole body, head and trunk, active blood-forming organs, gonads or lens of eye	Accumulated dose	5 Times the number of years beyond age 18
	13 Weeks	3
(B) Skin of whole body and thyroid	Year	30
	13 Weeks	10
(C) Hands and forearms, feet, and ankles	Year	75
	13 Weeks	25
(D) Bone	Body burden	0.1 Microgram of radium-226 or its biological equivalent
(E) Other organs	Year	15
	13 Weeks	5
Population:		
(A) Individual	Year	0.5 (whole body)
(B) Average	30 Years	5 (gonads)

*From Federal Register, 18 May 1960

Table 4-3

MAXIMUM INTEGRAL DOSE FOR THE 90-DAY TEST

Crewman's Activity	Maximum Integral Dose (mrem)*	Crewman's Activity	Maximum Integral Dose (mrem)*
LRC tester	9.4	Maintenance	26.5
Eating	24.0	Laundry	3.8
Sleeping	72.0	Cabin cleaning	8.0
Exercise	57.0	LSS monitoring	2.2
Recreation	178.0	Pass-out	2.0
Body hygiene	90.0	Questionnaire	0.8
Waste management	45.0	Microbiological	1.5
Communications	55.0	Waste water filter change	1.5
Photography	8.9		
Medical data	4.4	Psychiatric interview	0.2
Sample collection	16.0	Serum sample	0.6
Microbial culture	8.7	Pharyngeal	0.3
Data management	18.0	Unscheduled activities	34.0
Medical interview	16.5	VD-VF changeover	120.0
		Total	804.3
Integral dose for all activities during the 90-day test is approximately			800 mrem

*Calculated from preliminary onboard time demands with the assumption of a 0.1-meter shield of water around the VD-VF unit.

potential for criticality, which was clearly impossible. The worst credible accident would have occurred if the double encapsulation of a heat source were ruptured and the contents spilled onto the floor of the closed SSS. Approximations indicated that if an air monitor warning were given within 30 sec, the crew could have probably escaped from the SSS without overexposure to ^{238}Pu. The regulations which limit internal exposure to $^{238}PuO_2$ are shown in Table 4-4. The critical organ was considered to be the lung and only the limits for the insoluble form are relevant. Procedures were adopted to prevent such an accident or any damage to the capsules.

A more credible accident would have been the leakage of radioactivity from a capsule resulting from mechanical or chemical damage or manufacturing defect. The leakage would have been augmented by helium buildup in the capsule and might have been a slow seepage or a rapid leak (puff) with the helium expanding and diffusing through the microsphere fuel. No data are available for a reliable evaluation of the consequences of capsule leakage. Using several approximations, a slow leak was not expected to yield a maximum permissible concentration (MPC) of 10^{-11} $\mu Ci/cm^3$ for continuous exposure of the lung. However, a puff release might produce a concentration of $^{238}PuO_2$ in air that would exceed acceptable limits by factors as large as 10^2 to 10^3. Such concentrations could result in a maximum permissible lung burden (MPLB) for a crewman within 1 to 10 hours. Another credible, but unlikely, accident could have resulted from overheating of a capsule. If the capsule were thermally insulated until its temperature exceeded ~1300°K, (~2,000°F) the capsule might rupture because of internal helium pressure augmented by other mechanical stresses. Calculations showed that at such temperatures the volatilization of $^{238}PuO_2$ could release radioactivity at the rate of ~13 $\mu Ci/hr$. Such a release rate within the SSS would exceed the MPC for ^{238}Pu within 1 minute and could result in a MPLB within about 1 hour. However, in view of the many precautions instituted, no conceivable accident could have resulted in a capsule overheating or even reaching its design operating temperature.

The above considerations required considerable pretest planning of test procedures, instrumentation requirements, crew training, etc. Detailed plans for the test program were delineated in Reference 4-1, which was reviewed and approved by the Operational Readiness Review Committee and constitutes a part of the overall test plan. The general safety program was outlined in the "Application for Special Nuclear Material License", A-303-JOH-120, which was approved by the US Atomic Energy Commission. These plans were followed with few exceptions which are itemized as follows:

A. An isotope analysis unit was added to the inventory of radiation detection instruments. This instrument was used for assay of air-monitor filters and smear samples for low-level, α-emitting contamination, and to assay dried water samples for low-level α and $\beta\gamma$ contamination. These analyses were made immediately by the medical physicist or the crewman rather than a delayed assay by the radiochemistry laboratory.

Table 4-4

RADIOBIOLOGICAL TOLERANCES OF ^{238}Pu

Radionuclide and Type of Emission	Location of Reference	Permissible Burden in Total Body	Radiation Protection Guides			
			40-Hr Week		168-Hr Week[c]	
			(RPG)Water μ Ci cm^{-3}	(RPG)Air μ Ci cm^{-3}	(RPG)Water μ Ci cm^{-3}	(RPG)Air μ Ci cm^{-3}
$^{238}Pu(\alpha,\gamma)$	(Sol.) Bone	0.04	10^{-4}	2×10^{-12}	5×10^{-5}	7×10^{-13}
	(Sol.) Liver	0.2	6×10^{-4}	8×10^{-12}	2×10^{-4}	3×10^{-13}
	(Sol.) Kidney	0.3	8×10^{-4}	10^{-11}	3×10^{-4}	4×10^{-13}
	(Sol.) GI (LLI)[a]	--	8×10^{-4}	2×10^{-7}	3×10^{-4}	6×10^{-8}
	(Sol.) Total body	0.3	10^{-3}	10^{-11}	4×10^{-4}	5×10^{-12}
	(Insol.) Lung	b	--	3×10^{-11}	--	10^{-11}
	(Insol.) GI (LLI)	--	8×10^{-4}	10^{-7}	3×10^{-4}	5×10^{-8}

[a]The abbreviations GI and LLI refer to gastrointestinal tract and lower large intenstine.

[b]Currently accepted lung burden is 0.016 μCi. This value was calculated by the standard formula as given by: Report of Comittee II on Permissible Dose for Internal Radiation (1959), Recommendations of International Committee on Radiological Protection, Pergamon Press, Inc., London, 1959; Health Physics, Vol. 3, 1-380 (June 1960).

[c]Use 1/10 of these values for off-site environmental levels.

Reference: S. G. Abrahamson, S'G. Carfagno, and B. R. Kokenge, Plutonium-238 Isotopic Fuel Form Data Sheets, MLM-1564, Mound Laboratory, Monsanto Research Corporation, Miamisburg, Ohio, October 31, 1968.

B. The film packets for personal exposure badges were supplied, developed, and evaluated by the Office of Environmental Health at the University of California at Los Angeles. This change was instituted to obtain the metal film badges necessary to meet flammability requirements and to extend the accuracy and reliability of the film badge readings. Also, a second film badge was given to each crewman which contained only a gamma-sensitive film. This film was worn the full 90 days in an attempt to measure the very low level of gamma radiation.

C. During the 5-day test and early 90-day test, the daily dose was so low that charging of the pocket dosimeters was abandoned. Rather, only the accumulated dose was recorded daily in an effort to eliminate the inaccuracy of the charging procedure.

D. The five shipping containers originally supplied by Mound Laboratory were not approved for shipping of the heat source capsules by the Department of Transportation under DOT Special Permit No. 6000. Consequently, a SNAP 27 Ground Shipping Cask, DOT Special Permit No. 5229, was supplied by Mound Laboratory. The capsules were loaded into the cask according to special instructions and transferred to an AEC courier at the conclusion of the test for delivery to Mound Laboratory.

4.1.4 Pulmonary Function

A small number of pulmonary function tests were administered to the four experimental subjects and to two control subjects. The tests were given 17 days prior to the commencement of confinement. Although no changes in pulmonary function were expected to result from the simulator environment or from the moderately hypodynamic situation of the subjects, it was felt that this vital function should be generally examined.

The measurements included: vital capacity (VC), inspiratory capacity (IC), expiratory reserve volume (ERV), timed vital capacity, maximal mid-expiratory flow (MMF), and maximum breathing capacity (MBC). All measurements were made with a Collins 13 1/2 Liter Respirometer in accordance with procedures described in References 4-2 and 4-3.

Vital capacity was measured on the best of three attempts by each subject. IC and ERV should be considered as estimates only. The resting expiratory baselines from which IC and ERV measurements were made were probably altered by the respiratory awareness of the subjects produced by the test conditions. Timed vital capacity and MMF were measured from the forced expiratory spirograms (FES) with the recorder drum rotating at its maximum speed (0.032 meter/sec) and were again the results of the best of three efforts by each subject. Maximum breathing capacity was recorded for 15 sec and measured by the excursions of the ventilograph pen on the recorder paper. The ventilograph ratio factor was 11.09 for the 13.5 liter spirometer.

The results of the prerun measurements are shown in Section 4.3.3. All values were considered to be within normal range and, in most cases, as high normals. All volumes and rates were corrected to BTPS.

4.2 TEST PROCEDURES/OPERATIONS

4.2.1 Medical Monitors

Licensed physicians were recruited from the surrounding area to provide full-time medical coverage. They were hired on a contract, fee for service basis and worked 12 hour shifts. After the first weekend (covered by the Medical Director), all shifts were filled. The primary duty of the medical monitors was provision of immediate medical support under emergency test conditions. They were not expected to carry out routine medical procedures or to participate in the special medical studies, except for recording basal signs on night and weekend shifts. Some monitors, who worked a number of shifts, did participate in certain medical test operations.

4.2.2 Medical Station

The medical monitor remained in the test operations area at all times. A small room adjacent to the operations area was equipped with a bed and night monitors were allowed to sleep. An emergency treatment area was established immediately adjacent to the SSS. This station was equipped with emergency drugs (under lock, controlled by the Medical Monitor), cardio-respiratory resuscitation equipment, and miscellaneous medical support items. A hyperbaric chamber was not necessary under the conditions of this test. Emergency medical support supplies were selected primarily for immediate resuscitation, stabilization and support for injuries, burns, and cardiorespiratory distress or collapse.

4.2.3 Onboard Medical Kit

A medical kit with supplies to be used under the supervision of the Medical Director was placed on board. No drugs were included which could cause crew incapacitation by side-effect or reaction. Two antibacterial agents were supplied; sulfamethoxazole (Gantrisin) for urinary infections and erythromycin (Erythrocin) for streptococcal infections. A broad spectrum antiobiotic was not considered appropriate for use in long-duration confinement. Penicillin, though the drug of choice for streptococcal infections, was not supplied because of its potential for significant allergic reactions. A variety of drugs for symptomatic treatment of minor problems was available to the crew and the total medical kit content is listed in NASA CR-111882.

4.2.4 Medical Interview

A short interview was conducted daily with each crew member by the Medical Director. This interview was informal and directed toward a general assessment of crew status. This interview afforded crew members the opportunity to report medical problems, vague symptoms or any other problem, in absolute privacy. More formal system reviews were conducted at selected times during the test. The results of these interviews are being held by the Medical Director as confidential medical information. Operationally significant crew reports, however, were shared with key personnel during the test with the permission of the crew member.

4.2.5 Basal Vital Signs and Skin Folds

Radial pulse rate, body weight, and sitting blood pressures (Baumanometer, anaeroid type manometer) were obtained on board by each crew member immediately upon arising. Body weights were taken (in uniform because of constant television monitoring of the area) on a clinical (Health-O-Meter) balance scale. These data were reported verbally to the medical monitor and recorded on daily medical data sheets. Oral temperatures were obtained during this same period using a Yellow Springs Instruments thermistor, displayed on the biomedical console and recorded on the same sheets by the medical monitor. Skin fold measurements (right triceps and right subscapular) were obtained weekly and reported. Three measurements were made at each site; these were averaged and the final measurement recorded as the mean of the two means. The skin fold evaluations were a late addition to the test and were intended to evaluate this simple procedure in following trends in subcutaneous fat. The crew received very limited pretest training in the use of the caliper (Lange Skin Fold Caliper, Cambridge Scientific Industries, Cambridge, Maryland).

4.2.6 Clinical Chemistries

4.2.6.1 Blood

Whole and clotted blood samples for clinical chemical analysis were collected from all crew members shortly before pass-through using plain and EDTA Vacutainers and disposable needles (Beckton, Dickinson Company). Precleaned glass slides were used to prepare two blood smears per man from residual needle blood. Vacutainers were stored in a small ice bath from time of collection until initiation of processing in the Medical Laboratory. One of two backup crew members acted as an "outside control" for these blood chemistries; this sample was collected at approximately the same time and using the same techniques and materials as that used on board. The sampling frequency throughout the test was maintained at one set of samples/subject every 2 weeks.

Once pass-through had been completed, the blood samples were immediately transferred to the Medical Laboratory for processing. Processing consisted of centrifuging the clotted blood for separation of clot and serum; transfer of serum to shipping containers; and packaging of anticoagulated blood, serum, and blood smears for shipment to the clinical laboratory. Maximum elapsed time between collection of blood and arrival of samples at the clinical laboratory was 4 hours. Analytical procedures were initiated immediately upon arrival of the samples. Preliminary data was available for review late in the afternoon of the day of pass-through. The analyses performed were as follows:

A. Complete blood count

B. Alkaline phosphatase

C. Bilirubin, total

D. Fasting glucose

E. Blood urea nitrogen

F. Cholesterol

G. Serum calcium, sodium, potassium, chlorides, and inorganic phosphorus

H. Uric acid

I. Total protein and albumin-globulin ratio

J. SGOT

K. LDH.

A small quantity of serum from each blood sample was held frozen at 230°K (-70°C) in the Medical Laboratory should a medical/toxicological emergency occur during the test. The clinical laboratory also maintained a store of frozen residual serum in case repeat or unscheduled analyses might be required.

4.2.6.2 Urine

Urine samples for clinical chemistries were collected from each onboard crew member as a 10-percent aliquot of all voidings during selected 24-hour periods. Each crewman would start collecting his sample with the second void after arising on the day collections were to be initiated. He would continue measuring the volume of each void (volumetric cylinder) over the next 24 hours and freezing a 10-percent aliquot of each void in a plastic bag including the first void upon arising at the end of the collection period. All urine samples were held frozen at 269°K (-4°C) on board until pass-through. The maximum onboard storage time between initiation of collection and pass-through was 120 hours.

Upon completion of pass-through, the urine samples were immediately transferred to the Medical Laboratory for processing. Processing consisted of thawing the frozen samples in warm water with transfer of an aliquot of each 24-hour collection to a fresh plastic bag for shipment to the clinical laboratory. Residual urine was held frozen at 203°K (-70°C) in the original collection bag as a contingency sample. Upon arrival at the clinical laboratory, the urine samples were refrozen until analysis could be initiated the following day. Preliminary data was usually available for review within 48 hours of pass-through. The analyses performed were as follows:

A. Routine urinalysis

B. Sodium, potassium, calcium, chloride, and inorganic phosphorus

C. Total titratable acidity

D. Ammonia

Analyses B, C, and D were performed as part of the special CO_2 studies (Section 4.4.1). The clinical laboratory maintained a store of frozen residual urine in case repeat or unscheduled analyses might be required.

4.2.7 Radiological Monitoring

Prior to initiation of the test, the radioisotope capsules were installed in the VD-VF unit and the chill box. The neutron and gamma dose rates were measured with calibrated survey meters at various distances and locations around each installation.

Personnel dosimetry during the 5-day checkout and the 90-day test consisted of film badges and pocket dosimeters. The film badges were the legal record of radiation exposure of the crewmen. Each crewman wore two film badges and two pocket dosimeters. One film badge contained both neutron and gamma-sensitive films. During the 90-day test, a supply of film packets was stored in the cabinet in the living quarters most distant from the radiation area. Each week, the crew changed film packets in these badges and sent the exposed packets, plus a control packet, out of the SSS via the weekly passout of samples. The other film badge contained only a gamma-sensitive film and was retained for the full 90 days. The film packets were specially supplied, developed, and evaluated for the recorded dose by the Office of Environmental Health at the University of California at Los Angeles. Each crewman was also issued a set of direct-reading pocket dosimeters, one sensitive to gamma and the other sensitive to neutron and gamma radiation. The total accumulated dose indicated on each dosimeter was recorded daily. The pocket dosimeters were only used to indicate any excessive daily exposure. At low doses (<2 divisions/200 scale divisions), these dosimeters were prone to artifact and large inaccuracies in use and interpretation.

The procedures for detecting any release of radioactivity included air monitoring, smear analysis, radiation survey, and water analysis. The air in the vicinity of the capsules was continuously monitored for α-emitting contamination by an air monitor equipped with an audible and visual alarm. The daily air filters were assayed for low-level α-emitting contamination with the isotope analysis unit. During every handling operation, the entire surface of each capsule was wiped with a dry cloth. All smears were checked for α-emitting contamination with an α-survey meter and occasionally checked with the isotope analysis unit. Handling devices, personnel, clothing, and any surfaces coming in contact with the capsules were surveyed for α-emitting contamination. Prior to human consumption, samples of reclaimed water from the VD-VF unit were monitored for radioactive contamination by survey of the dried samples and analysis with the isotope analysis unit.

The air monitor filter was changed daily and the air monitor was checked for performance and calibrated with a ^{238}Pu α-standard. The α-standard was also used to calibrate the isotope analysis unit and the α-survey meter before use. Emergency and contingency procedures were adopted and were to be instituted whenever predetermined levels of radioactivity could be detected in the air or water or by a smear test.

4.2.8 Electrocardiogram

A two-lead electrocardiogram (ECG) was taken on each crew member once/week throughout the test. The leads consisted of a transaxillary and a sternal to V_5 configuration. Tracings were taken, one lead at a time, with the crewman in a supine position. The leads were reconfigured by requesting the crewman to remove the sternal electrode and replace it near the right axillary site of the common electrode.

The equipment consisted of three Ag-AgCl recessed pellet-type electrodes (positive, negative, and common) held to the chest with adhesive rings. Electrically conductive putty was used to make contact between the pellet and the skin surface. Lead wires from the three electrodes were gathered into a short cable and jack leading to a waist mounted J-box containing an electrical shock protector (Spacelabs, Inc., Van Nuys, California; Model No. 170-3101). The shock protector absolutely isolated the crewman being monitored from currents in excess of 10 microamperes. The output from the J-box was then transmitted by shielded cable to a non-power-carrying electrical feedthrough in the simulator bulkhead, through a cable trench into the control room, and was then terminated at the medical console. The ECG input was fed into a single channel Comput-EK (Computer Instruments Corporation, Hempstead, Long Island) strip chart recorder for visualization of the signal.

The procedure required approximately 300 sec to unstow and attach the electrodes and nominally less than 60 sec per subject to obtain the tracings. No difficulties were encountered in utilizing the instrumentation except for an occasional incorrectly positioned electrode evidenced by low amplitude and/or reverse polarity QRS complexes.

4.2.9 Pulmonary Spirometry

At the request of NASA-LRC, it was planned to record forced vital capacity velocity-volume ($\dot{V}$-V) loops before and after the 90-day test. Upon receiving the pretest data, it was recognized that the recording spirometer could be of great value in assessing pulmonary function on board in case of toxic contaminant buildup. The spirometer, accordingly, was added to the onboard equipment for this primary purpose. As a secondary goal, $\dot{V}$-V loops were recorded weekly to evaluate possible long-term changes in pulmonary function resulting from confinement or long-term exposure to very low levels of atmospheric contaminants.

Graphic $\dot{V}$-V loops can be recorded when an individual performs a force vital capacity maneuver through a low resistance spirometer (Model 470 Hi-Fi Spirometer, Med-Science Electronics, Inc., furnished by NASA-LRC). Appropriate transducers produce electrical outputs proportional to volume and velocity; these outputs were then recorded on a Tektronix, Inc. storage oscilloscope and a Polaroid photograph of the tracing was taken for a

permanent record. The forced vital capacity maneuver involves four steps: (1) several normal inspirations and expirations were accomplished; these are recorded as tidal volume, (2) the subject expires maximally; this is recorded as expiratory reserve volume, (3) the subject inspires maximally; this is recorded as inspiratory volume flow rate and inspiratory reserve volume is established, (4) finally, the subject expires maximally, closing the $\dot{V}$-V loop and establishing expiratory volume flow rate. The loop is illustrated in Figure 4-2 and the equipment is diagrammed in Figure 4-3.

The technique of recording flow-volume loops has been detailed by Dery, et al (Reference 4-4) and appears to be an extremely sensitive method for evaluating pulmonary function. It is of interest that each individual presents a characteristic loop, almost unique for himself. Alterations in that characteristic loop suggest pulmonary problems very early in their development.

4.3 POST-TEST PROCEDURES

4.3.1 Physical Examination

All crew members were given a complete physical examination immediately upon egress from the SSS and before showering. No remarkable changes were observed on this examination; all appeared to be in excellent health (and spirits). Pretest and post-test pertinent findings are summarized for each crew member in Table 4-5.

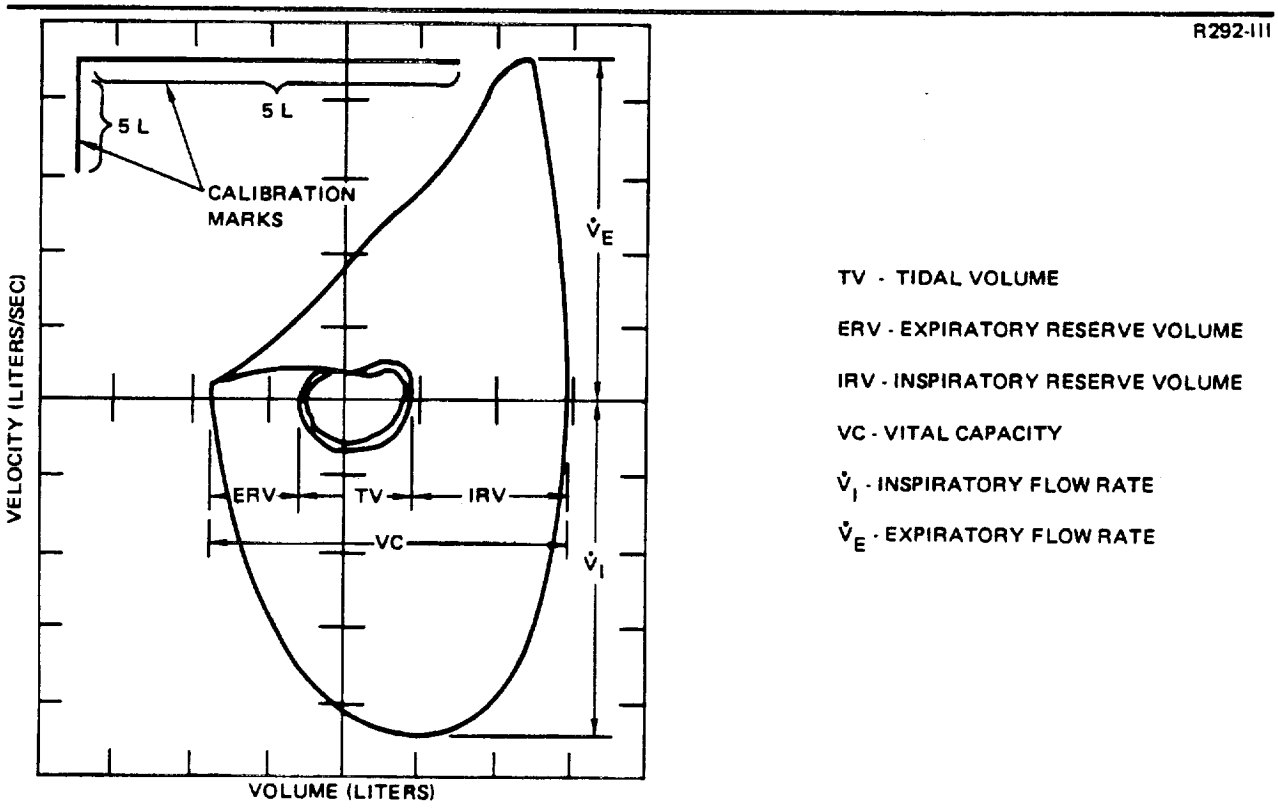
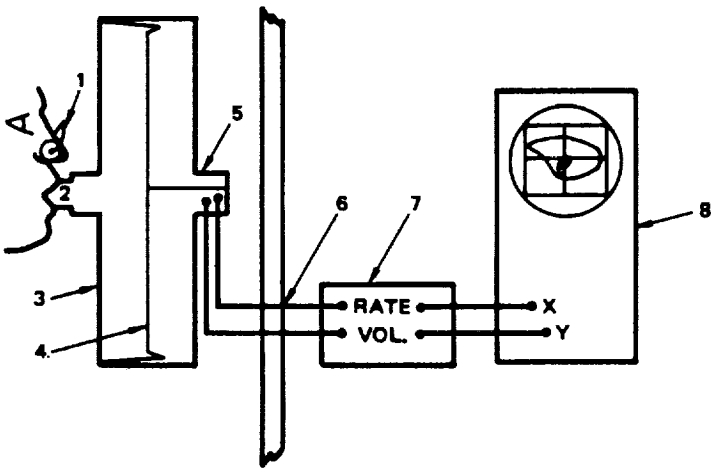


Figure 4-2. Typical Volume - Flow Loop and Subdivisions



1 NOSE CLIP
2 DISPOSABLE/INDIVIDUAL MOUTHPIECE
3 WATERLESS SPIROMETER
4 LOW MASS PISTON AND ROLLING DIAPHRAGM
5 TWO LINEAR DISPLACEMENT TRANSDUCERS FOR RATE AND VOLUME
6 SSS BULKHEAD ELECTRICAL FEEDTHROUGH
7 SIGNAL CONDITIONER
8 STORAGE OSCILLOSCOPE (WITH CAMERA ATTACHMENT)
X - AND Y - AXES FOR RECORDING IN THIS TEST

Figure 4-3. Spirometer Setup

4.3.2 Clinical Chemistries

Blood and urine samples were collected from all crew members 4 days after the test. Blood collection and processing techniques were identical to that used during the test. Urine samples were collected as previously described. With the exception of the VDRL serology test, all blood and urine analyses performed before the test (see Section 4.1.2) were repeated after the test. Stool examination was not required. Contingency serum and urine samples were obtained and preserved as previously described. Post-test clinical chemistry results are included in Appendix I.

4.3.3 Pulmonary Function

Pulmonary function tests identical to those administered before the run were repeated on the day following its conclusion. The values for the various post-test measurements are presented in Table 4-6 for comparison with the pretest baseline data. It may be noted that the pretest and post-test values for all crew members compare quite closely. All differences were considered to be within the normal variation of these completely unpracticed individuals. Three crew members (CM 1, 2, and one outside CM) showed manifest

Table 4-5

PRETEST AND POST-TEST PHYSICAL EXAMINATION SUMMARY

	Crew Member	Body Weight (kg)	Heart Rate	Blood Pressure (mm Hg-LAS*)	Remarks
Pretest (6-13-70)	1	57.5	112	130/70	Nasal congestion, slight pharyngeal erythema.
	2	58.4	100	100/56	Nasal congestion, slight pharyngeal erythema.
	3	73.3	68	116/60	Slight oropharyngeal congestion and erythema.
	4	78.3	64	118/60	No significant findings.
Post-Test (9-11-70)	1	57.4	64	112/76	Moderate scalp scaling, slight acneform eruption over shoulders.
	2	61.5	80	108/76	Moderate but extensive acneform eruptions, face and back.
	3	72.8	76	112/82	Still has evidence of suntan.
	4	77.8	66	124/88	Minimal acneform eruptions, back.

*LAS - Left Arm, Seated

Table 4-6
PULMONARY FUNCTION

Crew Member		Lung Volumes (BTPS)						Breathing Mechanics					
		Vital Capacity (cm^3)		Inspiratory Capacity (cm^3)		Expiratory Reserve (cm^3)		Timed Capacity (% of VC Exhaled in First Second)		Maximal Midrespiratory Flow (cm^3/sec)(BTPS)		Maximum Breathing Capacity (cm^3/sec)(BTPS)	
		Pre-run	Post-run	Pre-run	Post-run	Pre-run	Post-run	Pre-run	Post-run	Pre-run	Post-run	Pre-run	Post-run
Experimental	4	6,450	6,600	4,660	4,400	1,790	2,200	90	85	5,940	5,820	3,230	3,400
	3	7,150	7,500	4,450	4,500	2,700	3,000	78	75	5,600	5,470	2,620	2,560
	2	5,475	5,650	3,340	3,240	2,135	2,410	83	88	4,700	4,760	2,940	3,400
	1	4,480	4,400	2,620	2,800	1,860	1,600	99	100	7,750	7,800	2,520	3,300
Controls	5	6,550	6,350	4,050	4,025	2,500	2,325	75	81	4,320	4,570	2,700	2,600
	6	5,500	5,720	3,620	3,960	1,880	1,720	87	83	4,360	3,760	2,700	3,160

increases in their post-run maximum breathing capacities. It was felt, however, that these increases were due to improvements in technique rather than actual changes in breathing capacity.

It was concluded that the conditions of the test produced no change in the pulmonary function of the crew members.

4.4 SPECIAL STUDIES

As noted in the introduction to this section, basic medical procedures were established for the primary purpose of monitoring crew health. The procedures were broadly based to screen essentially all organ systems for developing pathology. Such a broadly based program cannot produce definitive information on the effects of specific stresses, particularly when the stresses are low level. These low-level stresses in an otherwise benign environment do not result in obvious changes over short periods of time - but carry significant connotations if trends continue or for interactions with other stresses, e.g., zero-g. Although the 90-day test had no real precedent allowing accurate prediction of all stresses, certain potential problems could be identified. Confinement in itself constitutes a stress which can cause organic changes, for example, loss of cardiovascular conditioning, loss of bone, muscle mass and changes in body fluid compartments. These effects also occur in other hypodynamic environments, e.g., bed rest, zero-g. The effects of 1-g confinement, therefore, should be evaluated to enable more accurate evaluation of the effect of zero-g alone. It was also known that the carbon dioxide level in the SSS would exceed normal atmospheric levels but would probably average well below that experienced in other prolonged exposures, for example, submarines. No data exist on the long-term effects of exposure to the predicted low CO_2 levels. For these reasons, several special studies were added to the Biomedical program in an attempt to identify effects of these unique stresses. In addition, one experiment was planned to evaluate an automated vision test apparatus. Additional studies were carried out to evaluate biochemical correlates of low-level stress.

4.4.1 Carbon Dioxide Exposure Studies

Average CO_2 levels (Pco_2) were planned to be in the 3 to 5 mmHg range for the 90-day test. Since an advanced CO_2 concentrator was to be used, excursions were expected but the maximum level was to be held generally to less than 8 mmHg. Since no data exist on long-term exposures to these low levels of CO_2, the studies to be outlined in this section were instituted. They are basically biochemical evaluations since no overt physiologic or performance decrements were expected. Biochemical changes, if significant within laboratory precision limits, would grossly complicate research into the effects of zero-g and for this reason are extremely important, even if not actually harmful to the individual.

4.4.1.1 USN SMC Blood Studies

Through the cooperation of Dr. K. E. Schaefer and coworkers A. Messier and E. Heider (US Naval Submarine Medical Center, Groton, Connecticut), a program to investigate venous* blood gas and electrolyte physiology during the test was instituted. Heparinized blood samples for this purpose were collected from all prime and a minimum of one backup crew member pretest, during, and post-test. The sampling schedule was once per man pretest, once per man per week during the test, and one sample per man immediately, and at 4, 18, 25, and 88 days post-test.

The collection and processing of these samples was similar to that used for the collection of blood for clinical chemistries. Two 7-cm^3 heparinized Vacutainers of blood were collected from each crewman shortly before pass-through each week. The blood samples were kept cold in an ice bath from the time of collection until processing was initiated in the Medical Laboratory. Processing consisted of quickly filling one of the two sample tubes with well-mixed blood from the other tube; centrifuging the rubber stoppered full tube to separate plasma and red cells; rapidly transferring the plasma and packed red cells to separate small syringes, and packing the syringes in dry ice for air shipment to the USNSMC. These procedures were instituted to reduce interaction between cellular and fluid compartments and between the ambient atmosphere and the whole blood sample between the time of collection and analysis.

All on-board and backup crew members were sampled after at least 4 hours of fasting. Crewmen 1 and 2 were sampled shortly after arising (0700) while crewmen 3 and 4 had been active before sampling since 2100 hours the previous evening. The backup crew member samples were taken at approximately the same time and using the same technique as those on board. These crew members were sampled from 1 to 2 hours after arising.

No major problems were encountered during the test program except for an occasional delay in receipt of the blood samples at USNSMC due to shipping tieups. The material had been packed with sufficient dry ice to preclude deterioration of the samples should this contingency occur. Only one set of samples was lost because of inadvertent freezing of the whole blood before separation of cells and plasma.

The analyses performed on these samples included both plasma and erythrocyte intracellular pH, Pco_2, HCO_3^-, Na^+, K^+, Cl^-, and water content. The analytical techniques for this study had been developed by Dr. Schaefer over a number of years during his continuing investigations of the physiological effects of elevated carbon dioxide tension on submarine crews. A complete description of the techniques utilized may be found by referring to previous papers in this series of experiments by Schaefer and coworkers (References 4-5 and 4-6).

*It is recognized that arterial blood would have been preferable. Arterial punctures were clearly impossible for this test and, in view of the short training period available between the inception of this study and test start, we did not attempt "arteriolized" venous blood sampling (warmed hand vein or ear lobe).

Briefly, for this experiment, pH and Pco_2 were analyzed with an Instrumentation Laboratory Blood Gas Analyzer Model 1135-1; pH was determined in triplicate and Pco_2 in duplicate. Plasma bicarbonate was read from a nomogram using the directly measured pH and Pco_2 values. Red cell bicarbonate was calculated from the hematocrit, plasma bicarbonate, and Pco_2 data as delineated by H. W. Davenport in "The ABC's of Acid-Base Chemistry". Red cell pH was calculated from plasma Pco_2 and red cell bicarbonate using a red cell pK_i of 6.092. Plasma and red cell Na^+ and K^+ were determined with an Instrumentation Laboratory Flame Photometer. Cl^- was measured by chloridometer. Water content was determined gravimetrically after drying samples of plasma and red cells to constant weight.

4.4.1.2 Urine Studies

As part of the CO_2 studies, urine electrolyte, titratable acidity, and ammonia determinations were performed by the clinical laboratory in addition to routine urinalysis. As indicated earlier, this sample was provided as a 10-percent aliquot of selected 24-hour urine collections from each of the four onboard crewmen. Samples were obtained once per week for the first 8 weeks and then twice per week for the remainder of the test. A single post-test sample/crewman was collected 5 days after egress. These studies were conducted for comparison with and to extend data obtained by other workers investigating long-term exposure to low-level inspired CO_2. Previous studies by Schaefer (Reference 4-5) of subjects exposed to 1.5 percent CO_2 for 42 days indicated the occurrence of an initial period (23 days) of uncompensated respiratory acidosis (CO_2 retention) followed by a period of compensated respiratory acidosis (CO_2 excretion and storage). Although the urine reflected blood pH and Pco_2 shifts during both phases of acidosis, the kidney played only a small part in regulating acid-base balance compared to its role at higher levels of CO_2 exposure (3 percent and above). What was more significant, possibly, was the electrolyte excretion data which indicated, along with plasma and red cells studies, that a significant exchange of CO_2 between blood and bone and between plasma and red cells was gradually taking place. On the other hand, Glatte, et al (Reference 4-7), in 5 days exposure to 3 percent CO_2 (21 mmHg Pco_2 – 2.8 kN/m^2), found no significant urinary excretion patterns except during the recovery period when decreased H^+ excretion was observed. On greatly prolonged exposure to low levels of inspired CO_2, however, the slow adaptive processes might induce pathophysiological states.

Trends toward such an adaptive process (acclimatization) would be studied over the course of the test by correlating MDAC urinary excretion data with USNSMC plasma and red cell data, atmospheric CO_2 level, and duration of exposure.

4.4.1.3 Sleep Heart and Respiratory Rates (A Crew Experiment)

As an individual crew experiment during the 90-day test, crewman 4 elected to study the sleeping heart and respiratory rates under confinement in the cabin atmosphere in relation to cabin partial carbon dioxide pressure. This

was done in a manner so as to create minimal disturbance to the normal sleep pattern from the instrumentation required. Heart rate was measured by the Collins ear clip photocell sensor wired to the remote strip chart recorder, and respiratory rate was determined by taping the probe tip of the onboard oral thermistor just below the nostrils. With optimal orientation of the probe tip, a temperature difference of 1 to 2°C was recorded with each respiratory cycle. The signal was recorded on a second remote strip chart recorder (C. E. C. Recording Oscillograph, Model 5-124).

The experiment protocol typically would involve fifteen to twenty minutes for applying the sensor leads in the SSS, while support personnel outside calibrated the strip chart recorders and confirmed recording of a signal. The heart rate recorder was operated at a slow speed (0. 6 cm/minute) and was generally left running continuously once recording began. As the respiratory recorder had to be run at a higher speed (6 cm/minute) to extract the respiratory frequency information, it was periodically run at five to fifteen minute intervals as personnel availability allowed, for at least a minute each time. Periodic time hacks were marked on the records to allow correlation.

4.4.2 NMRI Blood Studies

Through the cooperation of E. M. Neptune, Jr., R. E. Danziger, T. E. Sallee, and D. E. Uddin at the Naval Medical Research Institute (NMRI), Bethesda, Maryland, a program was funded by LRC and developed by MDAC and T. O. Wilson of LRC to study the extent and nature of subtle biochemical changes which might take place in the crew members over the course of the test. Changes in minor phospholipids have been reported to occur after acceleration stress, combat stress, and in schizophrenia (Reference 4-8). Data from the laboratories have indicated that severe psychological stress may be reflected in serum lipids and it is well known that there are hormonal and neurological factors controlling serum free fatty acid levels. Physical stresses and specific tissue damage are most conveniently assessed by examination of serum enzymes and isozymes. The program would investigate such changes for each crewman and groups of crewmen by comparing data gathered weekly during the test with pretest baseline and post-test recovery data. Trends and correlations between parameters would be sought by standard statistical methods; correlations between these biochemical and any environmental or psychological determinants obtained during the test would be of special interest.

The biochemical analyses selected for use during the test were as follows:

A. Neutral Lipids — Monoglyceride, free fatty acids, cholesterol, diglyceride, triglyceride, cholesterol esters.

B. Phospholipids — Lysophosphatidyl choline, sphingomyelin, phosphatidyl choline (incl. phosphatidyl serine and inositol) and minor phospholipids.

C. Lipoprotein Distribution — Alpha, pre-Beta, Beta.

D. Serum Enzymes — Acid phosphatase, alkaline phosphatase, amylase, creatine phosphokinase, lactic dehydrogenase.

E. Other Constituents — Cholesterol (chemical), free fatty acids (chemical), glucose, lactate, haptoglobin.

These procedures were developed by NMRI during previous investigations of the biochemical/psychological consequences of stress associated with hyperbaric confinement.

In addition to the analyses listed above, Dr. F. Lee Rodkey of NMRI performed carboxyhemoglobin determinations on residual clotted blood remaining from each crew member's weekly sample before, during, and after the test. These analyses would not only provide an accurate check of the atmospheric carbon monoxide concentration, but would also yield information concerning crewman-atmosphere CO equilibration kinetics and the magnitude of the contribution of simulator component CO outgassing to the total CO production.

4.4.2.1 Serum Analyses

Blood samples for the NMRI study were obtained from each primary and at least one backup crewmember shortly before pass-through each week of the test. As indicated previously, only crewmen 1 and 2 were truly in a near basal and fasting state at the time these samples were taken (0700 to 0800 hours); crewmen 3 and 4 had been active since 2100 hours and nominally had not eaten during the previous 4 hours; backup crewmen were fasting but had been awake and active for 1 to 2 hours before sampling. Blood was collected in 15 cm^3 Vacutainers and held cold in an ice bath from the time of collection until processing was initiated in the Medical Laboratory. Processing consisted of centrifuging the clotted blood samples to separate clot from serum, transferring the serum to $CHCl_3$-MeOH washed (lipid free) screw capped test tubes, and shipping the residual clot and separated serum tubes, packed in wet ice, by air freight to the NMRI. The nominal time between sampling and initiation of analysis was 24 hours. No difficulties were encountered during the test except for one unusually long delay caused by a shipping tieup. Although this set of samples was analyzed, some of the data are questionable because of the estimated 24 hours of sample storage at ambient temperature.

A total of 6 pretest, 13 test, and 3 post-test serum samples was analyzed for each crewman over the course of the program. The analytical procedures as developed by the investigators utilized commercial lyophilized serum as a control for serum enzyme analysis and pooled frozen serum (genetic type 2-1) as a control for haptoglobin analysis. Chemical standards were analyzed with glucose, lactate, cholesterol, and free fatty acid. No satisfactory controls existed for the other determinations.

A. Lipid determinations — Neutral and phospholipid distributions were determined by standard procedures developed in the laboratory (References 4-9 and 4-10). Lipoproteins were determined by a modification of Noble's procedure with quantitation being accomplished by densitometry (Reference 4-11).

B. Enzyme determinations — Total lactic dehydrogenase (LDH) was determined by the method of Babson and Phillips (Reference 4-12). LDH isozymes were detected after electrophoresis in 0.9 percent agarose on microscope slides and quantitated by densitometry. The electrophoresis was carried out in 0.05 M barbital pH 8.6 for 25 minutes at 150 volts. Alkaline and acid phosphatase were determined using Boehringer Mannheim kits. Creatine phosphokinase (CPK) was determined by a Calbiochem kit. Amylase was determined by a modified Cherry-Crandall starch hydrolysis method supplied as a kit from Harleco.

C. Other serum measurements — Glucose was measured as true glucose by the glucose oxidase method (Worthington Glucostat). Lactate was determined by a modification of the method outlined in Bergmeyer (Reference 4-13). Cholesterol was analyzed by the Liebermann-Burchard reagent (Harleco). Nonesterified fatty acids were quantitated by a modification of Novak's method (Reference 4-14).

4.4.2.2 Carboxyhemoglobin (COHb) Analyses

Clotted blood for the COHb determinations was collected, processed, and shipped to NMRI as described above. Upon arrival, the clotted specimens were analyzed by Dr. Rodkey for CO content by gas chromatography and a comparison with the total hemoglobin was determined by the cyanmethemoglobin method.

4.4.3 Automated Visual Sensitivity Tester

The primary objective of this investigation was to obtain a periodic assessment of selected visual functions of each crew member under the stresses imposed by confinement for 90 days. Secondary test objectives included the determination of the user acceptance of the test equipment, and operational reliability and maintainability under these particular test conditions.

An automated visual sensitivity tester (illustrated in Figure 4-4 and described in detail elsewhere, Reference 4-15) was designed and built at NASA Ames Research Center under the direction of Richard F. Haines, Research Scientist. It measured two visual functions. The blind spot mapping test measured the size, shape, and location of the normal blind spot (optic disk). Thus it provided an indication of intraocular pressure changes (Reference 4-16). The visual sensitivity test measured the retina's ability to detect the offset and onset of a small, white, moving test spot. An earlier clinical validation study of this device (Reference 4-15) showed that patients having chronic glaucoma also possessed an enlarged blind spot which could be plotted using the present tester. Those patients having other retinal insensitivities, such as punctate and arcuate scotomata, could be detected using the visual sensitivity test.

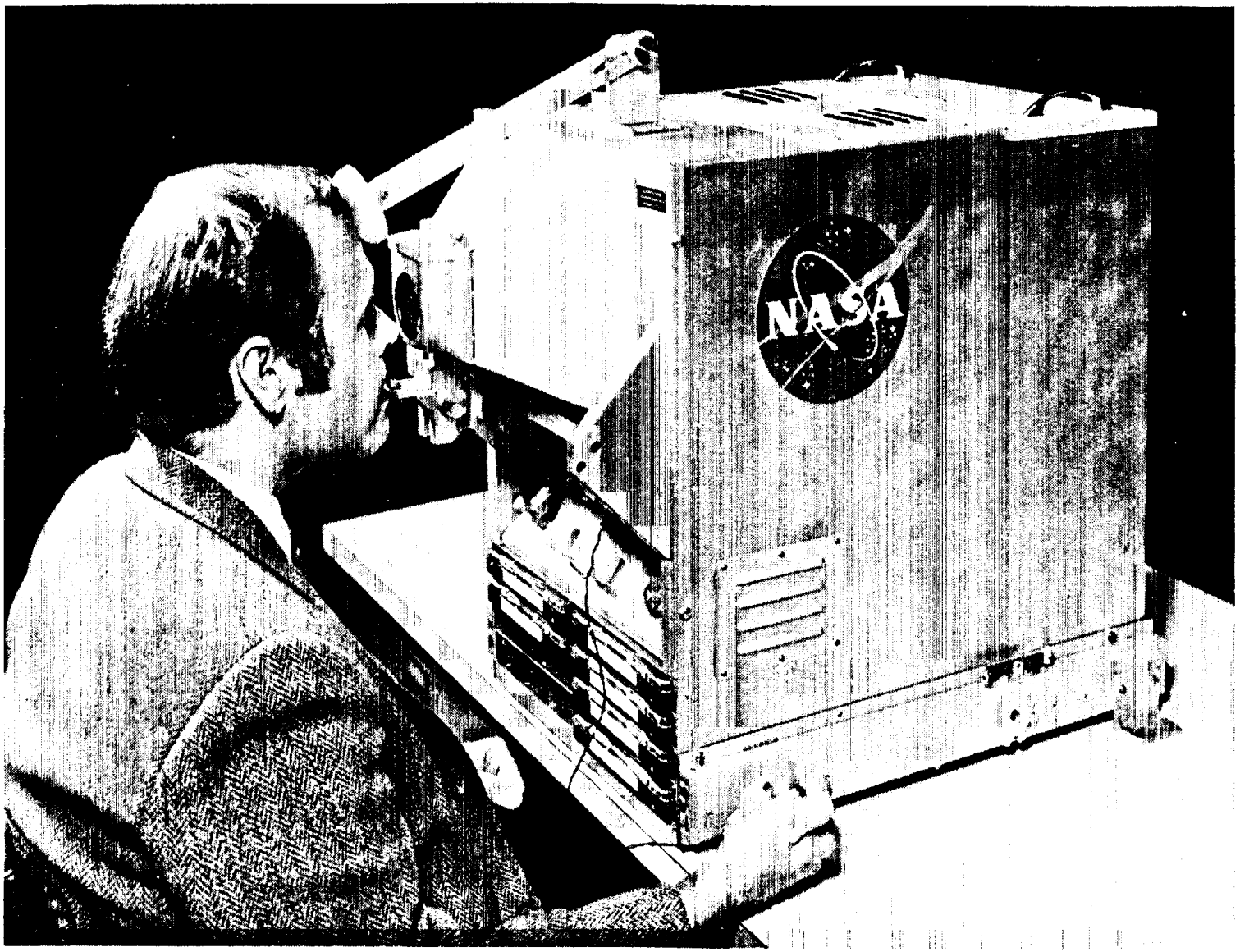


Figure 4-4. Subject Taking Automated Visual Sensitivity Test

The visual capabilities of the 90-day confinement crew were not expected to change as a function of the present test conditions. However, should some unexpected event occur to change the chamber's pressure, temperature, humidity, or other parameters, it is possible that the crew's visual capabilities could be affected. This is indicated by a number of studies. Beehler et al (Reference 4-17), Roth (Reference 4-18), and Saltzman et al (Reference 4-19) found that prolonged exposure to too high a partial O_2 pressure could be deleterious to human vision because of O_2 toxicity. It is also known that too high a partial CO_2 level impairs the transportation of O_2 within the retinal tissue. Studies by Brandis (Reference 4-20) and Kissen (Reference 4-21) found that elevations in body temperature can change visual thresholds. Kerslake (Reference 4-22) found that extremely low humidity levels may produce conjunctival inflammation. If hypoxic conditions should occur, they could lead to a raised scotopic (rod receptor) threshold, decreased acuity, reduced critical flicker frequency (CFF), cataract production, and even visual blackout and unconsciousness (References 4-23 through 4-29). In light of these findings, it seemed warranted to test for each crewman's light detection capability (within a 60 degree arc diameter field of view centered on the fovea) and for possible changes in dimensional characteristics of his blind spot.

4.4.4 Isotope Studies

Total body water, plasma volume, blood volume, and potassium content of the whole body were measured as a special study within the medical program for the 90-day test. These measurements were undertaken because of evidence of major problems in adaptation to zero gravity. Since alterations in fluid volumes and lean body mass may also result from the inactivity associated with confinement, any changes that occur in a simulated environment at earth gravity must be documented to establish a baseline for interpretation of changes at zero gravity. In addition, measurements of body fluids and lean body mass are necessary for normalization of other medical measurements used to monitor the health of the crew and determine any biological effects of the environment.

Using radiopharmaceuticals, total plasma and blood volumes, total body water, and the derived lean body mass were determined for six normal, healthy, young (age 21 to 35) male volunteers. Two individuals served as normal controls and the other four were crewmen in the SSS for 90 days. Baseline determinations for all six individuals were obtained 6 days before the entrance of the four experimental crew members into the SSS. This allowed partial excretion of the radionucleide burden, especially tritium, before the simulator study. The three determinations were repeated on the same six crew members immediately upon egress from the 90-day test. In addition, a total body water determination with tritium was performed on the 61st day of the simulator test by having the crew members drink tritiated water stored on board.

The plasma and blood volume determinations were made by M. B. Cohen, M. D., a consultant and medical specialist in radioisotope methodology. Using standard medical procedures, plasma volume was measured by intravenous

injection of 10 μCi of ^{125}I-RISA for each determination. After allowing a 15-minute interval for equilibrium, a blood sample was taken by venapuncture. Plasma volume (PV) was determined by:

$$PV = \frac{(\text{CPM/cm}^3 \text{ of standard solution}) (\text{dilution factor}) (\text{cm}^3 \text{ injected})}{\text{CPM/cm}^3 \text{ of postinjection sample}}$$

Total blood volume (TBV) was determined from the hematocrit (Hct) as follows:

$$TBV = \frac{\text{Plasma Volume}}{1 - (\text{Hct X0.91})}$$

The counting error was always reduced to less than 1 percent.

Total body water (TBW) was determined with tritiated water (^3H_2O). Total body waters were measured by and under the supervision of N. Telfer, M. D., in laboratories in the medical school of the University of Southern California. Approximately 1 cm^3 was mixed in a drinking cup of water and administered to the crew member orally. A second 1 cm^3 sample was kept as a standard. Accurate determination of the dose and standard was made by weighing the syringes with the tritiated water before and after administration on a laboratory balance accurate to 0.001 mg. Urine specimens were collected from each crewman at 3 and 5 hours. Water was separated from electrolytes, protein, etc., which interfere with counting, by freeze-vacuum distillation.

One cm^3 of the distillate was added to the counting solution and the standard and samples counted in a liquid scintillation counter.

$$\text{Calculation: } TBW\ (m^3) = \frac{\text{Ci administered}}{\text{Ci/m}^3 \text{ in sample}}$$

Because of the reclamation of drinking water from urine during the 90-day test, the routine determination of TBW was modified. For the baseline determinations, the crew members were given about 20 percent of the usual dose (150 μCi), or 30 μCi of tritiated water. The onboard dose given on the 61st day of the test was also 30 μCi. The subjects were each given a 90 μCi dose after egress when they were able to utilize biological excretion to reduce radiation exposure. The maximum counting error for the sample was 2 percent.

The natural content of potassium-40 was measured in the same six crew members 3 days before the 90-day test and on the afternoon of egress. Measurements were performed in the total-body counter at the University of California at Los Angeles under the supervision of Dr. N. S. MacDonald. The total-body counter was calibrated in terms of total potassium before the measurements. Natural potassium-40 and total potassium exist in a fixed ratio in biological materials.

4.4.5 Physical Conditioning Program

It was assumed that the restrictiveness of the simulator habitat could reduce the exercise normally associated with daily activities to an extent

sufficient to cause a deterioration of the pretest physical fitness of the crewmen. This loss of conditioning could potentially be accompanied by circulatory and metabolic changes that would confuse the evaluation of the effects of confinement and the overall simulator environment on crew physiology and performance. It was, therefore, decided to introduce an exercise program as a substitute for normal locomotor exercise in an effort to maintain an acceptable level of physical condition, particularly cardio-respiratory fitness, in the crew members. Also, by measuring the level of fitness before, after, and during the test, the effectiveness of the exercise program and the exercise device could be assessed.

In selecting a realistic and valid exercise program, it was decided to try to maintain the normal, preconfinement fitness of the crew rather than elevate them to a high level of fitness with a rigorous program difficult to continue within the constraints of the total test program. The selected regimen consisted of 15 minutes of exercise on a bicycle ergometer at a workload sufficient to produce a working heart rate of approximately 150 beats per minute. It was felt that this level of exercise would probably satisfy the program objectives.

The exercise program was performed by each subject for 5 days a week for a sufficient duration prior to the test to establish a level baseline. This same frequency of exercise was prescribed during the confinement period. Although the crew was requested to refrain from formal training programs in addition to the ergometer exercise, they were not discouraged from participating in sports, informal calisthenics, or additional ergometer exercise on an ad libitum basis either before or during the test.

Workloads were imposed by means of a Collins Pedal-mode Ergometer equipped with a hysteresis brake permitting a preset workload to be independent of pedal rates in excess of 40 rpm. Heart rate was measured by an earlobe pulse detector. Oxygen consumption was monitored by means of a Webb Associates Metabolic Rate Meter. Workload, heart rate, and oxygen consumption were displayed on individual meters and were recorded simultaneously on strip chart recorders. The resting heart rate, working heart rate, and 10 minutes of the post-exercise heart rate were registered on the strip chart recorder and manually entered by the medical monitor on the exercise program worksheet shown in Figure 4-5. Oxygen consumption was similarly recorded for each crewman during one run per week.

The maximal oxygen consumption (max. $\dot{V}O_2$) also known as aerobic capacity, is one of the best criteria of physical fitness. Max. $\dot{V}O_2$ can be predicted from submaximal work with acceptable accuracy by applying the relationship of the working heart rate with the work output (ergometer workload) or working oxygen consumption to the Åstrand-Ryhming nomogram (Reference 4-30) shown in Figure 4-6. This method of estimating physical fitness was used during the period of confinement. In addition, prior to and following confinement, physical fitness was evaluated by means of the Balke Optimal Work Capacity Test (Reference 4-31). The Balke is an accurate, well-recognized test which served as a standard of comparison for the other tests.

Each crewman served as his own control for both the Balke and Åstrand-Ryhming tests. The results were plotted against time for the period of confinement.

SUBJECT: _____ HOUR: _____

RUN NO.: _____ ROOM TEMP.: _____

DATE: _____

RESTING HEART RATE:		RESTING OXYGEN CONSUMPTION:	
Minute 10:		Minute 10:	
Minute 9:		Minute 9:	
Minute 8:		Minute 8:	
Minute 7:		Minute 7:	
Minute 6:		Minute 6:	
Minute 5:		Minute 5:	

WORK LOAD SETTING: _____

WORKING HEART RATE:		WORKING OXYGEN CONSUMPTION:	
Minute 10:		Minute 10:	
Minute 5:		Minute 5:	
Minute 0:		Minute 0:	

RECOVERY HEART RATE:		RECOVERY OXYGEN CONSUMPTION:	
Minute 5:		Minute 5:	
Minute 0:		Minute 0:	

COMMENTS:

Figure 4-5. Exercise Program Worksheet

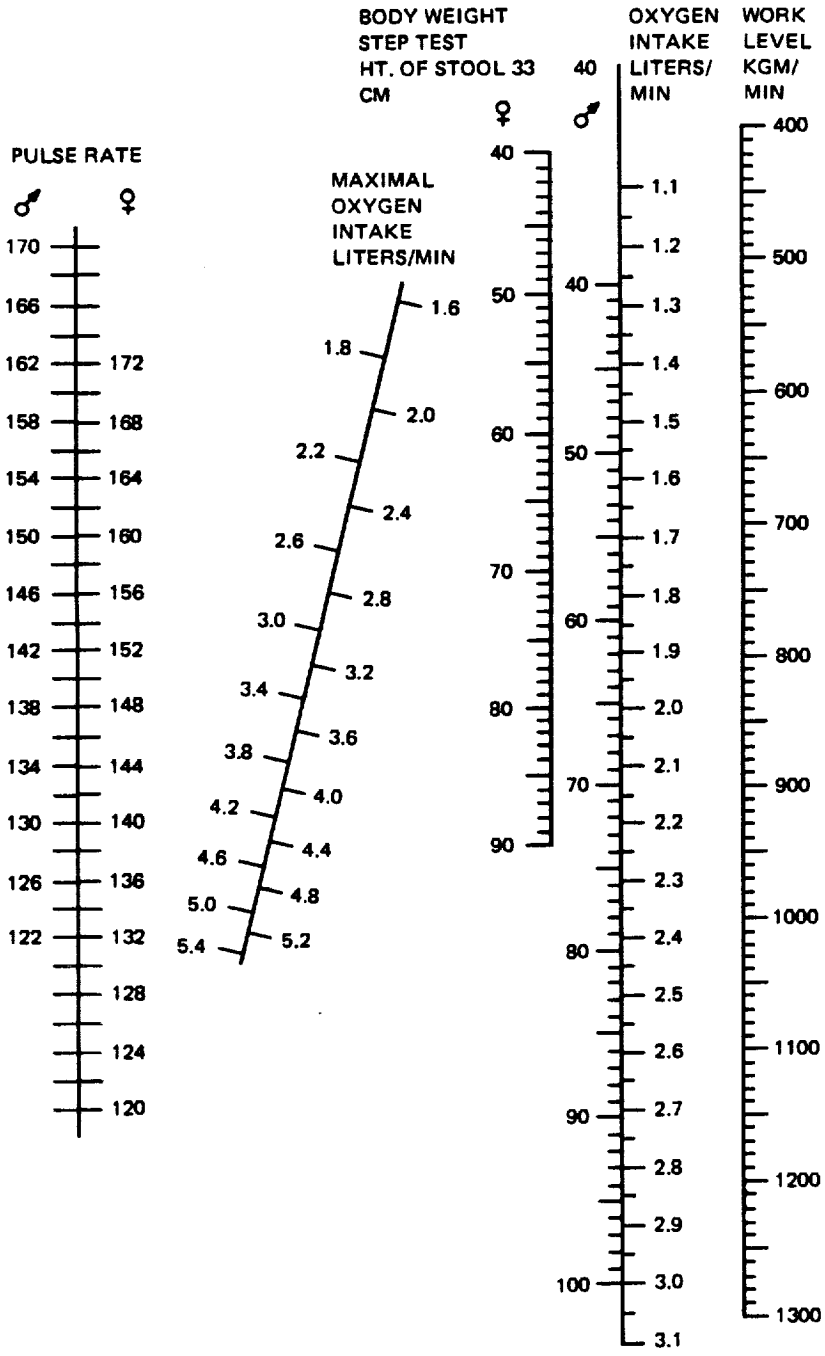


Figure 4-6. Calculation of Aerobic Capacity During Submaximal Work [Åstrand and Ryhming (1954) Ref. 4-30]

4.5 TEST RESULTS

Results from basic medical evaluations during the test and post-test reveal that no changes significant to crew health occurred. Several findings were of medical interest, however, and will be detailed in this section.

4.5.1 Operations

Medical operations were quite smooth with interested contract medical monitors on duty throughout all but part of the second weekend of the test; this 52-hour period was covered by the test Medical Director. Although not expected to participate in scheduled medical procedures, many of the contract physicians became personally involved in the test and contributed significantly to those operations and to the success of the test.

The Medical Director was on call throughout the test. He was furnished an electronic paging system which made the on-call period more comfortable. Because of requirements for medical interviews, a more or less official patient-doctor relationship between the Medical Director and the crew, and requirements for accomplishment of medical test procedures, it was necessary for the Medical Director to be in attendance every day of the test. On days when exercise tests were scheduled (Monday through Friday), the Medical Director was in attendance from approximately 0430 to about 1400 hours. This work schedule was not unduly tiresome for this duration test. The early morning coverage paid additional dividends in providing some semblance of normal "day" to the night crew (crewmen 3 and 4) rather than communicating with extra technical personnel during normal work hours only. This work schedule would not be recommended for longer tests.

Emergency facilities were not used during the test. Onboard medical items were dispensed on occasion as listed in Table 4-7. As can be seen, drug use was minimal and insignificant except for the antibiotic used by crewman 1 during days 70 to 80.

Onboard medical supply use is further detailed as follows:

A. One crewman had a chronic, apparently atopic, nasal congestion problem since childhood. The use of nose drops prior to ascent was prophylactic. The use of decongestants and nose drops around day 50 was in an attempt to alleviate symptoms. He quickly decided, however, that the medication was not very effective and discontinued further use after test day 55.

B. There was some difficulty adjusting to the commode. The mild laxative aided in this adjustment for one crew member.

C. Crewman 3 incurred a small laceration on the right forearm from a wrench slip while manually operating the solid amine unit valves. This cut healed without problems but left a small scar.

Table 4-7

ONBOARD MEDICATION USED IN 90-DAY TEST

Test Day	Drug or Medication	Indication	Results
1	Neosynephrine 1/2 percent nose drops	Nasal congestion, used prior to ascent	No ear problems on ascent.
8	Dulcolax, 1 tablet before bed, twice	Constipation	Good
13	Band-aid	Cut, right arm	Healed adequately
13	Auralgan	Itching skin	Prescribed for local anesthetic property by medical monitor - marginally effective
32	Tinactin	Itching toes	Good.
52	Ornade, 1 capsule and Neosynephrine nose drops, before bed	Nasal congestion	Not effective, use discontinued.
54	Ornade, 1 capsule and Neosynephrine nose drops, before bed	Nasal congestion	
55	Ornade, 1 capsule and Neosynephrine nose drops, before bed	Nasal congestion	
54	Methyl cellulose eye drops	Eye irritation (see text)	Marginally effective.
67	Tinactin	Itching toes	Good.
70-80	Erythromycin 1 gram per day for 10 days	Group A beta-hemolytic Streptococcus throat culture - no symptoms	Eradicated all gram positive nasopharyngeal bacteria.

D. One crewman had skin dryness and irritation problems before the test. The local anesthetic was probably not effective, but he solved his problem by altering the elastic waistband of his uniform. The itching toes problem in the same crewman probably was not due to Tinea pedis but the medication seemed to help.

E. Crewman 1 noted eye irritation (left eye) when asked to move his eyes in checking the EOG signal. On examining the eye, crewman 4 reported a "cyst" or "pustule" in the lower left sclera. The methylcellulose was of little help. This lesion could not be visualized in post-test examination and its nature remains unknown.

F. Crewman 1 first demonstrated Group A beta-hemolytic Streptococcus as a transient throat inhabitant early in the test (see Section 4.6). It was not treated at that time. The infestation reappeared in samples obtained on test day 60 and recurred in increasing colony count on test day 67. After conferring with NASA, the Medical Director prescribed Erythromycin, 250 mg four times a day for 10 days. Throat cultures on test day 74 and subsequently confirmed eradication of the streptococcus. Although crewman 1 was totally asymptomatic, this action was considered necessary because of the potential sequelae of streptococcal infections, the age group of the crew and the close confinement. Antistreptolysin 0 titers were run on frozen contingency sera collected prerun and early in the test, and on fresh samples collected on test days 74 and 81. No significant changes in ASO titer were seen in any of the crew members.

As noted, medical operations were quite smooth and no significant medical problems were encountered. False alarms from sampling problems to be discussed in a following section resulted in concern at times, but in all cases medical procedures were adequate to rule out real problems. The streptococcal incident was interesting and reflected well on the pretest decision to include an antistreptococcal antibiotic in the onboard medical kit. It is speculative whether or not that crewman would have been removed if treatment were not possible. At no time was there evidence of overt infection (fever, elevated white blood cell count, ASO titer change, symptoms), but sequelae can occur in apparently asymptomatic infestations. The other crew members were also at risk. It is clearly better to anticipate easily treated problems and provide for them. The fact that the ASO titers did not change in 90 days of isolation suggests that this period is too short to expect immunological changes. The fact that a streptococcus was aboard may weaken this observation but, on the other hand, crewman 2, 3, and 4 at no time demonstrated infestation by the organism. It is clear, however, that they were not isolated from contact with it.

4.5.2 Basal Signs and Skin Fold Measurements

Basal vital signs (oral temperature, radial pulse, blood pressure) were obtained on each crewman immediately upon arising from scheduled sleep and before eating. Figure 4-7 illustrates oral temperature trends. Crewman 1 and 2, who remained on a normal work-rest cycle, show no changes. Crewman 3 and 4, who reversed their work-rest cycles, show a gradual progression

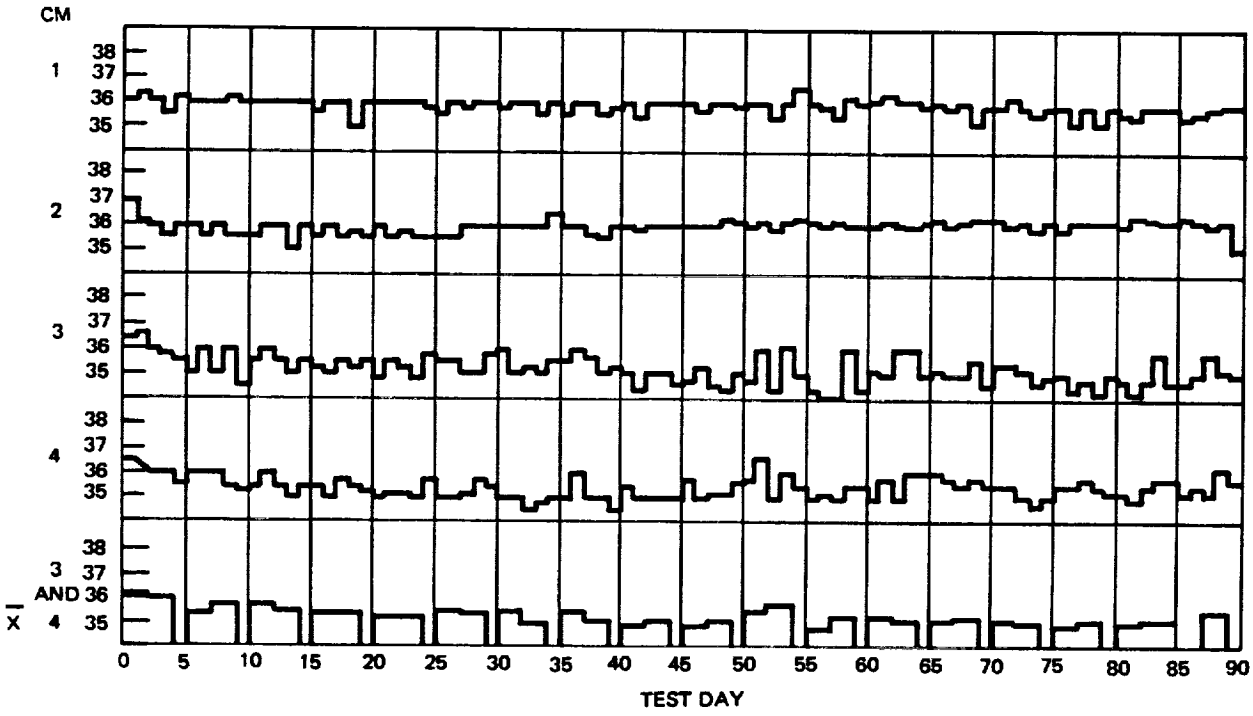


Figure 4-7. Basal Biomedical Data-Oral Temperature (^{o}C)

toward a basal body temperature. Crewman 3 made the transition more slowly and was symptomatic longer (excessive sleepiness in early A.M. - his "afternoon"). It appears that complete transition was not effected by these two crew members in respect to basal oral temperature until after 20 to 25 days. This is longer than usually thought necessary for adjustment of diurnal rhythms. Biochemical results tend to support this view. Radial pulse rates and blood pressures were unremarkable throughout the test.

Body weight changes are illustrated in Figure 4-8. Crewman 2 gained weight (on his own volition) and Crewman 4 lost weight. Skin fold measurements (Figure 4-9) reflect the weight changes. The early wide variations in skin fold measurements result from the lack of training in the techniques before the test. The trends appear to be quite real and suggest that skin fold measurements offer a simple method for following trends in subcutaneous fat. There is, of course, a copious literature on the use of skin fold calipers in anthropometric determinations of lean body mass, etc., and in nutritional surveys. The limited results of this test seem to corroborate the nutritional usefulness; no effort was made to extrapolate further to body composition.

The loss of weight and apparent loss of subcutaneous fat in Crewman 4 are not easily explained in view of his caloric intake. While his exercise regimen was the most strenuous of the crew members, his energy output was not expected to balance his caloric input - it apparently did. Following the test (plus 14 days and 21 days) and after returning to a less demanding exercise program, he regained approximately 1 kg, suggesting that the input-output difference indeed accounted for the weight loss.

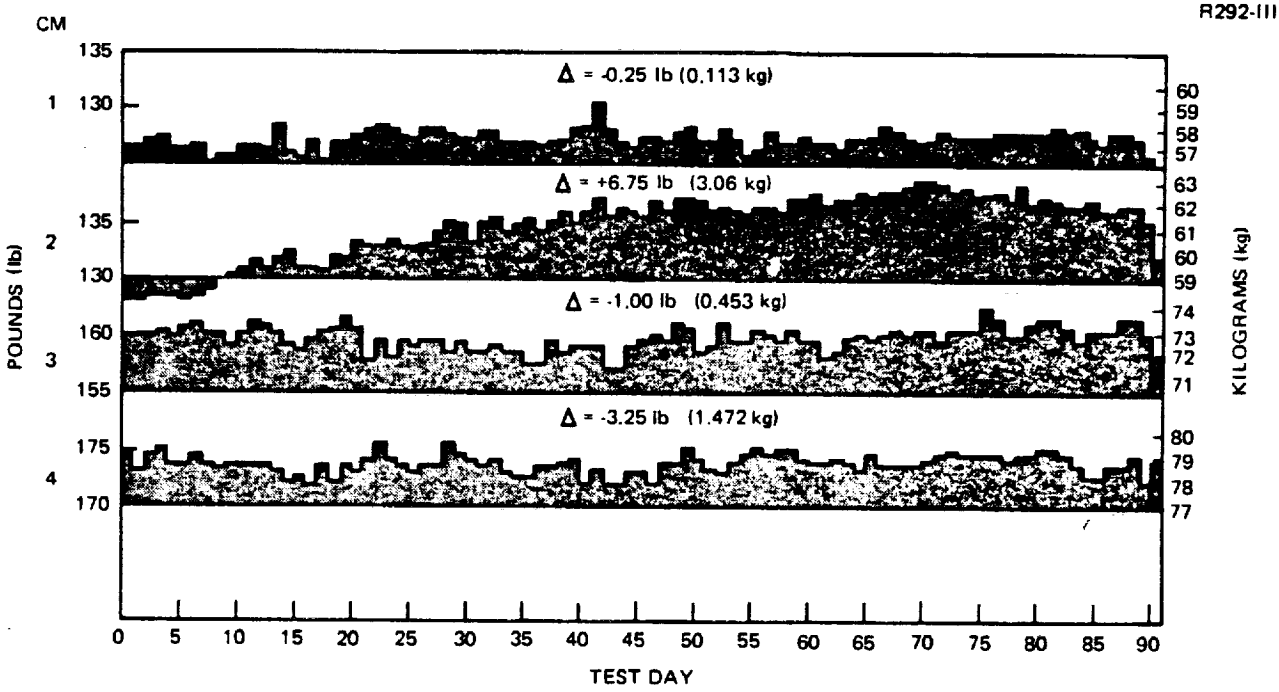


Figure 4-8. Basal Biomedical Data–Body Weight

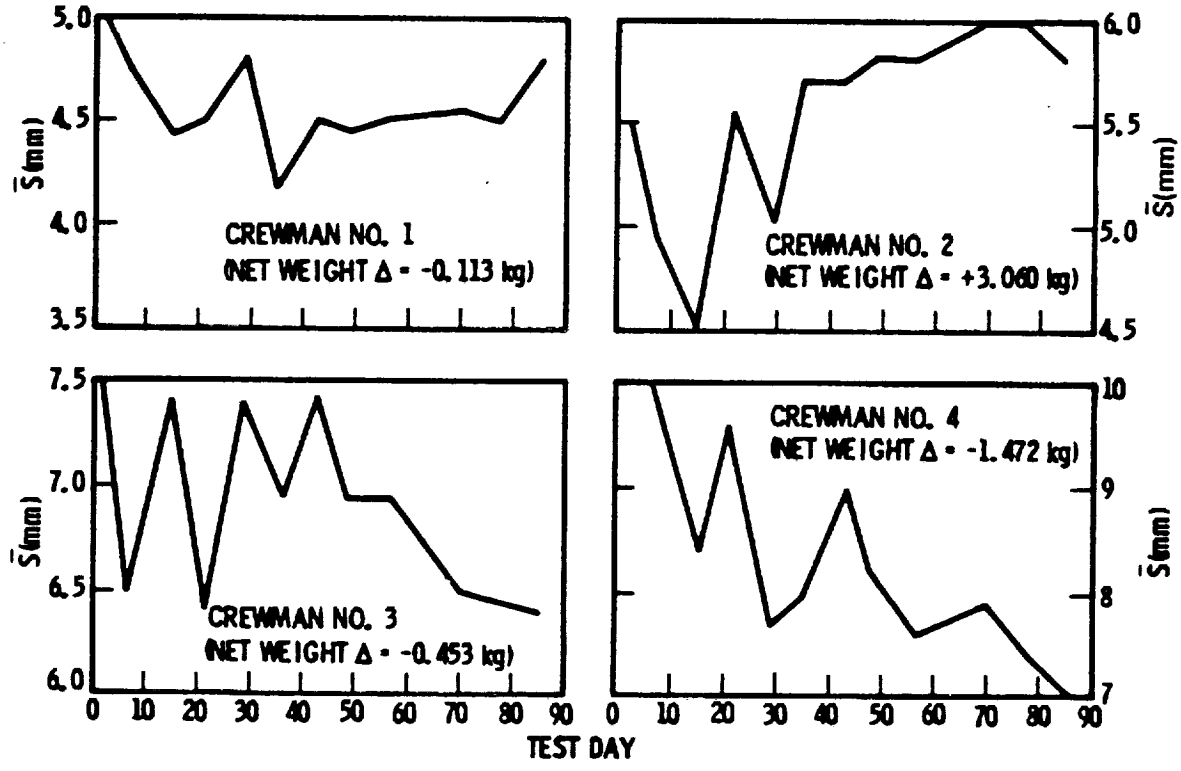


Figure 4-9. Skin Fold

4.5.3 Clinical Blood Chemistry, Urine Analysis and Hematology

While there were no significant changes in blood chemistry or hematology from a clinical point of view, there were findings of significance to future operations. A complete tabulation of raw data is presented in Appendix I. Some of the more interesting observations will be discussed here.

4.5.3.1 Clinical Chemistry

Figure 4-10 illustrates blood urea nitrogen (BUN) and alkaline phosphatase determinations for each crewman. The pretest value represents, in each case, the mean ($\bar{x}_o$) of six or seven pretest samples. This value is carried across the figure as a solid line. The dotted line represents the "t" times the standard deviation(s) 95 percent confidence limits for each individual's pretest mean; "t" depending in value on the number of pretest samples. Any test sample which falls outside the $\bar{x}_o \pm ts$ limits can be considered significantly different from the pretest mean at the 95 percent confidence level. This method of presentation is used in all subsequent clinical chemistry and hematology figures.

It can be seen that crewmen 1 and 2 show no significant deviations in BUN or alkaline phosphatase during or after the test (T + 4 days). Crewmen 3 and 4, however, show significant changes in BUN. The elevation on test day 11 in crewman 3, when linked with findings in hematology, caused a certain amount of consternation; this problem will be discussed later (see Section 4.5.3.3). It became apparent as the test progressed that the coincident changes observed

R282-III

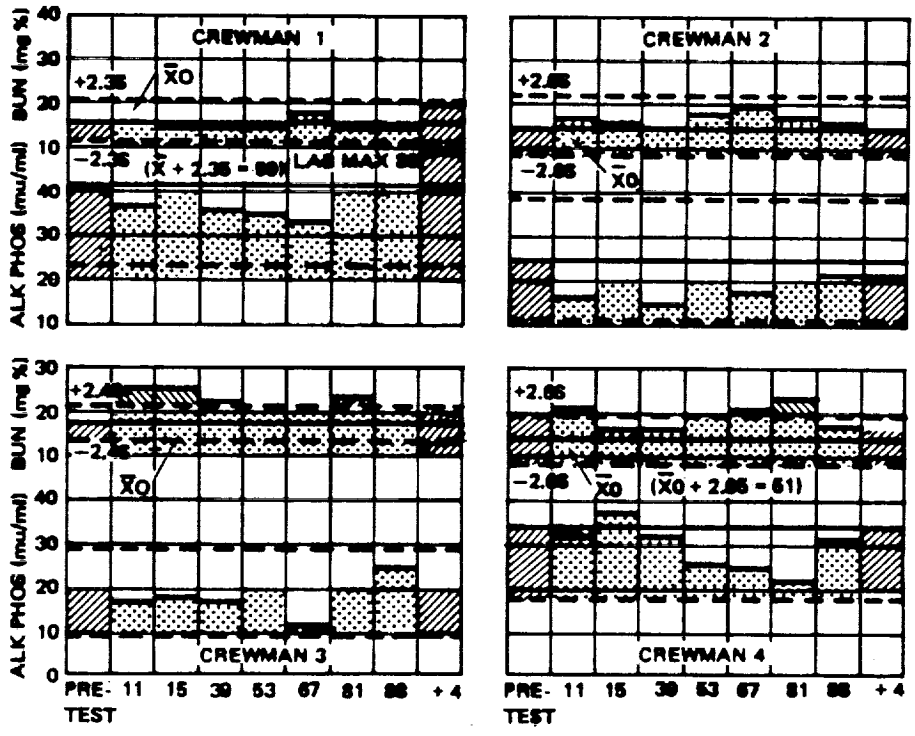


Figure 4-10. Blood Urea Nitrogen and Alkaline Phosphatase

in crewmen 3 and 4 were most probably a result of sampling error. All pretest samples were obtained in the morning, fasting. During the test, all samples were drawn at a prescheduled time to meet certain other requirements. This time was approximately 0800 on Tuesdays, just before scheduled passout. For crewmen 1 and 2, 0800 hours represented morning and the samples were obtained from fasting, basal crewmen. For crewmen 3 and 4, 0800 represented approximately 2000, or evening, in their diurnal cycles. They were not basal, though post-absorptive. In addition, the sample was drawn only 2 hours after completion of the daily exercise period. It is our opinion that the BUN changes reflect diurnal variation and are of no other significance. Operational significance of this conclusion will be discussed in a later paragraph.

It can be seen from Figure 4-10 that there were no changes in alkaline phosphatase for any of the crew. There appears to be a trend toward a depression in this enzyme which is significant at the 0.05 level for crewman 2. We have no tenable explanation for the apparent trend toward a depressed alkaline phosphatase. From a practical standpoint, however, an observation which could occur by chance only five times in a hundred, can occur by chance at least that frequently. In any case, alkaline phosphatase determinations are usually obtained for evaluation of liver function; an elevated value indicating defective hepatic excretion. Clearly, there was no evidence of that sort of problem.

Figure 4-11 illustrates another principle in sampling. Albumin values determined from samples drawn on test day 39 were uniformly depressed,

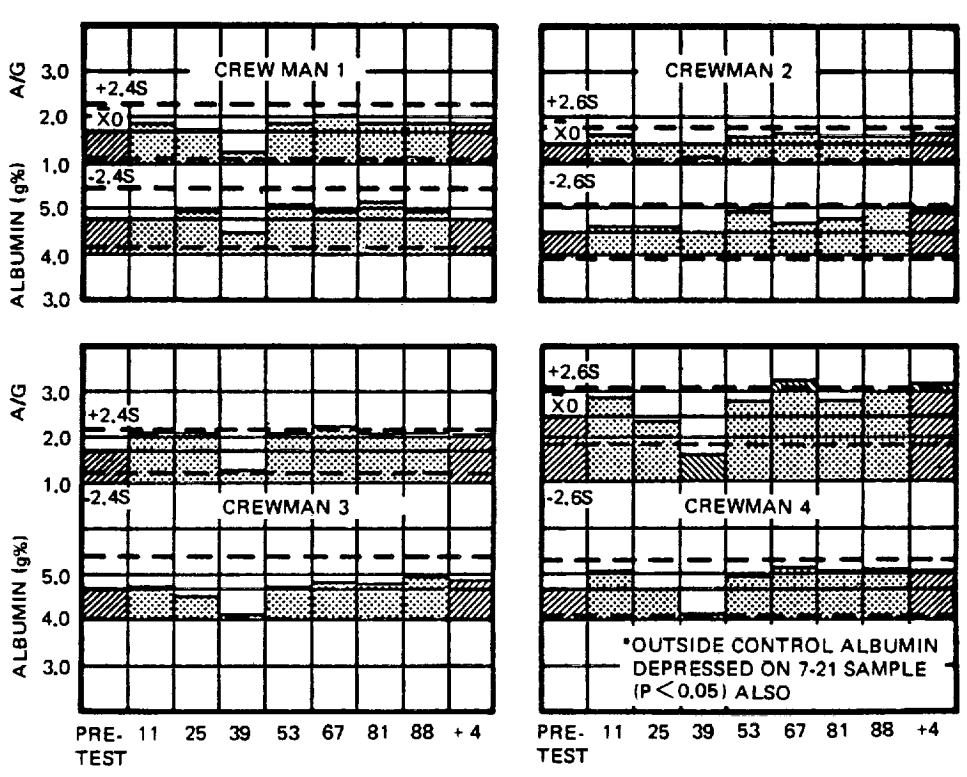


Figure 4-11. Serum Albumin and Albumin-Globulin Ratio

significantly so for crewman 4. This finding could suggest liver problems. During the course of the test, samples were obtained on backup crew members who were serving as the outside test team. These samples were handled exactly the same way as the samples obtained from the inside crew and served as processing controls (as distinct from experimental controls since the outside crew regimen was in no way similar to that of the test crew). The outside control sample also revealed a significant depression in serum albumin and the observation is considered irrelevant to the test. We have no explanation for the apparent processing error.

Figure 4-12 shows serum glutamic-oxalacetic transaminase (SGOT) and lactic dehydrogenase (LDH) determination results. These enzymes usually indicate tissue cellular damage when elevated and are determined for that purpose. The classical use is in suspected myocardial infarction. The highly significant rise in SGOT and LDH in crewman 2 on test day 11 was, to put it mildly, alarming. The SGOT was not only elevated in respect to his pretest values, but to levels considered clinically significant. The elevations in these enzymes and in creatinine phosphokinase (CPK) were confirmed by determinations by the Naval Medical Research Institute (NMRI) on samples sent to them from the test day 11 passout. Coincident with these reports, an apparent change was seen in the electrocardiogram (ECG) obtained on crewman 2. Careful evaluation of the ECG (see Section 4.5.5) revealed the observation to be of no clinical significance and review of other data on crewman 2 (clinical, hematologic, exercise tolerance, etc.) failed to confirm any other evidence for tissue damage. This spike in SGOT, LDH, and CPK

R292-III

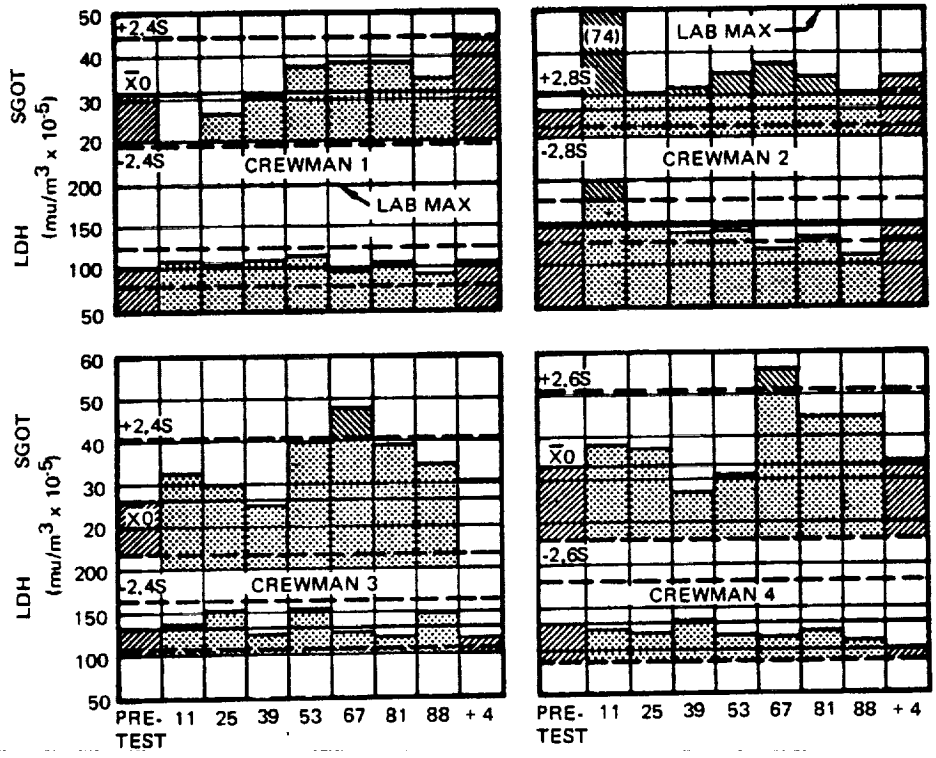


Figure 4-12. Serum Enzymes-SGOT and LDH

remains unexplained, but it is hypothesized that it was related to test stress coupled with a very high workload for crewman 2 in early test operations- he was subjectively fatigued and somewhat annoyed. The workload was more evenly distributed subsequently but crewman 2's SGOT remained elevated with respect to pretest values for the entire test, though not to a clinically significant level.

An interesting phenomenon was observed in SGOT trends for all crew members. It can be seen that this enzyme tends to rise, peaking on test day 67. This peak is significantly different from the pretest mean in three out of the four crewmen. Test day 67 occurred during a period of low morale for the test crew which culminated in an onboard "encounter session" on test day 69. This session cleared the air and morale markedly improved. The rise in SGOT apparently is coincident with this period of psychological stress. Other biochemical (blood and urine) determinations also reveal trends or peaks coincident with the test days 60 to 70 stress period. NMRI has indicated (Reference 4-32) possible similar peaks in some of their determinations which will be reported elsewhere (see Section 4.5.8.2). Our observations suggest that serum enzymes, in this case specifically SGOT, when elevated in respect to an individual's own control values, may reflect psychological stress. It is obvious that this relationship would not have been observed without an adequate knowledge of the "normal" value for the individual in contradistinction to a laboratory "normal."

4.5.3.2 Urine Analysis

Aliquots of 24-hour urine volumes were collected and frozen on board for passout weekly until test day 53 and subsequently twice a week. These urine samples were subjected to routine urinalysis in support of the basic medical program. Urine chemistries were obtained primarily in support of the special CO_2 study (Section 4.4.1), but certain observations will be reported here. Routine urinalysis results were not medically remarkable at any time. During the course of the test, observations of sodium/potassium ratios (Na^+/K^+) in the urine suggested a relationship between this parameter and psychophysiologic stress and diurnal (circadian) biological rhythm shifts. Urinary Na^+/K^+ represents a relatively simple biochemical analysis which could easily be performed in flight.

Trends (Figure 4-13) indicate that, for crewmen 3 and 4, Na^+/K^+ remains depressed (below that for crewmen 1 and 2) for about 30 to 35 days. This suggests a significant lag in complete shift of their biological diurnal rhythms. This lag is longer than usually thought necessary for recycling. Data also show a consistent peak in Na^+/K^+ at about day 73. This peak, which reverses a downward trend, coincides with a marked improvement in crew morale discussed in the previous section. These observations suggested, even during the test, that Na^+/K^+ could be used to follow or corroborate changes in diurnal cycles and in psychological status. The observations will be studied further in an effort to substantiate the usefulness of this simple biochemical determination in following stress trends.

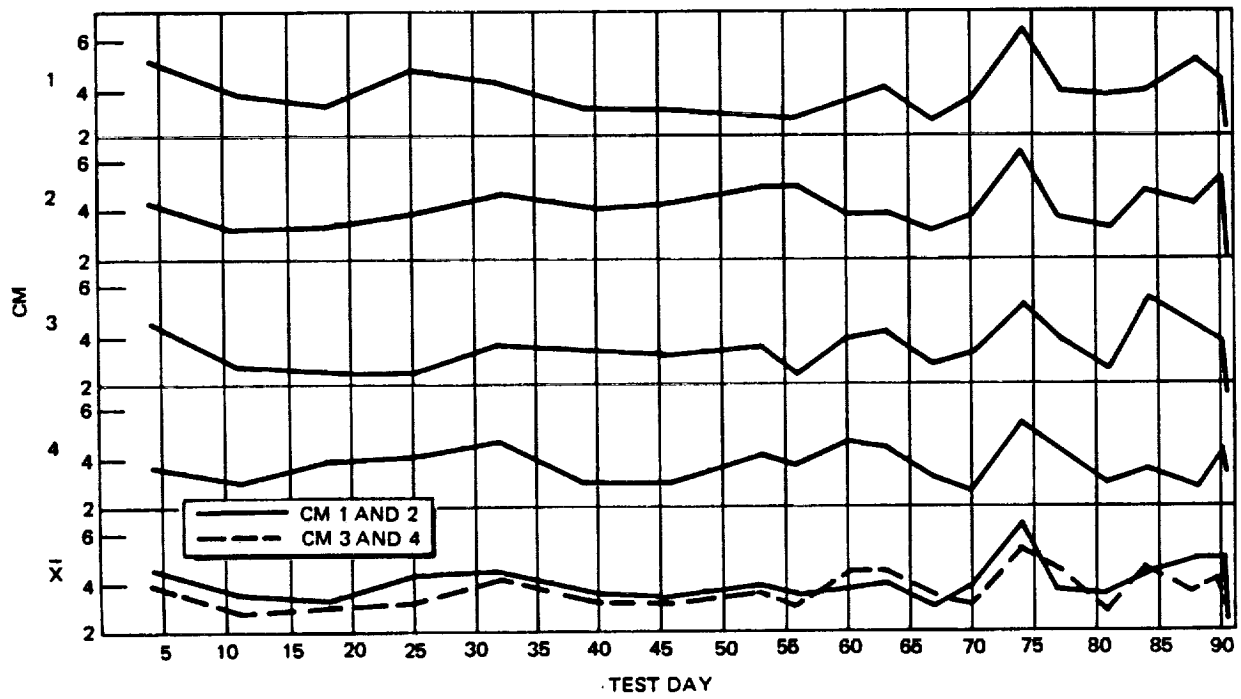


Figure 4-13. Urinary Excretion Patterns, Na+/K+ Ratios

The lag in diurnal recycling deserves additional comment. As noted in Section 4.5.2, crewman 3, particularly, showed a lag in achieving a waking basal oral temperature and was symptomatic of incomplete recycling for 10 to 14 days. His Na^+/K^+ contributes most to the group difference in mean Na^+/K^+ illustrated in Figure 4-13 ($\bar{x}$). The mechanism for this is hypothetical but is offered here for consideration. Excretion of Na^+ and K^+ is controlled in part by aldosterone. Aldosterone secretion shows a diurnal variation, either posturally linked or directed both by postural influences and by a built-in "biological clock." The trend seen here suggest both the influence of a basic diurnal variability and postural influence. Secretion of aldosterone usually peaks during the normal afternoon hours and reaches a low in the early morning hours during sleep. In the case illustrated here, the upright posture creates a stimulus for continued secretion during the otherwise "low" period. With the lag in resetting the basic biological clock, a relatively continuous aldosterone secretion results without a low secretion period. The difference in crewmen 3 and 4 demonstrates individual variability in recycling the basic rhythm.

Admittedly this is making much of a quite limited sample. If, however, diurnal recycling does require the time suggested in crewman 3 for some individuals, there may be significant connotations for future tests or missions. While we have no evidence for the lag influencing performance (beyond the early sleepiness noted above), we were not specifically investigating this aspect of confinement. In all probability, future long-duration missions in

complex vehicles will require 24-hour operations - some crew members will accordingly be unable to remain on a normal work-rest cycle. The lag in biological recycling suggested here should be more extensively evaluated for its operational significance.

Another interesting observation concerned the large differences between the night crew and day crew in excretion of urine solids. This difference is apparently a body weight phenomenon (see also Section 4.8.1) and illustrates the need to express urinary data in terms of body or metabolic mass.

4.5.3.3 Hematology

Hematological observations are summarized in Figures 4-14 and 4-15. Crewmen 1 and 2 reveal no significant changes while crewmen 3 and 4 show significant depressions in red cell parameters and crewman 3 had a consistently elevated white blood cell count. These hematological changes reflect the same diurnal rhythm sampling problem encountered in some of the blood chemistries.

The significant depression of red blood cell count (RBC), hemoglobin (Hgb) and hematocrit (Hct) in crewman 3 on test day 25, when coupled with the observed rise in BUN (see Section 4.5.3.1), was alarming. (The concomitant but less dramatic decrease in RBC and Hgb in crewman 4 was not immediately noted.)

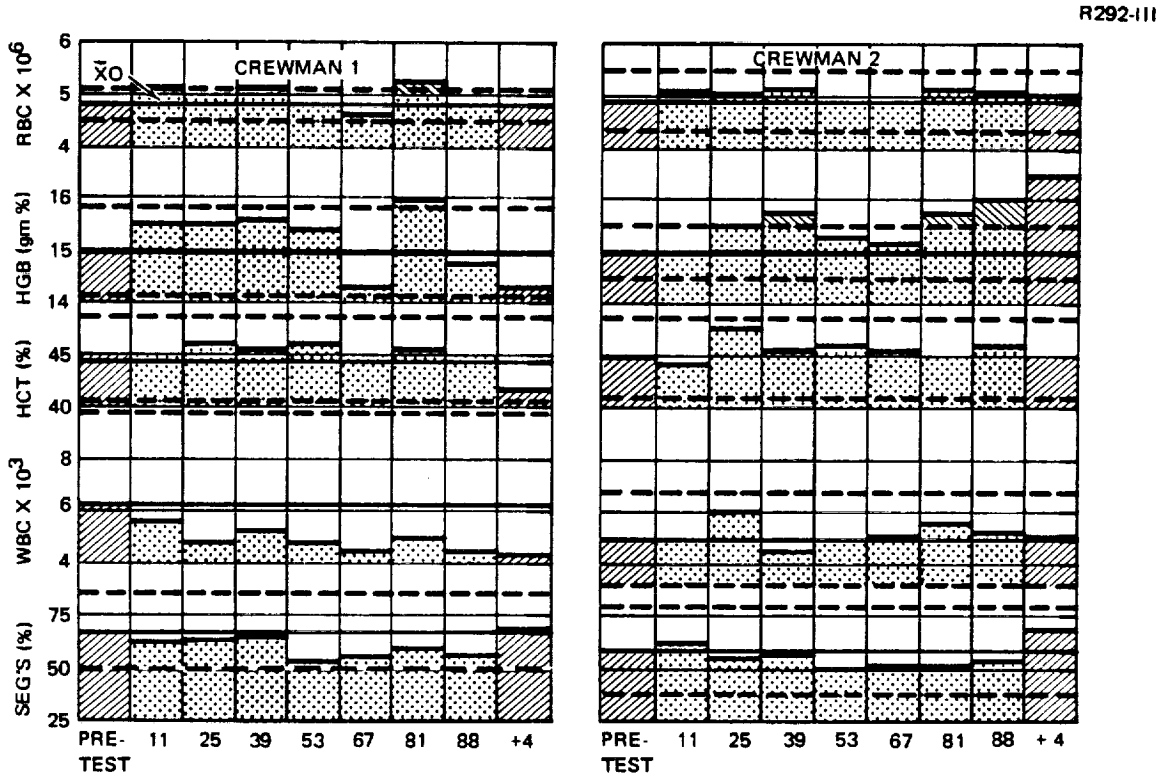


Figure 4-14. Hematology Summary for Crewmen 1 and 2

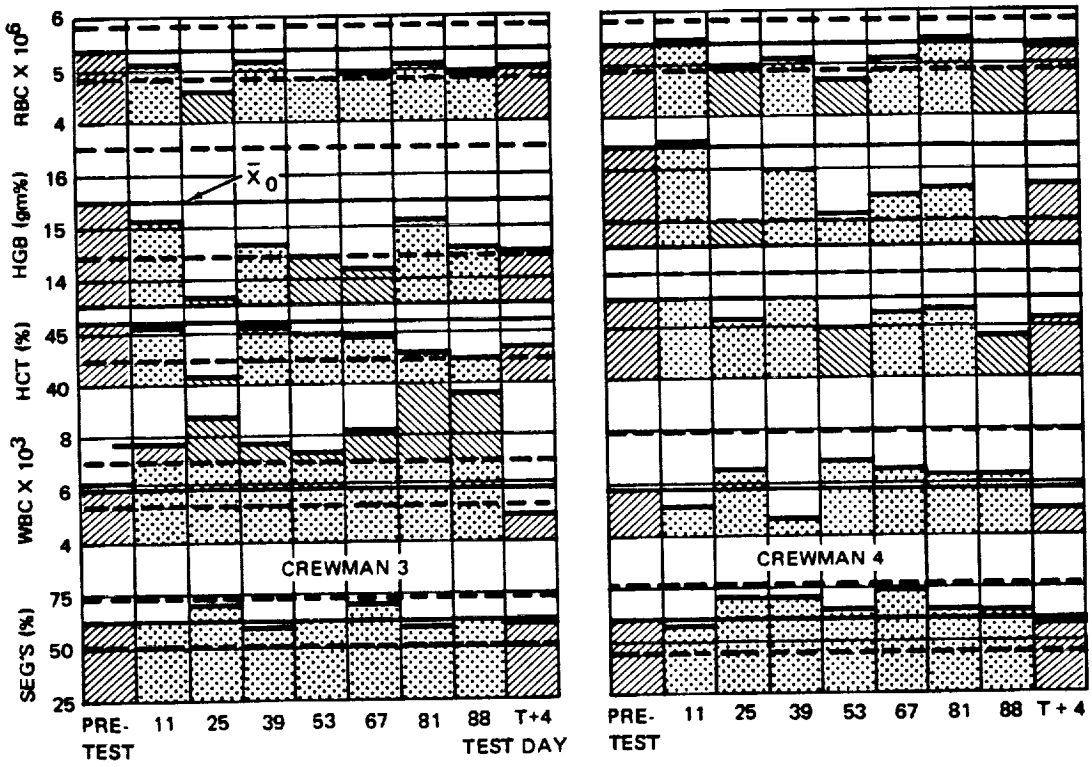


Figure 4-15. Hematology Summary for Crewmen 3 and 4

Because crewman 3 had complained mildly of stomach symptoms, the possibility of gastrointestinal bleeding was investigated. A fecal sample was obtained for passout on test day 32 from crewman 3 (also from crewman 2 under pretext of testing the fecal sampler in order not to alarm the crew unduly). This sample was guaiac negative for occult blood. A careful systems review did not reveal any stomach symptoms attributable to other than minor problems adjusting to the higher fat content of the first frozen meal. A telephone report from NMRI at this time revealed that crewman 3's haptoglobins were high normal - ruling out a hemolytic process. With these observations and an unscheduled repeat hematocrit and hemoglobin on day 32, we were satisfied that no clinical problem existed. As a precaution, crewman 3 was subjected to an upper gastrointestinal and small bowel x-ray examination after the test. It was normal.

4.5.4 Radiological Monitoring

The actual dose rates in the vicinity of the VD-VF unit and chill box when the radioisotope capsules were installed are shown in Figures 4-16 and 4-17. These dose rates were measured with calibrated neutron and gamma survey meters and essentially agreed with the calculated dose rates used to predict the maximum crewman exposure for the 90-day test.

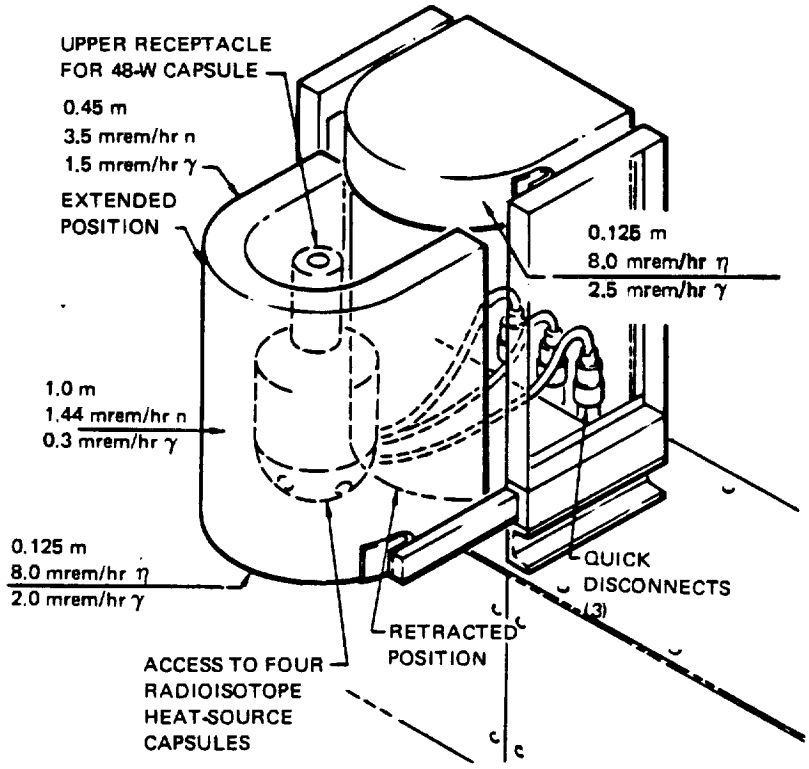


Figure 4-16. Radiation Survey Near VD-VF Unit with Retracted Shield

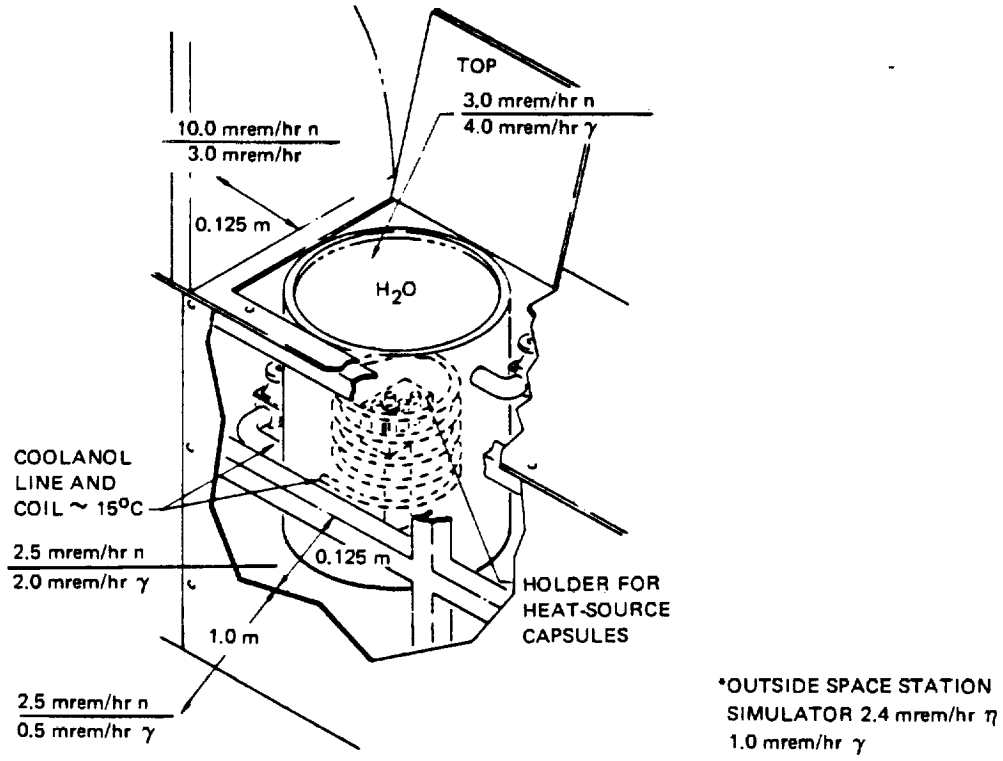


Figure 4-17. Radiation Survey Near Isotope Storage Container (Chill box)

The film badge results are shown in Table 4-8. Three of the four crewmen received total doses lower than permitted for the general population. The fourth crewman received only 25 percent of the maximum expected dose, 14 percent of the generally allowed dose, and about 6 percent of the maximum permissible dose of 13 weeks. The low levels of gamma radiation were not detectable on either the weekly or 90-day film packets. The pocket dosimeter readings were considered to be unreliable due mostly to large errors in interpreting the readings and lack of agreement between the neutron and gamma dosimeters of each set.

In general, both the film badge results and the pocket dosimeters indicated that handling of the capsules constituted the greatest source of radiation exposure. The record of capsule handling is shown in Table 4-9. The capsules were exchanged between the VD-VF unit and the chill box on 14 occasions which resulted in 76 manipulations of individual capsules. By examining the frequency that each crewman handled the capsules and the differences in their recorded radiation doses, the average dose to a crewman for each handling operation can be estimated. Figure 4-18 illustrates the technique of handling and the radiation environment surrounding the capsule. The capsule was held in about the same geometry throughout each transfer, so that the average dose can be approximated at 1 to 3 mrem. The average transfer time, including a smear test, was estimated at 2 to 6 minutes.

The results of continuous air monitoring are shown in Figures 4-19 and 4-20. The daily reading of the air monitor ratemeter decreased rapidly during the first few days corresponding to the rapid decay of radon after the SSS was closed. Based upon the MPC of ^{238}Pu in air for continuous exposure and the sampling rate and counting efficiency for the air monitor, contingency conditions were established for an alarm at 5 cps. Emergency procedures were required to prevent inhalation of an MPLB when a time of less than 5 minutes elapsed between an alarm at 5 cps and an alarm at 16.6 cps. The air monitor failed on several occasions. Two false air monitor alarms occurred once during the 5-day trial and once during the 90-day test. In both cases, the crew established within 0.5 to 1 minute that the alarm did not result from radioactivity, but instrument malfunction. A short circuit in the ratemeter caused the first alarm, while a noisy photomultiplier tube caused the second alarm. Batteries in the scintillation probe had to be replaced twice during the 90-day test. Finally, the constant-flow air pump failed on the 88th day and was replaced with an air pump normally used for bacteriological sampling of the atmosphere. Measurement for any radioactivity on the daily air filters was also performed with the isotope analysis unit. From Figure 4-20, the early results were unusually variable considering the stability of the instrument. Further, the value of a particular measurment was found to decrease as the time after removal of the filter increased. Preliminary tests by the crew suggested that the aberrant measurements were caused by a static charge on the filter which neutralized the charge on the quartz fiber electroscope (isotope analysis unit). This conclusion was verified by experiments following the 90-day test. The difficulty was corrected on test day 57 by allowing an extra day to elapse before measurement. Using the isotope analysis unit, the contingency level for air filters corresponded to the time for the quartz fiber to move 20 scale divisions in less than 45 minutes or at a rate of 27 units/hour. An emergency condition prevailed when a deflection or 20 scale divisions occurred in less than 50 seconds.

Table 4-8

PERSONNEL DOSIMETRY FILM BADGE READINGS

Film Badge Sequence (5-Day Test)	Individual Dose (mrem/week)							
	Crewman 1		Crewman 2		Crewman 3		Crewman 4	
	$\frac{\beta\gamma}{0}$	$\frac{n}{0}$	$\frac{\beta\gamma}{0}$	$\frac{n}{0}$	$\frac{\beta\gamma}{0}$	$\frac{n}{0}$	$\frac{\beta\gamma}{0}$	$\frac{n}{0}$
1	0	0	0	30	0	20	0	20*
2	0	10	0	0	0	40	0	10
3	0	0	0	10	0	10*	0	10
4	0	60	0	0	0	0	0	0
5	0	30	0	40	0	30	0	10
6	0	10	0	20	0	10	0	0
7	0	20	0	0	0	0	0	10
8	0	0	0	10	0	20	0	0
9	0	10	0	0	0	10	0	20
10	0	10	0	0	0	0	0	0
11	0	0	0	10	0	0	0	0
12	0	0	0	0	0	60	0	30
13	0	20	0	10	0	10	0	10
Subtotal	0	170	0	130	0	210	0	120
Total Dose, mrem		170		130		210		120
Corrected Total Dose, mrem**		110		60		170		80

*High-energy event (star), no exposure calculated.

**The total dose is the summation of the weekly dose minus background, $\Sigma(n - n_{bkg})$ where n is the number of neutron tracks, while the corrected total dose is the summation of the total neutron dose minus the background dose, $\Sigma n - \Sigma n_{bkg}$. The corrected dose thus accounts for the neutron tracks and is not as affected by the poor statistics of the weekly total.

NOTE: Film badges issued for the 13-week period showed general darkening compared to control films issued at the same time. Since the darkening was uniform over the whole film it was probably not due to radiation expsoure, but due instead to differences in temperature and/or humidity during the 90-day test.

Table 4-9

RECORD OF CAPSULE HANDLING AND SURVEYS FOR RADIOACTIVE CONTAMINATION

Date	Alpha-Emitting Contamination from Each Capsule					Capsules Transferred		Reason for Transfer
	BT-2	BT-15	BT-16	BT-21	BT-38	From	To	
6-14	BKG	BKG	BKG	BKG	BKG	Chill box	VD-VF*	Startup of VD-VF I
7-9	BKG	BKG	BKG	BKG	BKG	VD-VF	Chill box	Urine solid accumulation
7-9	BKG	BKG	BKG	BKG	BKG	Chill box	VD-VF	Startup of VD-VF II
7-10	BKG	BKG	BKG	BKG	BKG	VD-VF	Chill box	Flooded catalyst
7-13	BKG	BKG	BKG	BKG	BKG	Chill box	VD-VF	Startup of VD-VF
7-13	BKG	BKG	BKG	BKG	BKG	VD-VF	Chill box	Flooded catalyst
7-16	BKG	BKG	BKG	BKG	Alarm**	Chill box	VD-VF*	Startup of VD-VF
7-21	BKG	BKG	BKG	BKG	BKG	VD-VF	Chill box	Sterilization required
7-22	BKG	BKG	BKG	BKG	BKG	Chill box	VD-VF	Startup of VD-VF
7-27	BKG	BKG	BKG	BKG	BKG	VD-VF	Chill box	Flooded catalyst
8-3	BKG	BKG	BKG	BKG	BKG	Chill box	VD-VF	Startup of VD-VF
8-17	BKG	BKG	BKG	BKG	BKG	VD-VD	Chill box	Sterilization required
8-17	BKG	BKG	BKG	BKG	BKG	Chill box	VD-VF	Startup of VD-VF
9-1	BKG	BKG	BKG	BKG	BKG	VD-VF	Chill box	Accumulation of urine solids, final shutdown of VD-VF II

BKG = No radioactive contamination could be detected above background radiation levels indicated by the alpha survey meter.

* = Additional transfers of individual capsules resulted in six additional manipulations with VD-VF in extended position: a 73w capsule was used for rapid heating of the catalyst and was later exchanged for the 48w capsule in the evaporator unit.

** = False indication of radioactive contamination: smear immediately checked on air-monitor alpha probe and isotope analysis unit, both revealed no contamination; false alarm traced to faulty PM tube.

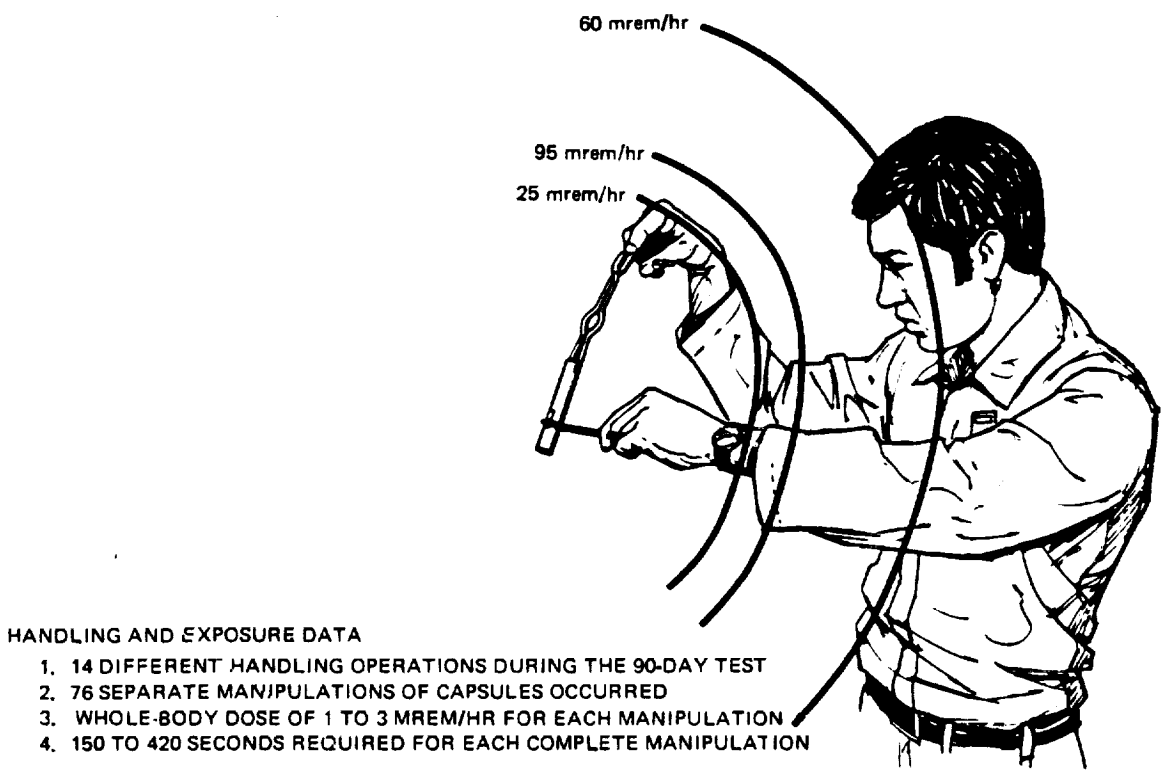


Figure 4-18. Exposure to Ionizing Radiation During Handling of Pu-238 Capsules

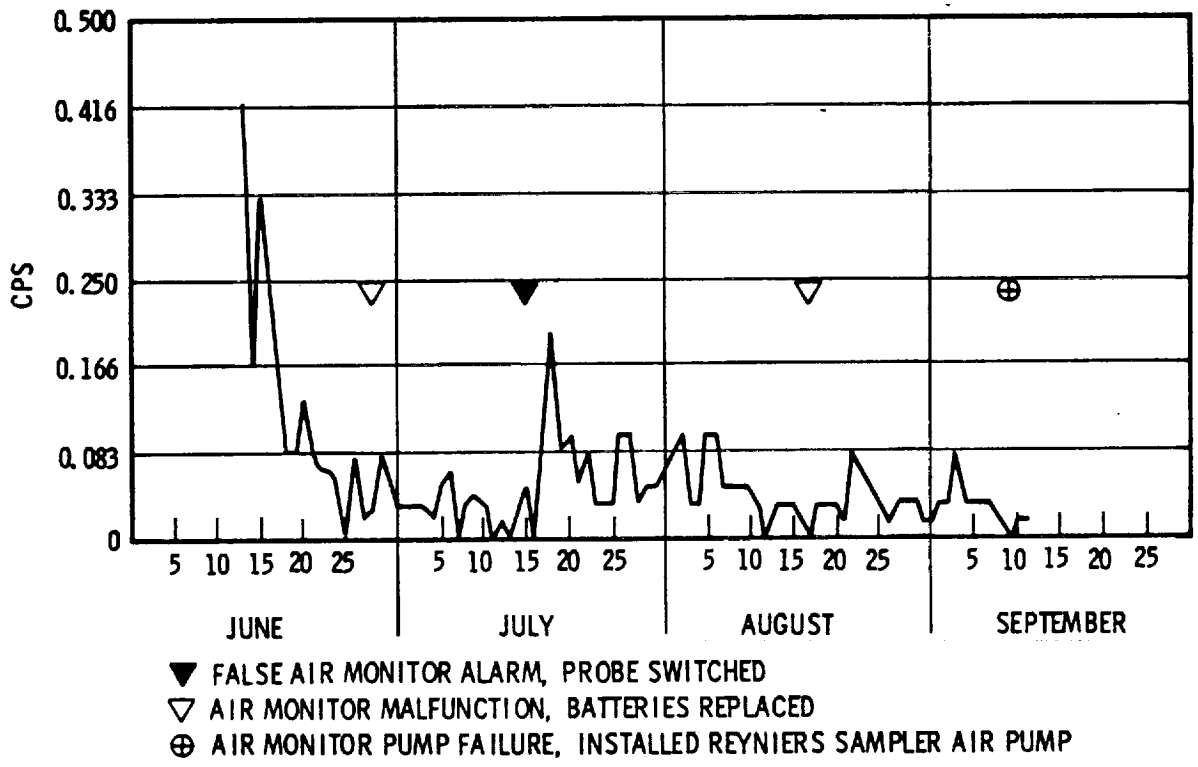


Figure 4-19. Measurement of Radioactivity on Daily Filters from the Air Monitor
Daily Reading of Air-Monitor Ratemeter

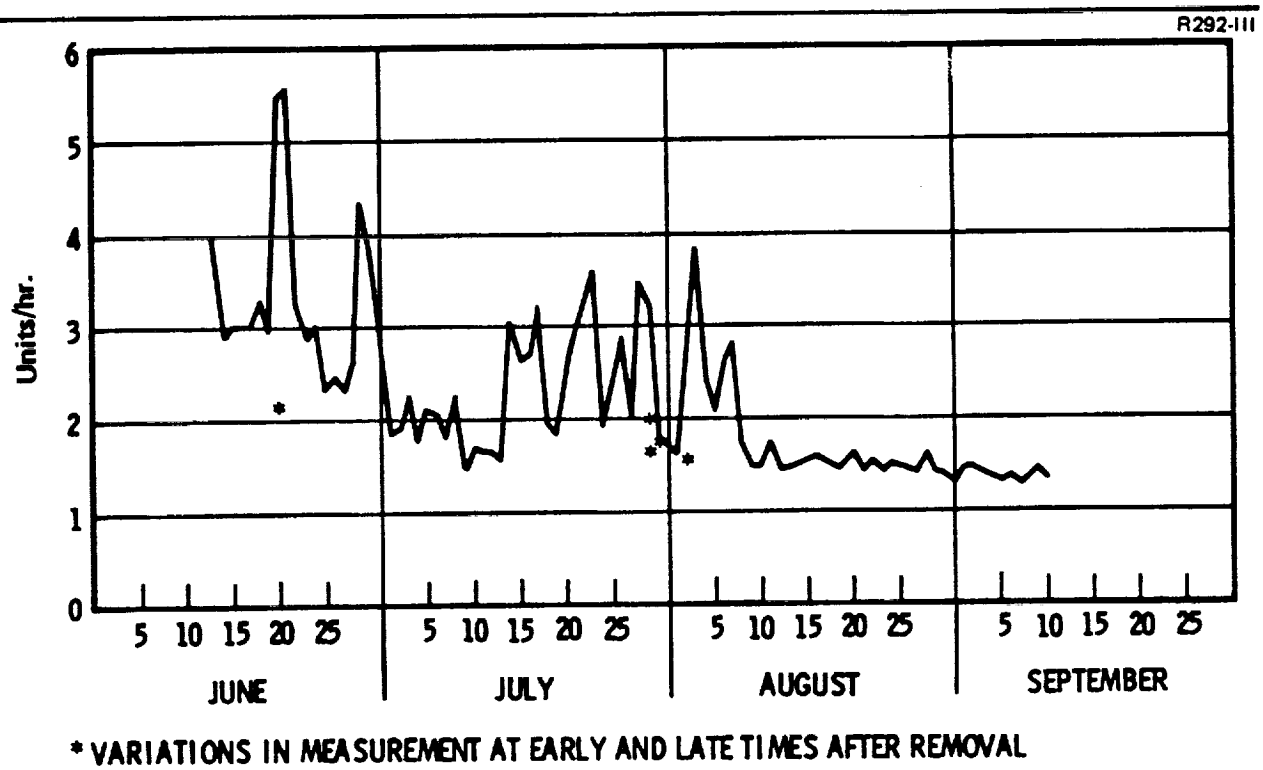


Figure 4-20. Measurement of Radioactivity on Daily Filters from the Air Monitor Measurement from Isotope Analysis Unit

The results of surveys for radioactive contamination are shown in Table 4-9. No α-emitting contamination could be detected above the background radiation levels normally indicated by the α-survey meter. One false indication of radioactivity occurred following a smear test on capsule BT-38. This smear was immediately checked on the air-monitor probe and with the Isotope Analysis Unit. Both revealed no radioactivity. The false alarm was traced to a noisy photomultiplier tube which was replaced.

Measurements of water samples and some smear samples with the Isotope Analysis Unit are shown in Figure 4-21. None of these measurements were significantly different than background measurements. The contingency levels for gross activity were a rate of 10 div/hr for a smear sample and 5 div/hr for a dried 20-cm^3 water sample. A MPC of ^{238}Pu in the drinking water would have given a deflection rate of about 300 div/hr for a dried 20-cm^3 sample. An emergency level corresponded to a deflection of 20 scale divisions in less than 6 minutes for a smear sample and less than 20 seconds for a water sample contaminated with ^{238}Pu.

Some of the results suggest definite answers to the questions of difficulties and hazards in handling of the heat source capsules and the dose resulting from crew activities in the presence of an open radiation area. Thus, the heat source capsules were handled in 76 separate manipulations without incident or difficulty. Simple and manageable handling tools and practical

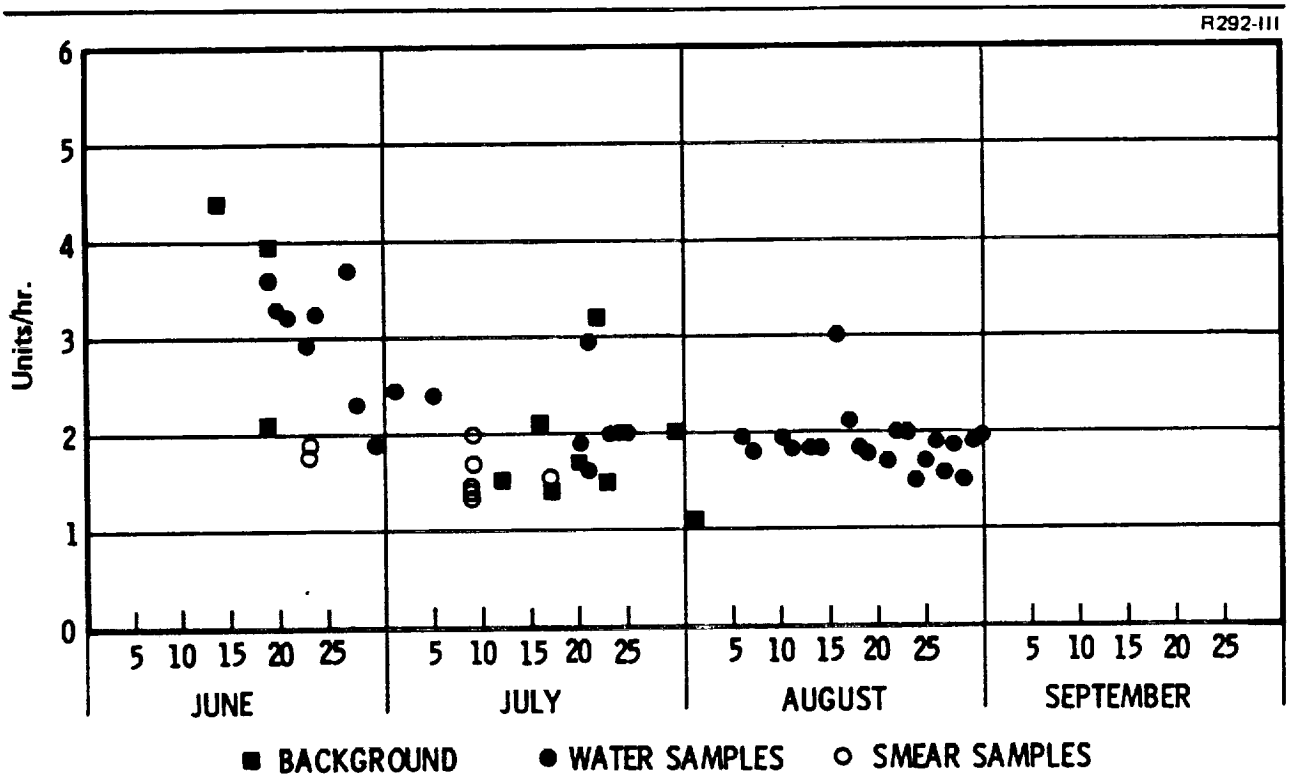


Figure 4-21. Measurement of Water and Smear Samples for Radioactive Contamination with the Isotope Analysis Unit

procedures prevented any thermal injuries and deterred excessive exposure of the extremities to ionizing radiation. No discernible damage was sustained by any of the capsules and no release of radioactive contamination could be detected. Despite the existence of an open radiation area in a regularly traversed section of the SSS, the average exposure of the crewmen was less than 10 percent of the normally allowable dose, within the level permitted for the general population, and only 14 percent of the maximum predicted dose. Such observations should counteract prevalent tendencies to overshield, overcomplicate, and overprice in those space programs that seek to employ the advantages of radioisotope power.

Perhaps the most useful result of this test will be the development of a methodology to more accurately predict the dose to the crew of a Skylab or Space Station as a result of the use of radioisotope heat in life support subsystems. Personnel dosimetry indicated that total dose of the test was much less than that estimated. The overestimate was caused by the inclusion of safety factors in the calculations of dose from handling, shielding, and the distance and time associated with each scheduled crew activity. Detailed data are now available regarding actual crew movements within the SSS. The crew work schedule was planned in detail and meticulously monitored throughout the test. The location of each crewman was determined every 2-1/2 minutes during substantial portions of the test. Following computer reduction of

these data, summaries of the locations and durations of the tasks can be compared with the planned schedule for the crew. Once integrated with the other test results, this information will yield more realistic safety factors for future use in optimizing the shielding weight and the location of radioisotope sources in relation to expected crew activities.

The 90-day test also indicated that a definite spacecraft requirement exists for the development of instruments, devices, and procedures to detect and contain radioactivity. Although capsule leakage is unlikely, the effects of a radioactive contamination hazard must be neutralized in the closed environment of a manned spacecraft. Approximate calculations indicated that damage resulting in leakage from one or more of the capsules or overheating with capsule rupture could release airborne radioactivity that would rapidly exceed the maximum permissible concentration in air and result in a maximum permissible lung burden within minutes. However, the magnitude and characteristics of any release of radioactivity would need to be experimentally determined to realistically design for the hazard. Nevertheless, design requirements, such as the inclusion of a small, lightweight containment vessel with air monitoring, or a heat pipe to remove excessive heat, could be adopted that would greatly reduce the significance and hazards of these remote possibilities and provide the opportunity for remedial action.

In particular, the 90-day test revealed the need for several improvements in radioactivity monitoring instruments. Some of the features that should be included in the design of the air monitor and survey meter are:

A. An electronic means of discriminating between an alarm caused by instrument malfunction and one resulting from radioactivity.

B. Warning indicators of radioactivity level, radioactivity release rate (air monitor), and instrument failure.

C. Built-in radioactive calibration sources, electronic calibration, and elective indications of critical voltages.

D. Interchangeable ratemeters, detector assemblies, and some electronic components.

Although the development and test of such equipment and methods are an essential adjunct to use of radioisotope power, they involve existing capability and technology and should require only a minor effort and expense. Most of the design improvements suggested in this report were identified as a direct result of the monitoring experience in the SSS.

An important contribution of the 90-day test was proof of the value of simulated testing of procedures and instrumentation designed for radiological safety in manned space systems. Thus, before final acceptance of instrument designs and procedural concepts for radiological safety in a future Skylab or Space Station, prototypes should be evaluated in a manned test of an SSS. This should include an evaluation of the methodology used to predict crew dose and

determine shielding based on location of the radioisotope heat sources and crew activities. The handling characteristics of flight-rated radioisotope heat sources and the long-term operating characteristics of these sources in life support subsystems should be determined. The performance of space-flight prototypes of the air monitor, survey meter, and personnel dosimetry should be substantiated. The procedures, instrumentation and crew performance should be further evaluated under the duress of simulated credible accidents. The experience gained by such testing is certain to establish confidence and perspective not attainable by speculation.

Several recommendations are apparent from the foregoing analysis of results. Most important, prototype instrumentation must be designed, constructed, and tested to monitor for leakage of radioactivity onboard manned spacecraft. Safety design criteria must be established to integrate radioisotope heat sources into life support subsystems. These criteria are necessary for optimum utilization of inherent shielding potential and placement of capsules in relation to the radiation exposure of the crew during work within the radiation environment. These steps must be taken in order to neutralize the uncertainty about onboard radiological safety problems that has thus far impaired the acceptance of radioisotope power as a simple and dependable source of thermal energy within manned spacecraft.

To summarize, approximately 1/3 kilowatt in heat from five capsules containing $^{238}PuO_2$ in the form of microspheres was used to power a water recovery subsystem in the 90-day manned test or a regenerative life support system in an SSS. Despite 76 manipulations of capsules at a whole-body dose rate of 25 mrem/hr and the existence of a radiation area in a regularly traversed area of the SSS, the average integral exposure for 90 days of confinement was only about 100 mrem, less than 10 percent of the normally allowed dose. Simple, manageable handling tools and straightforward procedures prevented any thermal injuries and deterred excessive exposure of the extremities to ionizing radiation. No discernible damage was sustained by any of the capsules and no release of radioactive contamination could be detected. Several improvements in devices and procedures for the radiological safety of radioisotope power applications in manned spacecraft were identified as a direct result of studies in the Simulator. These studies indicate that current tendencies toward excessive protective measures may be unnecessarily impeding application of thermal power from radioisotopes to such space systems as Skylab and Space Station. Altogether, the use of $^{238}PuO_2$ fueled heat sources in a 90-day manned test of a life support system in the SSS represented a significant advancement in the acceptability of radioisotope power sources for use within manned space stations.

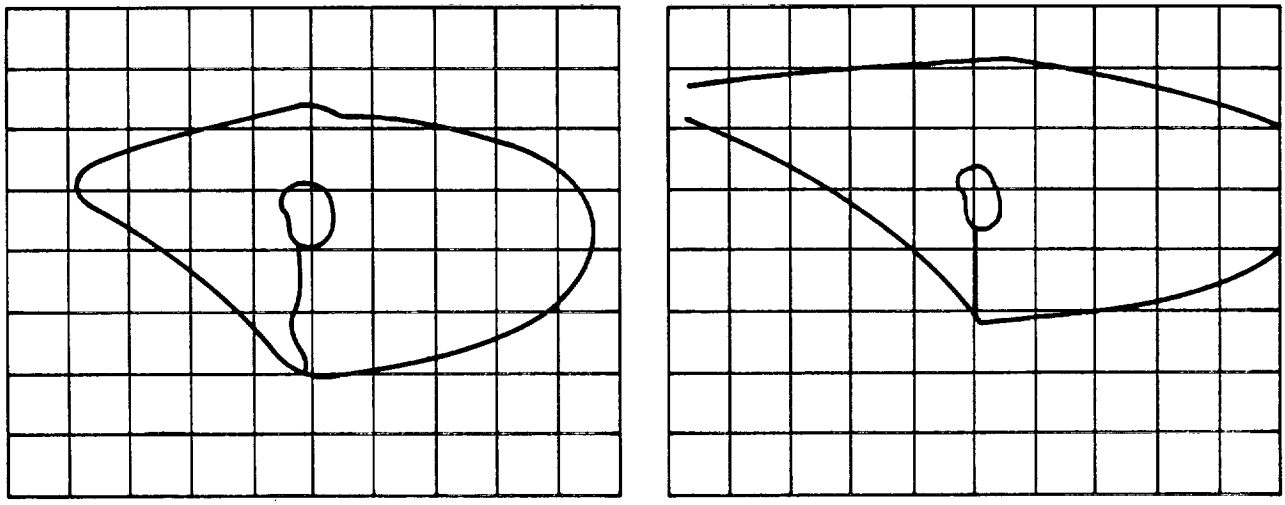
4.5.5 Electrocardiography

Resting, recumbent ECG's were obtained on each crew member weekly. Crewmen 1 and 4 revealed no changes throughout the test. Crewman 3 demonstrated occasional unifocal, single premature ventricular contractions (PVC) on one tracing, test day 27. These PVC's were not considered significant. Crewman 2, also on test day 27, revealed an "abnormal" rhythm

not previously noted. This rhythm consisted of frequent supraventricular intercalated beats with a compensatory pause and without a preceding atrial beat, i.e., nodal premature beats. On questioning crewman 2, it was learned that he had noted "skipped" pulse beats (pulse deficit) previously, specifically about a year before the test. Further evaluation of the ECG revealed what appeared to be a wandering atrial pacemake but with no apparent association with the nodal beats. This rhythm persisted throughout the test and was considered to be of no pathologic significance, especially in light of the previous history of pulse defict. Why the shythm was not found in preselection clinical ECG is open to conjecture but may represent a random event. The coincidence of crewman 3's PVC with crewman 2's nodal prematures on test day 27 also appears to be due to chance and no environmental parameters would seem to be connected. The coincidence of abnormal serum enzymes (SGOT, LDG and CPK) in crewman 2 (on test day 25) with the apparent rhythm change was disturbing at the time. The previous history, normal exercise tolerance, normal hematology, and absence of clinical symptoms were deemed adequate evidence for considering this rhythm to be a normal variant without significance to the test.

4.5.6 Pulmonary Spirometry

Spirometry recordings were obtained weekly from all crew members. The recordings were of excellent quality throughout the test, but the calibration was inadequate for the volume flow attained at reduced barometric pressure. This calibration could not be changed with the scope graticule available and, consequently, most loops went off-scale. A new graticule was not available to correct for this in time for the test. Figure 4-22 illustrates a typical pretest loop at barometric pressure 101.32 kN/m^2 (760 mmHg) and a loop recorded during the test at 70.03 kN/m^2 (526 mmHg). The calibration was recorded and is the same for both loops. In the sea-level loop, the vital capacity (VC) is 4.9 liters, the expiratory reserve volume (ERV) is 2.3 liters, the inspiratory reserve volume (IRV) is 1.5 liters, the tidal volume (TV) is 1.1 liters, the inspiratory volume flow ($\dot{V}_I$) is 8.6 liters/sec, and the expiratory volume flow ($\dot{V}_E$) is 8.6 liters/sec. In the loop recorded at altitude, the VC, ERV, IRV, and TV are not substantially different but the $\dot{V}_I$ and $\dot{V}_E$ are both off scale in excess of 10 liters/sec. This apparent increase in volume-flow rate persisted in all crew members for the duration of the test and is probably an effect of the reduced barometric pressure, i.e., reduced air density. No other significant changes in volume-flow loops were observed. There was a tendency toward decreased recorded tidal volumes in all crew members which is thought to be an effect of familiarization with the use of the spirometer. Baseline (pretest) TV's varied around 1 liter and gradually decreased to around 0.5 to 0.7 liter which is more nearly a normal value. The results of the spirometry study are reported also by Trout (Reference 4-33). In summary, the volume-flow loop appears to be a valuable tool for rapid assessment of pulmonary status especially in situations where pulmonary irritants are potential problems and baseline recordings are available. The pulmonary loop patterns were highly reproducible for all crew members throughout the test. It was apparent, however, that some "coaching" during the test enhances reproducibility.



SEA LEVEL RECORDING (101 KN/M^2) RECORDING AT 70.03KN/M^2

Figure 4-22. Typical Volume Flow Loops at Sea Level and Altitude

4.5.7 Contingency Samples

As previously indicated, residual serum and urine from scheduled sampling periods were held frozen in the Medical Laboratory in case of contingency. In addition to these on-site reserves, the clinical laboratory also retained residual serum and urine for contingency purposes. On occasion, the clinical laboratory was requested to use some of these samples to perform unscheduled procedures or for re-assay of one or more serum and urine constituents. Serum samples were analyzed in this way for ASO (antistreptolysin O) titer and for several electolytes. Urine samples were also analyzed on occasion for ammonia content and for creatine and creatinine. The majority of these additional tests were performed on samples of urine and serum stored at the clinical rather than at the on-site laboratory. All samples of serum and urine remaining at the clinical laboratory were returned to MDAC post-test and are presently being held frozen with the on-site contingency samples. It is anticipated that selected urine and serum samples collected throughout the program will be analyzed for 17 ketogenic steroids and hydroxyproline (urine) and immunoglobulins (serum). Steroid analyses will be used to back up Na^+/K^+ ratio data, hydroxyproline for the CO_2 study (see Section 4.5.8.1), and the immuno-assays will be used to evaluate crew immunological status over the course of the test.

4.5.8 Special Studies

As previously outlined in Section 4.4, test procedures were devised for several special studies, not necessarily required during normal test operations, to take advantage of the special circumstances of the 90-day test. These studies include determination of the biomedical effect of prolonged exposure to CO_2 levels above the normal level, analysis of blood samples by the NMRI, measurement of visual sensitivity changes, and use of radioisotopes for determination of and evaluation of the test crew member's physical conditioning program. The results of these studies are included in the following discussion.

4.5.8.1 Carbon Dioxide Studies

Carbon Dioxide Exposure History

Figure 4-23 illustrates the CO_2 exposure history as related to sample passout. Figure 4-24 shows the frequency distribution of recorded CO_2 levels during the entire 90 days and Figure 4-25 compares frequency distributions for the first 46 and last 44 days of the test. Carbon dioxide levels are recorded six times each day (every 4 hours). It can be seen from Figure 4-23 that there was a gradual rise in test mean Pco_2. The total increase was, however, only 1.3 mmHg (173 N/m^2). This figure also suggests that weekly mean Pco_2 and Pco_2 at sample time during the last half of the test were considerably higher than during the first half. Figure 4-24 shows the actual frequency distribution of Pco_2 recordings during the entire test. The control goal was a Pco_2 of 530 to 670 N/m^2 (4.0 to 5.0 mmHg) and it can be seen that the mode of the distribution is indeed 600 to 650 N/m^2 (4.5 to 4.9 mmHg); 57 percent of the observations are below 740 N/m^2 (5.5 mmHg) and 83 percent are less than 940 N/m^2 (7.0 mmHg). This distribution seems to place the SSS Pco_2 generally within current control limits for space vehicles with only sporadic observations in excess of 940 N/m^2 (7.0 mmHg).

In fact, however, this test actually appears to consist of two exposure phases in relation to CO_2. Figure 4-25 shows that during days 1 to 46 the modal Pco_2 is 600 to 650 N/m^2 (4.5 to 5.0 mmHg); 80 percent of the observations are under 740 N/m^2 (5.5 mmHg) and only 3.4 percent are in excess of 1,070 N/m^2 (8.0 mmHg). During test days 47 to 90, the modal Pco_2 is 740 to 800 N/m^2 (5.5 to 6.0 mmHg); only 33.4 percent are under 740 N/m^2 (5.5 mmHg) and 10.5 percent are above 1,070 N/m^2 (8 mmHg). Clearly control of the CO_2 was less precise during the last half of the 90-day test with higher and more prolonged peaks of Pco_2. It should be noted that during the last 43 days, no observations were made of Pco_2 less than 530 N/m^2 (4.0 mmHg) while during the preceding period 16.5 percent of the observations were in this range. Hence, not only did more prolonged peaks occur during the last half of the test, but also no really low levels of Pco_2 were recorded. These analyses of the Pco_2 history will be seen to be quite significant to the following discussions.

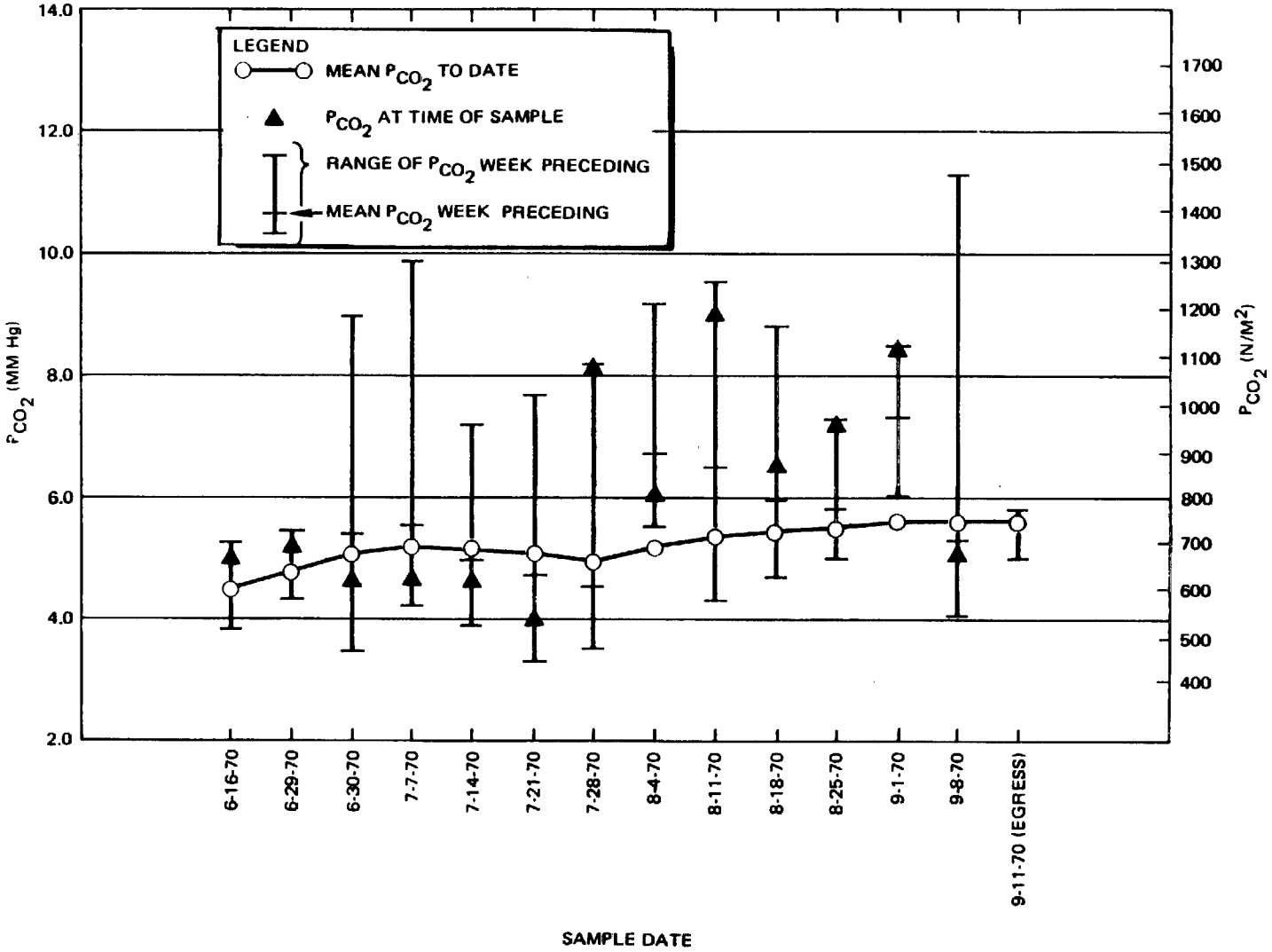


Figure 4-23. CO_2 Exposure History Related to Sample Pass-out

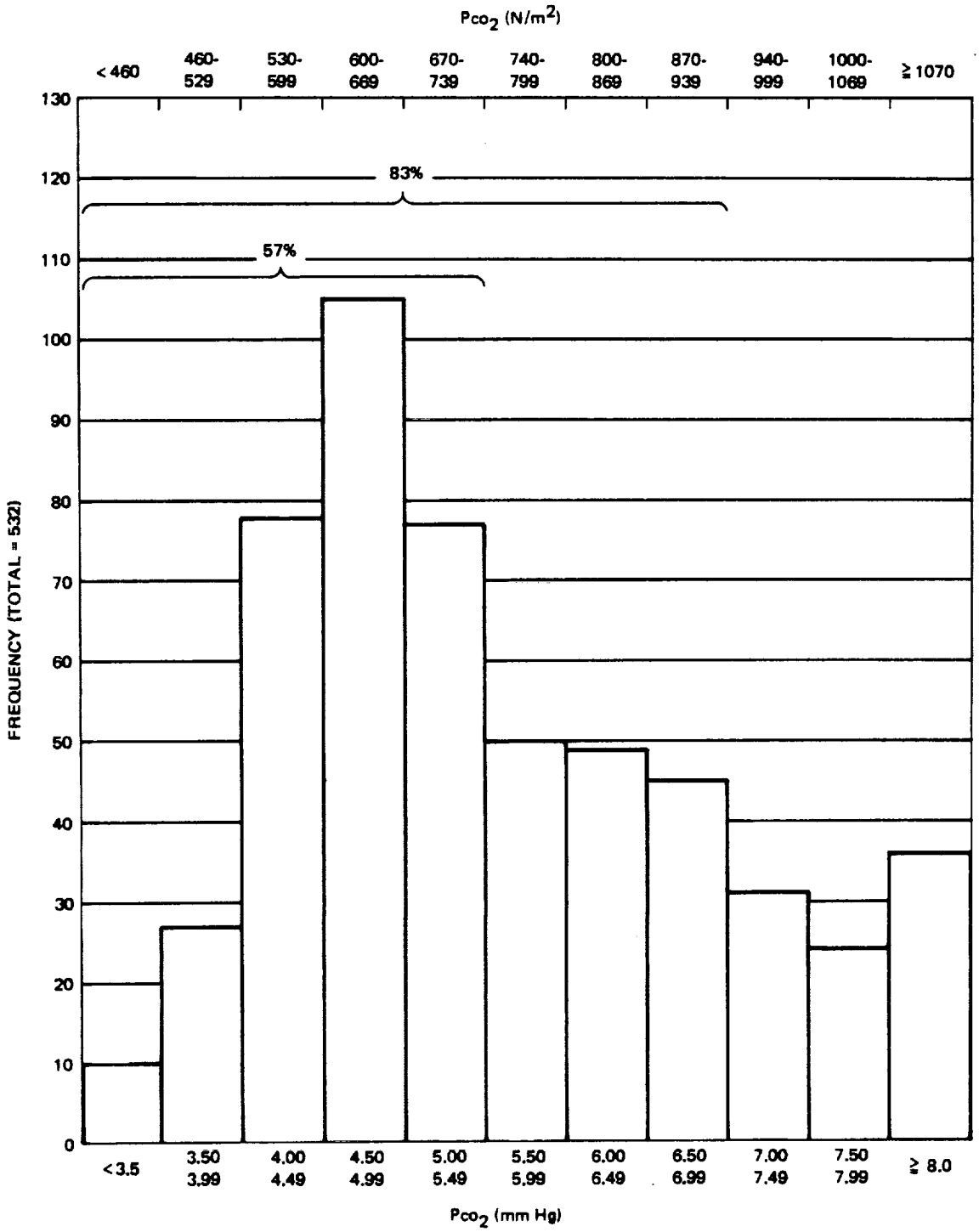


Figure 4-24. Frequency Distribution of Pco_2 Recorded Observations (90 Days)

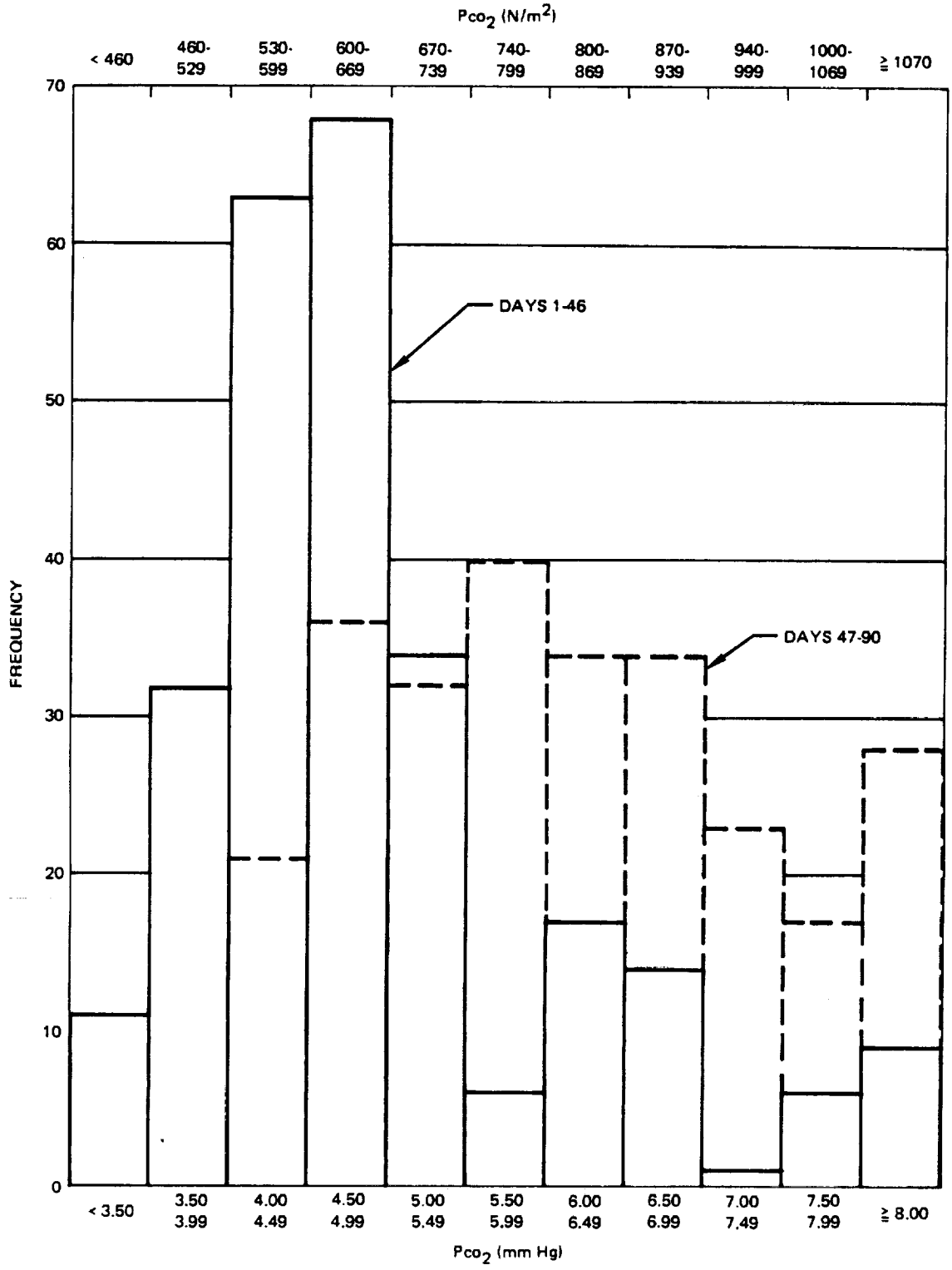


Figure 4-25. Frequency Distribution of Pco_2 Recorded Observations, Days 1-46 and Days 47-90

11 0

Psychophysiologic and Subjective Effects

At no time during any CO_2 exposure were there detectable psychomotor or physiologic deficits. In fact, there was a negative correlation between Pco_2 and psychomotor performance (Reference 4-34). Whether or not this correlation indicates a real psychomotor performance improvement in rising Pco_2 or is only part of the training effect, it certainly suggests that Pco_2 in the range seen in this test causes no detectable degradation. Exercise tolerance was not altered at any level of CO_2 and there were no changes observed in heart rate, blood pressure, electrocardiogram, resting/sleeping respiratory rates (one crew member, see below), or spirometry.

During the first rise in CO_2 on test day 14 at Pco_2 1,214 N/m^2 (9.1 mmHg), crewmen 3 and 4 reported subjective symptoms of CO_2 exposure (i.e., dizziness), lack of coordination, and blurring vision. At the same time, both crew members attained their best scores yet on the Langley Psychomotor Tester. This initial rise in CO_2 was accompanied by a great deal of apprehension on the part of these crew members and not shared by crewmen 1 and 2 (at least not expressed) and crewmen 1 and 2 reported no symptoms. In view of the psychomotor performance, it was concluded that the symptoms were not related to the CO_2, per se, but rather to the concern about it. During the remainder of the test, at higher levels of CO_2, the symptoms did not recur. Absence of subjective symptoms and lack of detectable psychophysiologic degradation in exposure to the test levels of CO_2 were not unexpected in light of previous studies, as reviewed by Glatte and Welch (Reference 4-35) and as examined in acute, high exposure by Wamsley, et al (Reference 4-36) and Gibbons, et al (Reference 4-37). We, therefore, anticipated no operational significance in the range of test Pco_2 and saw none. The question of biochemical alteration in CO_2 adaptation, however, remained open.

Sleeping Heart and Respiratory Rates

As outlined in Section 4.4.1.3, one crew member elected to conduct an experiment correlating sleeping respiratory and heart rates with CO_2 levels. Sleep recording sessions were begun on 7 or more days during the test, but because of equipment malfunctions, complete data on both heart rate and respiratory rate are available for only four test days: 38, 47, 58, and 60.

Portions of data analyzed from other days appear very similar to the records reproduced here. Average cabin partial carbon dioxide pressures during the recording periods on these four days were, respectively, 554, 1225, 1,200, and 1,146 N/m^2 (4.15, 9.20, 9.00, and 8.60 mmHg). Because of time line requirements for use of the recording equipment in conjunction with the daily exercise program, most recording sessions had to be terminated some three hours into the sleep period.

The heart rate recordings showed only long-term variations due to the slow chart speed and response time of the recorder. The data were rounded to the nearest number of beats per minute for presentation in Figure 4-26. Variations of less than one beat/minute were not measurable. The smooth curves

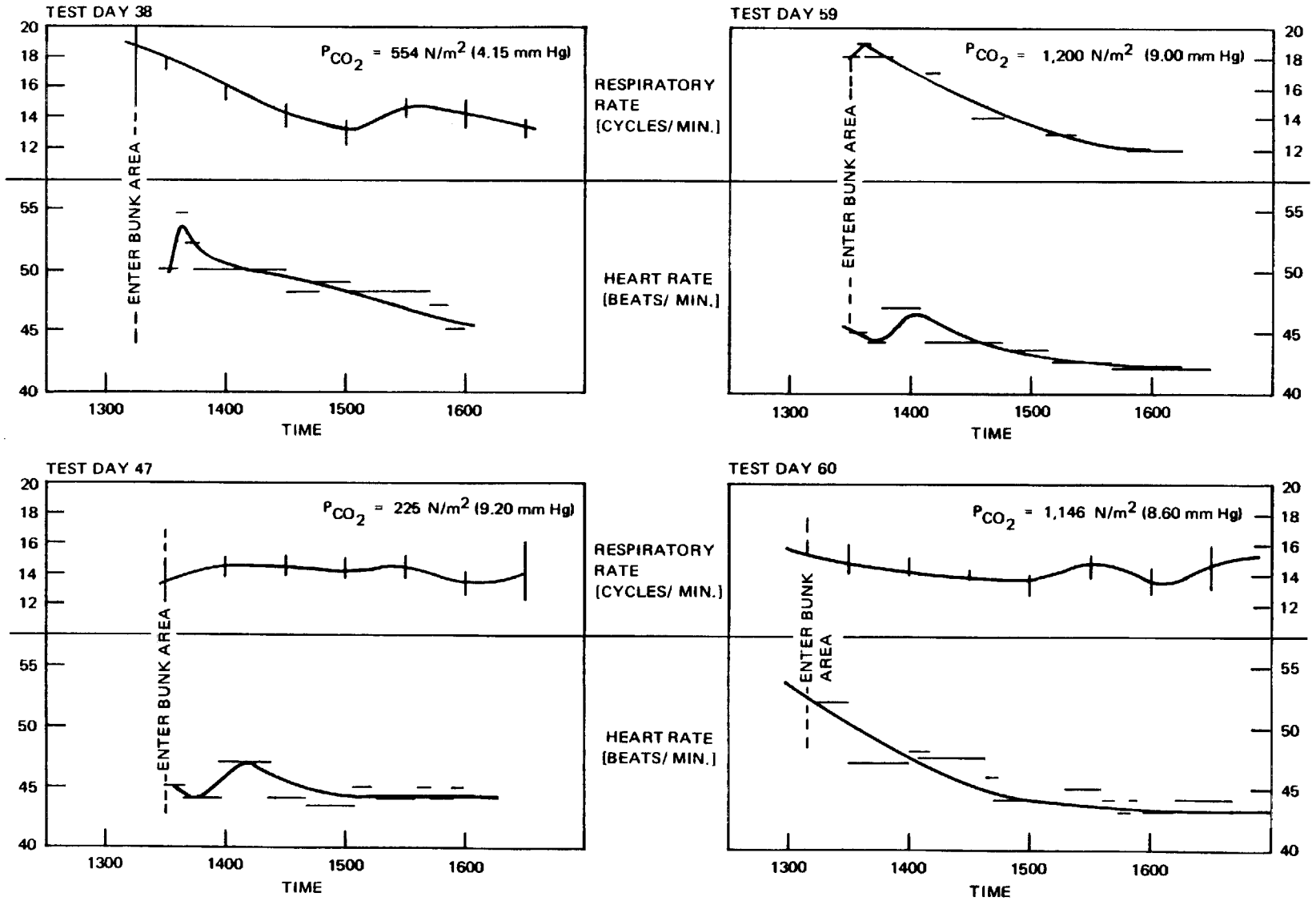


Figure 4-26. Sleeping Respiratory and Pulse Rates

drawn through the data are intended to give a picture of the general trends. The data on respiratory rates were read from the strip charts by measurement of the respiratory frequency over one minute intervals. The observed respiratory rates show much larger short-term variations than heart rates and, in a 0.5-hour period, twenty data points would typically range several cycles/minute. The vertical bars represent the range of frequencies in each 0.5-hour interval, while the solid line is drawn through the modal portions of those distributions.

The initial rates or respiration and heartbeat on all four days reflect the generally inactive state of the crewman immediately prior to retiring for the day. All records begin with pulse rates of less than 55 beats/minute. A pulse rate of 50 to 55 beats/minute was typical for this crewman while performing light activities, such as, reading, brushing teeth, writing, etc. Ten minutes of reclining with essentially no muscular activity would lower the pulse to 44 to 48 beats/minute. Initial respiratory rates were highly variable, ranging from 13 to 19 cycles/minute.

As the crewman entered the sleep period, respiratory and heart rates would begin to fall to basal levels. In several instances (days 37, 46, and 58), the initial response of heartrate was to rise 3 or 4 beats/minute for a short time. In several cases after two and one half hours of recording, basal rates still had not been reached. Two hours into the sleep cycle, heart rates generally settled down to 42 to 45 beats/minute, except in the first recording session when the heart rate was still 48 beats/minute. It is quite possible that this reflects the minor discomfort involved in wearing the ear clip and taped wiring for the first time. No sleep recordings were made during periods when the cabin Pco_2 was rapidly changing.

Figure 4-27 summarizes heart and respiratory rates at the end of two hours for all four days. Clearly the data do not indicate any effects of different CO_2 levels on respiratory rate. The effect on cardiac rate is not what one would expect, but it is seen only in the first recording session and probably must be discounted. Statistically, the data are insufficient to make any clear-cut distinctions. No consideration has been made of carbon monoxide level, exercise, or other variables.

It is apparent from these data that the range of CO_2 from 554 to 1,225 N/m^2 (4.15 to 9.20 mmHg) had no effect on sleeping respiratory rate or heart rate in this crew member. These results were not entirely unexpected in view of similar measurements at higher Pco_2 in waking crew members (Reference 4-37). The limited data collected here do not allow generalization. The best that can be said is that no effect was seen in this test on this crew member. Schaefer (Reference 4-38) has described different reaction groups and it may be that this crew member is relatively insensitive to CO_2. (His urine chemistry would not necessarily suggest this.) In any case, future measurements of this sort should be made on subjects selected for their sensitivity recordings. Longer recordings through entire sleep periods may be necessary to establish true basal levels.

Biochemical Analyses — Urine Chemistry

Raw data from urine chemical analyses are presented in Appendix J. If significant alterations in acid-base balance were occurring, one would expect

R292-II

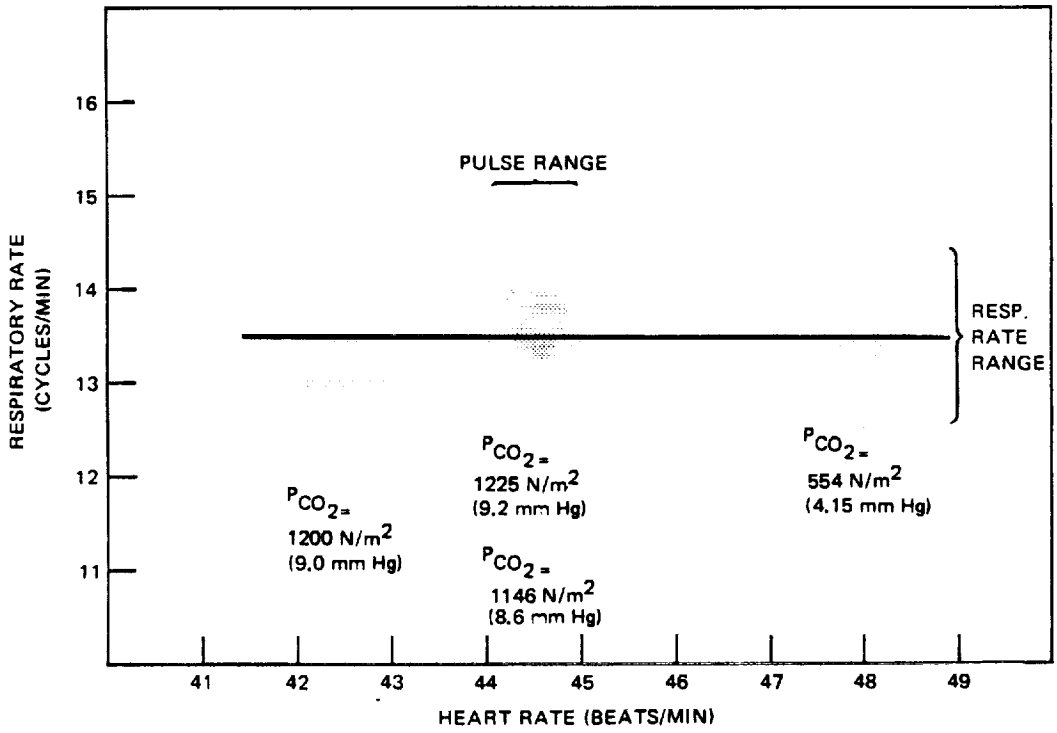


Figure 4-27. Summary of Pulse Versus Respiratory Rate--2 Hours Into Sleep

to see increased hydrogen ion (H^+) excretion. As Glatte and Welch (Reference 4-35) point out:

> ". . . . . On a normal diet, 40 to 80 mEq of H^+ are excreted in a 24-hour period. With incresing acid loads as noted with marked hypercapnia, this figure is doubled or tripled for a 24-hour period. This parameter can be readily measured by carrying out a hydrogen ion balance study for 24 hours by measuring urinary NH_4^+, titratable acidity (T. A.) and bicarbonate. The total 24-hour H^+ excretion then becomes NH_4^+ + T. A. - HCO_3. . . . . "

During this test we were able to measure only T. A. and NH_4^+ with the consequence of slightly inflating our "H^+ excretion" data if HCO_3^- were being excreted.

Figure 4-28 illustrates hydrogen excretion for each crew member and the mean for the group for the duration of the test. Unfortunately, no pretest urine chemistries were available for control. The "normal range" noted in the figure is that quoted in Reference 4-29 for healthy subjects on normal diet. We are assuming no dietary influence here since the crew were on a controlled recurring menu. From Figure 4-28, it appears that H^+ excretion is elevated for crewman 3 and 4 but not for crewmen 1 and 2. This difference

R292

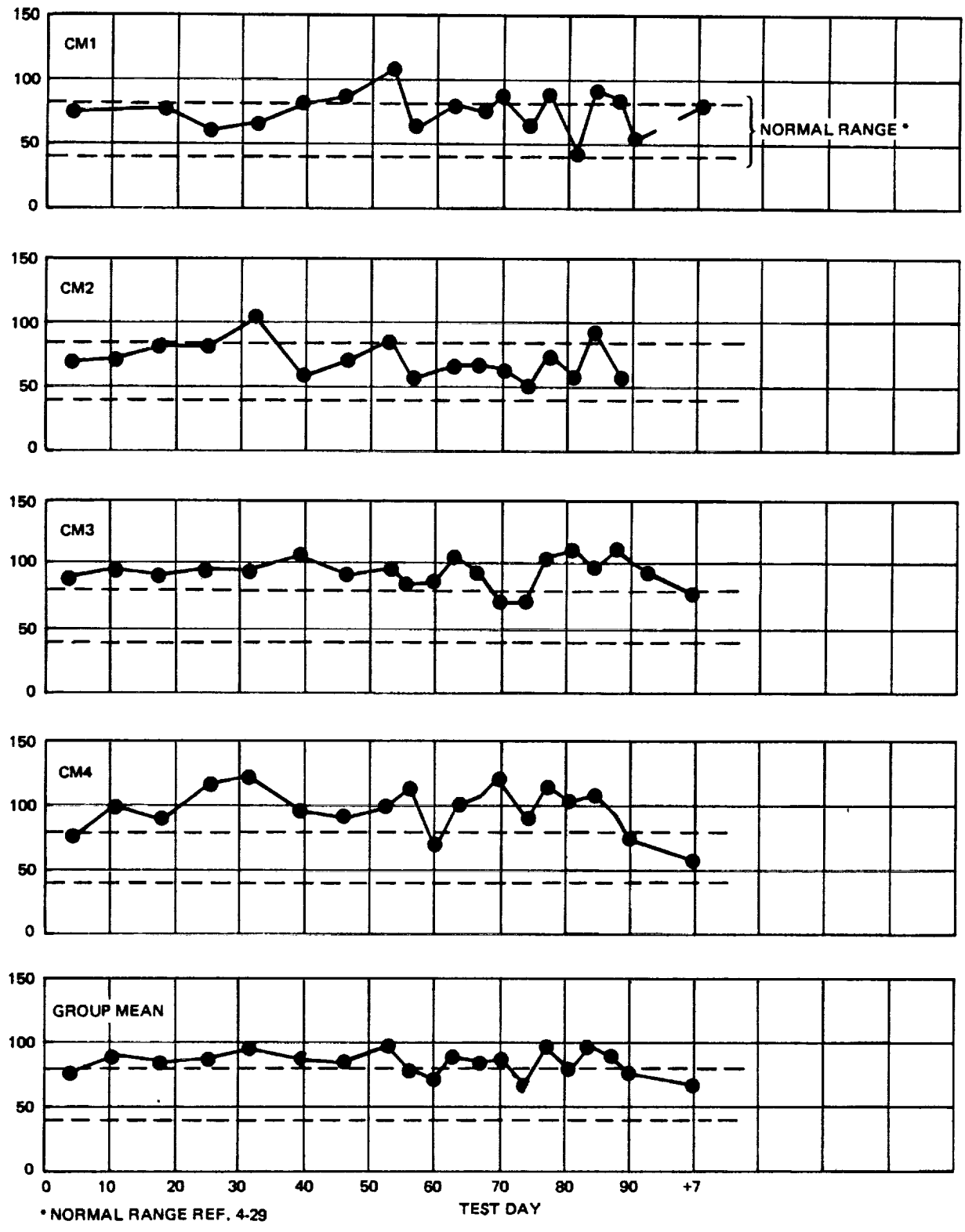


Figure 4-28. Hydrogen Ion Excretion (mEq/24 Hours)

cannot be explained on a circadian basis because the urine samples represent 24-hour collections. In other urinary constituents, including total dissolved solids, crewmen 3 and 4 consistently excreted greater amounts without concomitantly greater volume output. This difference would appear to be a body mass effect which should be compensated in the statement of "normal range" quoted for H^+ and the difference in H^+ excretion associated with some other effect. (Urinary pH was always less than 7.0 and there were no differences among the crew members.) It would seem improbable that the two crew pairs should react so differently to the same CO_2 exposure even though Schaefer has described different reaction groups (Reference 4-38). In fact, there were no significant correlations between weekly mean Pco_2 and H^+ excretion—all correlations were negative, the highest for the urine acidity parameters was -0.437 for T.A. with weekly mean Pco_2 in crewman 1 ($p > 0.10$). There is no completely credible explanation for the differences between crew pairs in H^+ excretion. Crewmen 3 and 4 were involved in constantly more strenuous exercise than 1 and 2, though, and heavy exercise is known to induce a metabolic acidosis (Reference 4-39) and an acid urine (Reference 4-40). It may be that the combinations of heavy exercise and greater metabolic mass account for the H^+ excretion difference. We cannot attribute it to CO_2 exposure. No other urine parameters appeared to reflect a CO_2 exposure. These findings are consistent with those reported by Glatte, et al (Reference 4-35) in chronic exposures to higher Pco_2 (2,800 N/m^2 or 21 mmHg).

Biochemical Analyses — USNSMC Blood Chemistry

With the exception of serum calcium and inorganic phosphorus (obtained biweekly, see below), relevant blood chemistries were accomplished at the USNSMC, Groton, Connecticut. The raw data from these analyses are presented in Appendix L. It is assumed that most of those data will be reported elsewhere by SMC but certain results will be presented here.

Venous plasma pH (pH_v) data are given in Figure 4-29. With the exception of certain points which appear to be processing errors, no trends are observed especially when outside "control" values are considered.* The increased variability in pH_v during days 50 to 90 also appears to be due to processing since the control values reveal the same instability. It should be noted in reference to these data that during the first half of the test an average of 2 days elapsed between drawing blood samples and processing them; during the last half of the test, processing was delayed for several samples resulting in an average of 4-1/2 days from sampling to analysis. The day 53 sample was analyzed 8 days after the blood was drawn; the day 81 sample, 7 days, and the day 90 sample, 6 days. These delays (incurred largely in transit or at the SMC) could account for sample variability. No such prolongation of storage occurred for the first eight samples or for the four post-test samples.

Venous plasma bicarbonate (HCO_{3v}^-) data are presented in Figure 4-30. The control group HCO_{3v}^- is as high or higher than values for the inside crew and

*Outside controls were backup crew members who were not on the same regimen as the crew, hence are not considered "experimental controls" but rather laboratory or processing controls. Blood was drawn at the same time and handled exactly the same as for the inside crew.

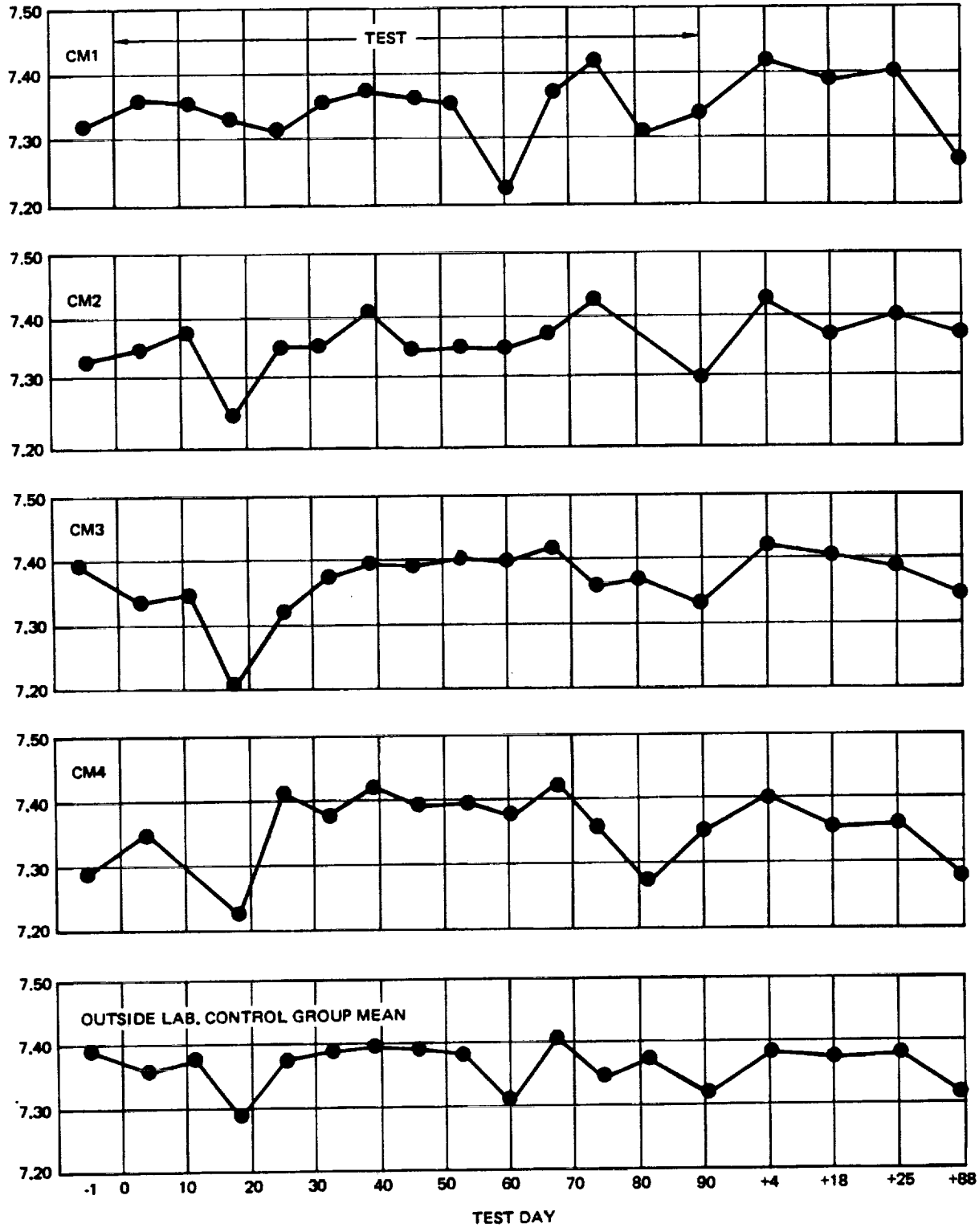


Figure 4-29. Venous Plasma pH

R292

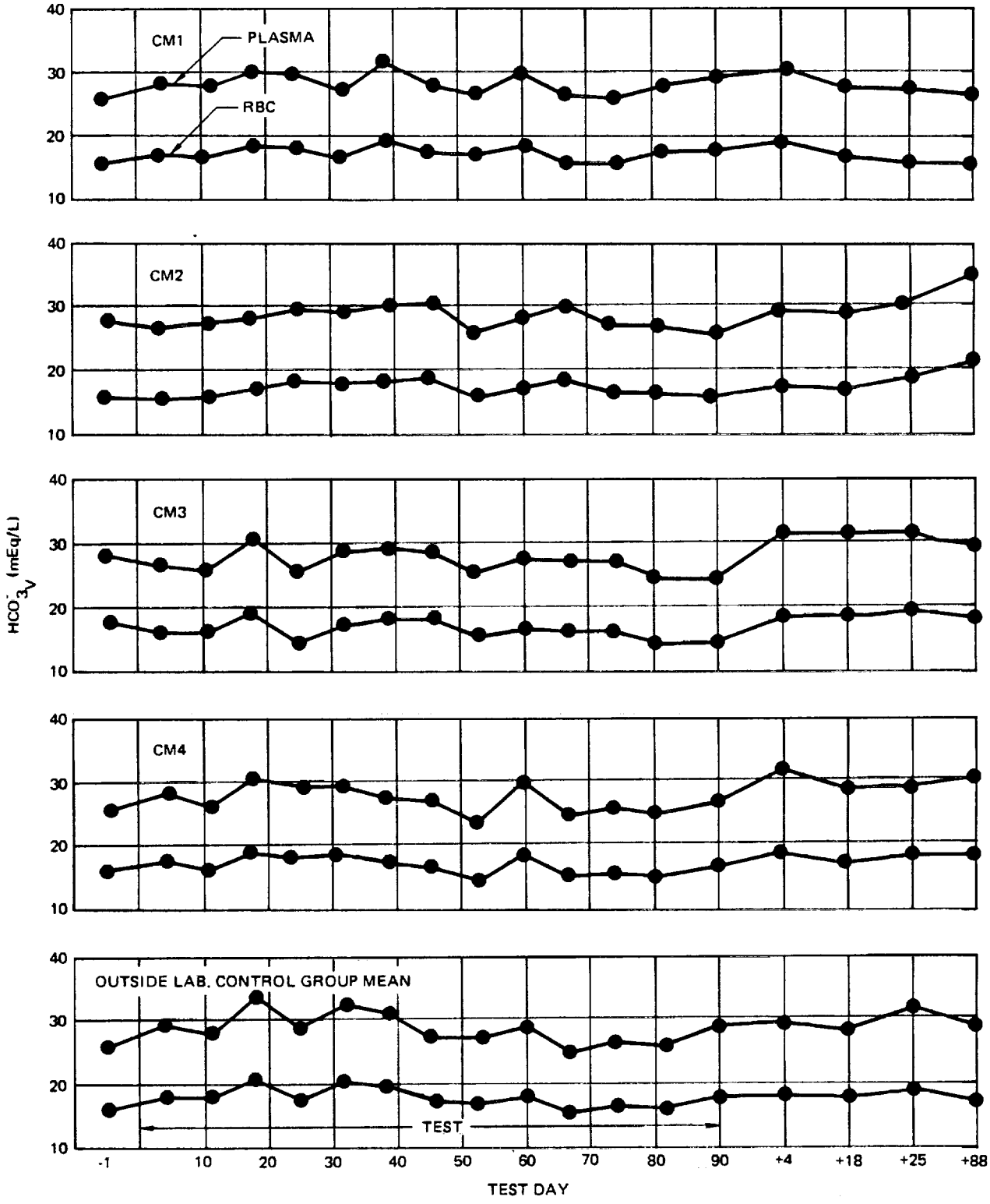


Figure 4-30. Venous Plasma and RBC Bicarbonate

post-test values tend to be higher than values obtained during the CO_2 exposure. Correlations of plasma HCO_3^- and Pco_2 were all negative ranging from -0.24 to -0.50 with a group correlation of -0.38 ($P < 0.01$).

Schaefer (Reference 4-6) has described increases in RBC sodium (Na^+) in CO_2 exposure. RBC Na^+ data obtained during our test are displayed in Figure 4-31. The trends seen in Figure 4-31 would suggest an increase in RBC Na^+ with increasing duration of CO_2 exposure. However, it can also be seen that the outside, unexposed controls show a similar trend. The high control point on day 32 represents a single sample which was obviously hemolyzed. This demonstrates dramatically the effect on intracellular Na^+ of disrupting the cell membrane. The same disruption occurs during storage of cells to a lesser extent, that is, the integrity of the cell membrane is compromised. Since the packed cells are not washed prior to shipment and processing, they are still surrounded by plasma with a relatively high Na^+ content. If the integrity of the cell wall is compromised, then Na^+ will enter the cell and the resultant increases will be quite significant. It is our opinion, based on the control data, that the increases in intracellular sodium seen here are not a CO_2 effect but represent ingress of plasma Na^+ with increased cell wall premeability to that ion.

Biochemical Analyses—Serum Calcium (Ca^{++}) and Inorganic Phosphorus (P)

Raw data for serum Ca^{++} and P are presented with clinical blood chemistries in Appendix K. Serum Ca^{++} trends are shown in Figure 4-32. Test values are shown as deviations above or below the pretest mean ($\bar{x}_o$) and the dotted lines represent the "t" times the pretest standard deviation for p of 5 percent (95 percent confidence limits), the value of "t" depending on the number of pretest samples. It appears from this figure that there was a general downward trend for serum Ca^{++} during the test. The decrease was significant in crewman 3 for the sample obtained on test day 81. Similar analysis of serum phosphorus revealed a general increase in P, significant in 13 samples out of 21 in crewmen 1, 2, and 3; none significant in crewman 4. The decrease in Ca^{++} accompanied by an increase in P suggests a valid biochemical change since this is the expected relationship and the laboratory determinations for the two are independent, ruling out a systematic laboratory error. Further analysis shown in Figure 4-33 revealed a negative correlation between the group serum calciums and test duration as well as weekly mean Pco_2. Urinary Ca^{++} revealed similar negative correlations, ruling out excessive urinary excretion. No urinary trends in P were seen but Figure 4-34 reveals a positive correlation between serum P and Pco_2 (see also Figure 4-35)*. Because of the higher CO_2 experienced during the second half of the test, means for days 1 to 53 and days 53 to 90 were compared. Figure 4-36 illustrates the trends for the period means. The group mean Ca^{++} for days 53 to 90 is significantly lower than the mean for days 1 to 53 and the post-test mean. The

*The correlation with time is interesting in showing a completely opposite effect between crew pairs; positive for the day crew and negative for the night crew. This finding has not yet been studied in detail but seem irrelevant to the CO_2 discussion.

R292

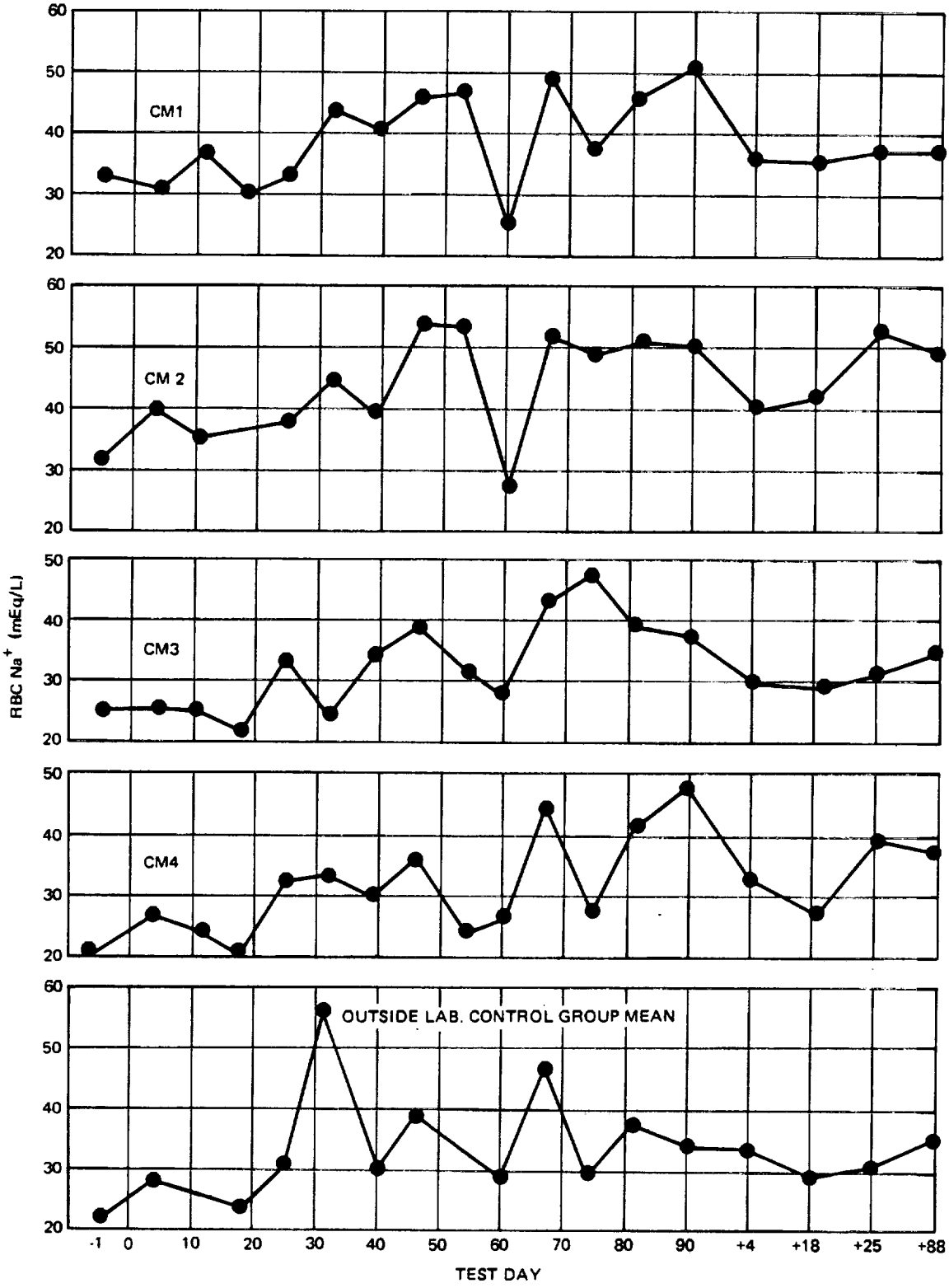


Figure 4-31. Red Blood Cell Sodium

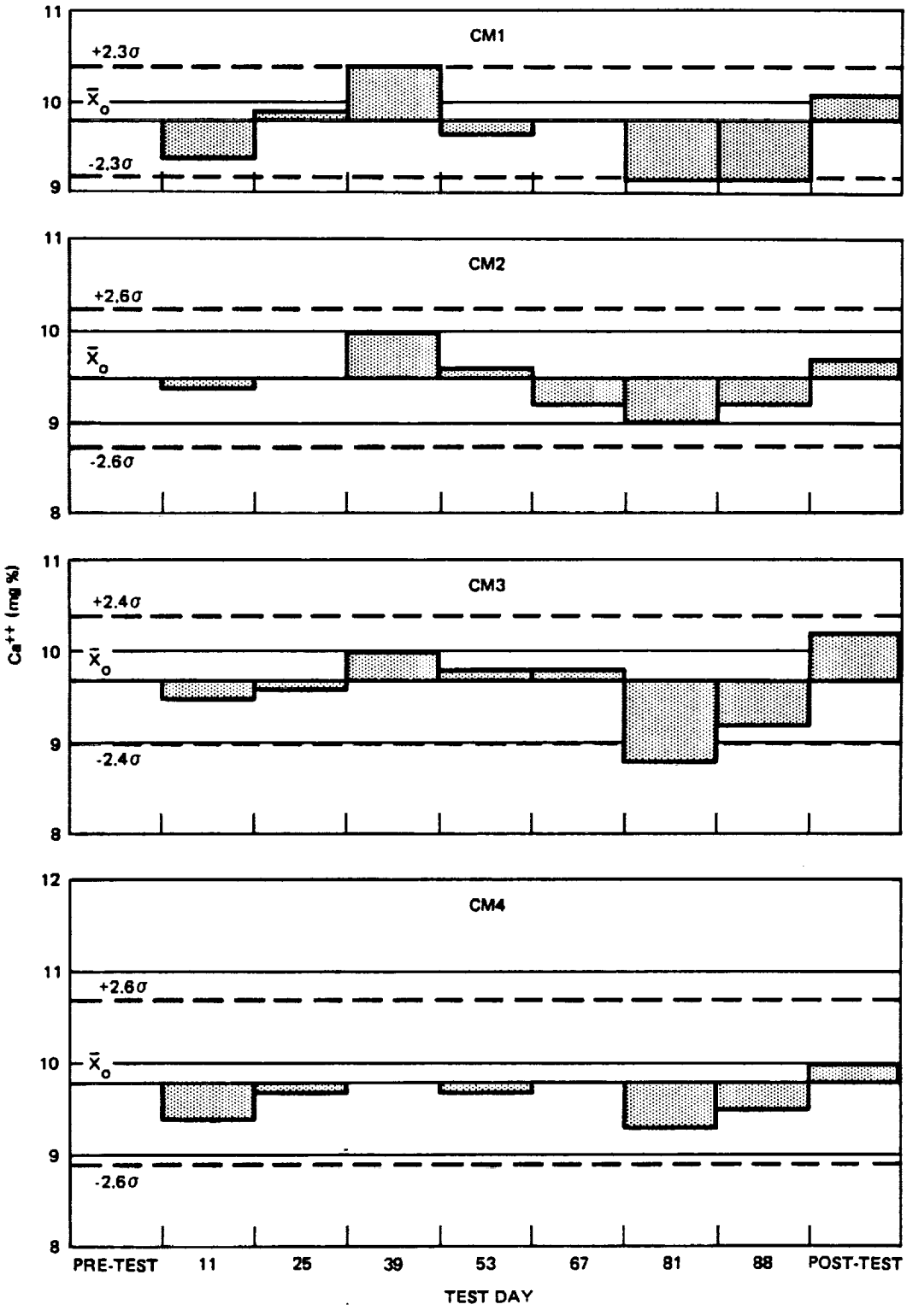


Figure 4-32. Serum Calcium

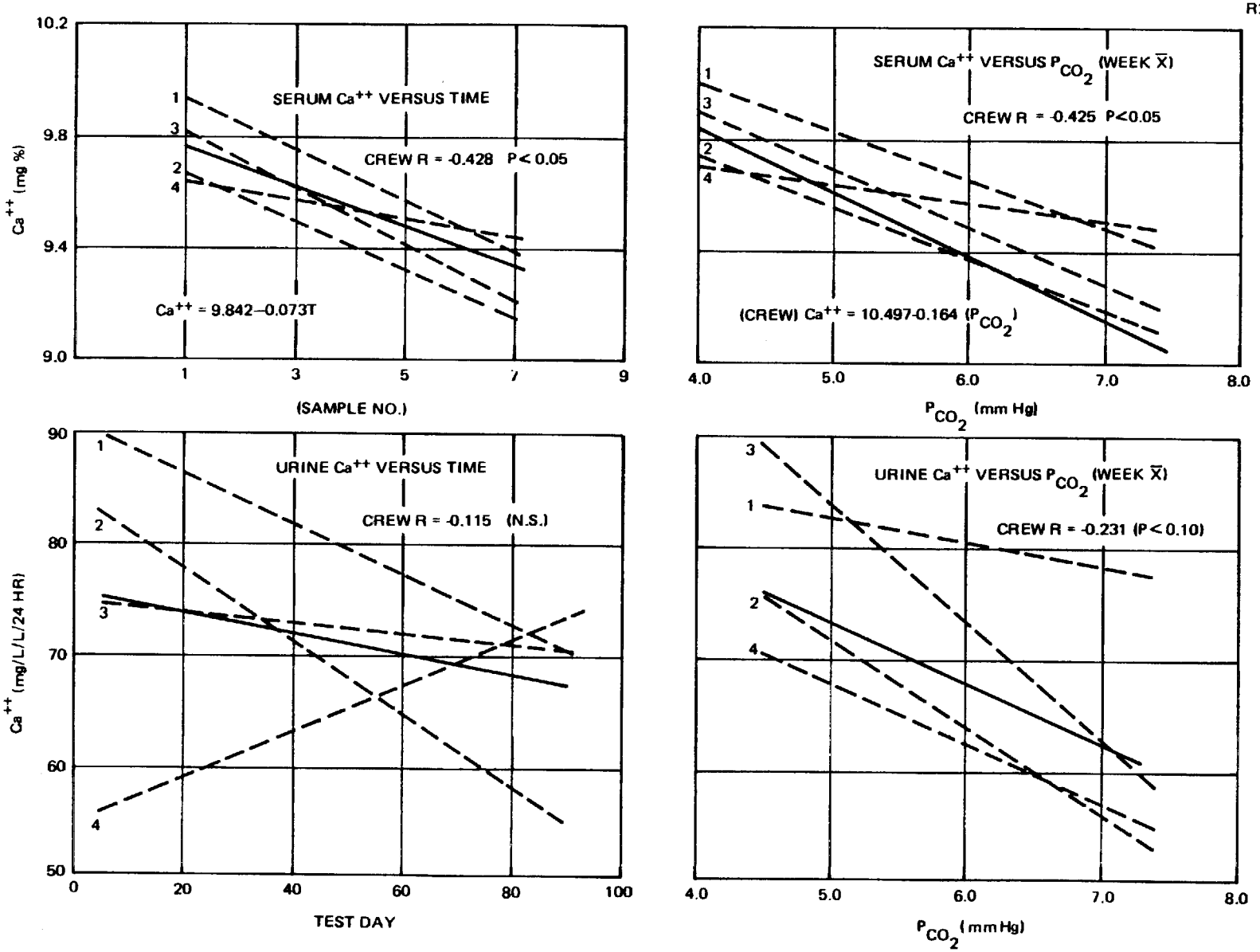


Figure 4-33. Serum and Urine Calcium Trends

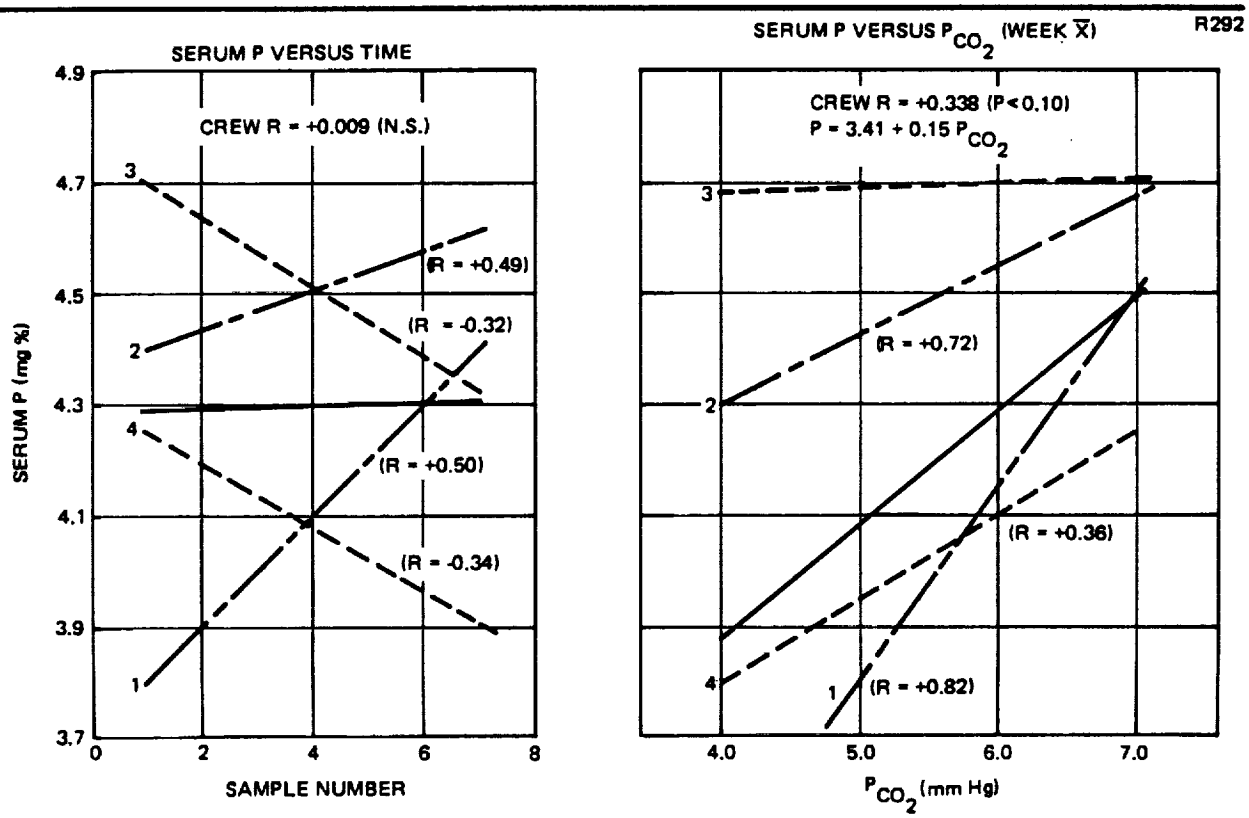


Figure 4-34. Serum Inorganic Phosphorus Trends

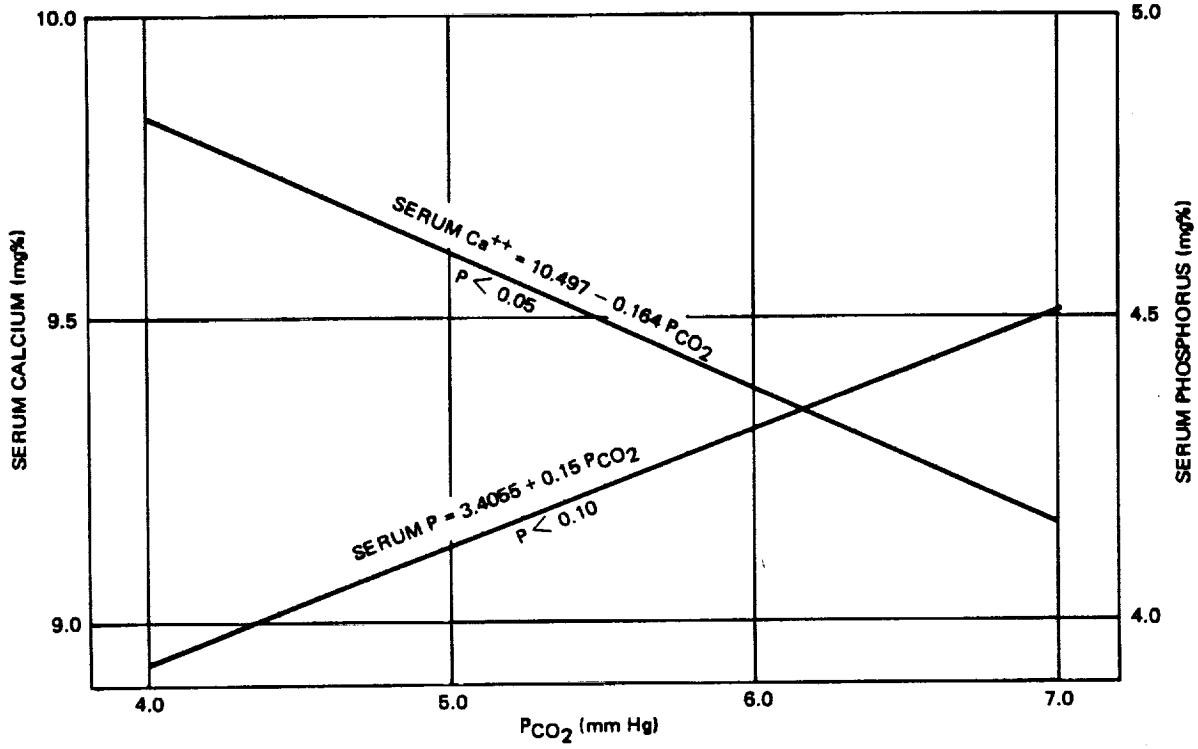


Figure 4-35. Serum Calcium and Inorganic Phosphorus Trends

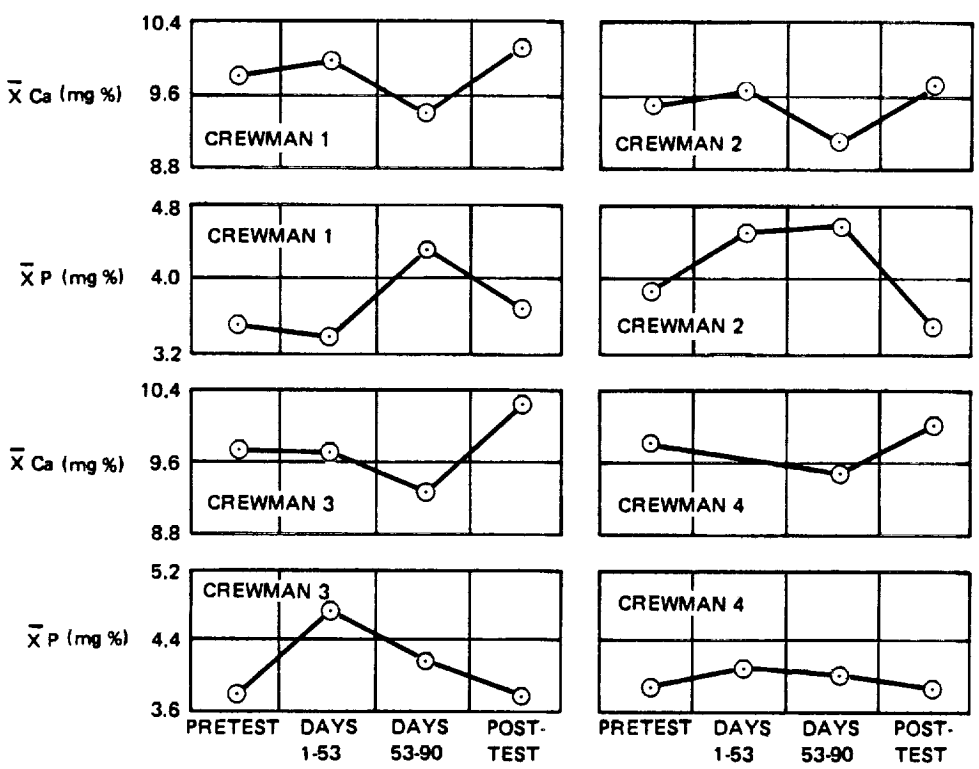


Figure 4-36. Calcium-Phosphorus Trends

group mean P is higher for both periods than the post-test mean. It is our opinion that the alterations in calcium-phosphorus reflect CO_2 storage and was an effect of the generally higher and more prolonged peaks of CO_2 experienced in the last half of the test. The lack of response during the first half would seem to rule out a low CO_2 effect (i.e., CO_2 generally in the 3.5 to 5.5 mmHg range), since such an effect should have appeared well within that time. It is possible, however, that because of our delay in obtaining the first Ca^{++} determination we missed an initial depression and are seeing only the last part of a biphasic response as described by Schafer (Reference 4-41). This possibility during the first half of the test cannot be ruled out. The trend in the last half, however, reveals no biphasic characteristic and appears to reflect a response to intermittent prolonged peaks superimposed on a continuing low level exposure to CO_2.

Discussion

In their review, Glatte and Welch (Reference 4-35) point out in respect to increased CO_2:

> "If the stimulus is strong enough.....the respiratory (increased ventilation to blow off more CO_2), intracellular, and extracellular buffering systems will not be adequate. The kidney will then contribute by increasing the excretion of H^+ in the form of NH_4^+ and increasing the generation and reabsorption of HCO_3^- to buffer

body fluids....Clinically, then, we would see an elevated Pco_2, elevated respiratory minute volume, reduced pH, elevated serum HCO_3^- or total CO_2 and increased 24-hour hydrogen ion excretion. These are the main physiologic parameters to be followed....."

Obviously, our stimulus was not strong enough to cause perceptible changes in respiration, performance or any of the biochemical parameters noted above. The stimulus during the last half of the test did seem strong enough to induce alterations in Ca^{++} and P. The changes may represent CO_2 "storage" as described by Schaefer (References 4-41 and 4-42). At this writing, though, we cannot rule out a calcium deficit arising from inadequate Ca^{++} and vitamin D intake while unexposed to ultraviolet radiation. It seems unlikely that these deficiencies would lead to depressed serum Ca^{++} in adults; the bone store of Ca^{++} should be adequate to maintain blood levels if the parathyroids are functioning. Vitamin D levels are being determined on samples of the crew blood and we plan to analyze stored urine samples for hydroxyproline. These analyses may shed some light on the true causal relationships. It is our current opinion that the Ca^{++} - P changes reflect exposure to high CO_2 in the last 45 days of the test. We can conclude, then, that the chronic exposure to low CO_2 did not cause perceptible alterations psychophysiologically or in acid base balance but recurrent acute exposure to high CO_2 (>7.0 mmHg) was associated with significant changes in blood Ca^{++} and P. These findings suggest that exposure to Pco_2 within currently specified Skylab limits (<5.5 mmHg) should not result in changes detectable with current methods. It should be noted, also, that the processing delays experienced with our samples are less than those which will be expected in space missions of the near future, that is, our passout and processing procedures were analagous to planned Skylab procedures—no onboard processing.

It is a moot point whether the early exposure to low CO_2 increased sensitivity to later, higher CO_2's in respect to Ca^{++} and P. The whole matter requires further study. There is also the question of interactions between low CO_2 and zero-g. The latter tends to increase blood Ca^{++} with bone resorption. Whether CO_2 would tend to reverse this process or would tend to introduce additional instability in Ca^{++} control cannot be answered at this time. Problems of abnormal calcium deposition must also be considered (see Reference 4-42).

Summary and Conclusions

Exposure to low levels of CO_2 over 90 days induced no perceptible biochemical, psychological or physiological effects. Exposure to intermittent prolonged periods of high CO_2 (Pco_2 > 7.0 mmHg) superimposed on long-duration low level exposure apparently caused changes in blood Ca^{++} and P.

It is concluded that from these data that current spacecraft CO_2 limits are realistic and will not cause detectable changes. Some questions in respect to interactions between zero-g and CO_2 exposure remain unanswered.

4.5.8.2 NMRI Serum Analyses

The principal investigators at the NMRI reported the following test results at the 90-Day Manned Test Symposium (Reference 4-32). Computer correlations comparing observed behavior trends (NIPA) and certain biochemical results are reported in Section 3.6.

Inspection of the test results showed that few components of serum were significantly altered by the 90-day exposure. Among the nonlipid constituents, glucose was quite stable with the only remarkable variation being a general small decrease in all subjects on test day 53. The mean serum lactate values were found to range from 23 to 27 mg percent. The serum enzymes showed some regular fluctuations, but few clear-cut changes relative to the test could be ascertained. Lactic dehydrogenase, acid and alkaline phosphatase showed no significant change throughout the test period. Creatine phosphokinase (Figure 4-37) was significantly elevated in crewman 2 on test days 11, 39, and 60. Crewman 4 had high CPK levels prior to the 90-day test, and these were further increased during the test. These changes will be discussed in relation to exercise phenomena and adaptive changes. Serum amylase levels (Figure 4-38) were increased over the pretest mean in all subjects with crewmen 3 and 4 showing the most significant elevations. Of the serum lipid classes analyzed, the only noteworthy phospholipid change was in sphingomyelin (Figure 4-39). A significant elevation of sphingomyelin was observed for crewmen 1 and 2 on test day 18. Crewman 4 had an elevated value throughout the test while most of the values for crewman 3 ran below the pretest mean. In the neutral lipids, cholesterol (Figure 4-40) showed a steady decrease during the test. The low values persisted throughout the post-test sampling period.

In general the biochemical values that were determined over the course of this study indicate no marked alteration that could be interpreted as hazardous to these men.

One crew member, crewman 2, had three elevations in creatine phosphokinase after entry into the chamber, each elevation being lower than the previous rise. Such an increase in CPK may accompany skeletal muscle injury or severe exercise. A prolonged exercise routine can lead to progressively less significant enzyme changes resulting from an unchanged exercise regimen. This phenomenon, a type of adaptation, could possibly account for the pattern observed in this crew member.

Serum amylase was elevated in all subjects during the test. The origin of this enzyme (parotid or pancreatic) was not determined and no explanation for the rise can be offered at this time.

In all of the subjects there was no detectable change in the minor phospholipids measured as the sum of phosphatidyl glycerol, cardiolipin, and phosphatidic acid. If Polis (Reference 4-8) is correct, that elevation of phosphatidyl glycerol is an indicator of "stress," no evidence of stress such as found in acceleration, combat aviation, and schizophrenia was apparent in the chamber crew. The analytical techniques used by Polis, however, were different than those applied here, and direct comparisons are not possible.

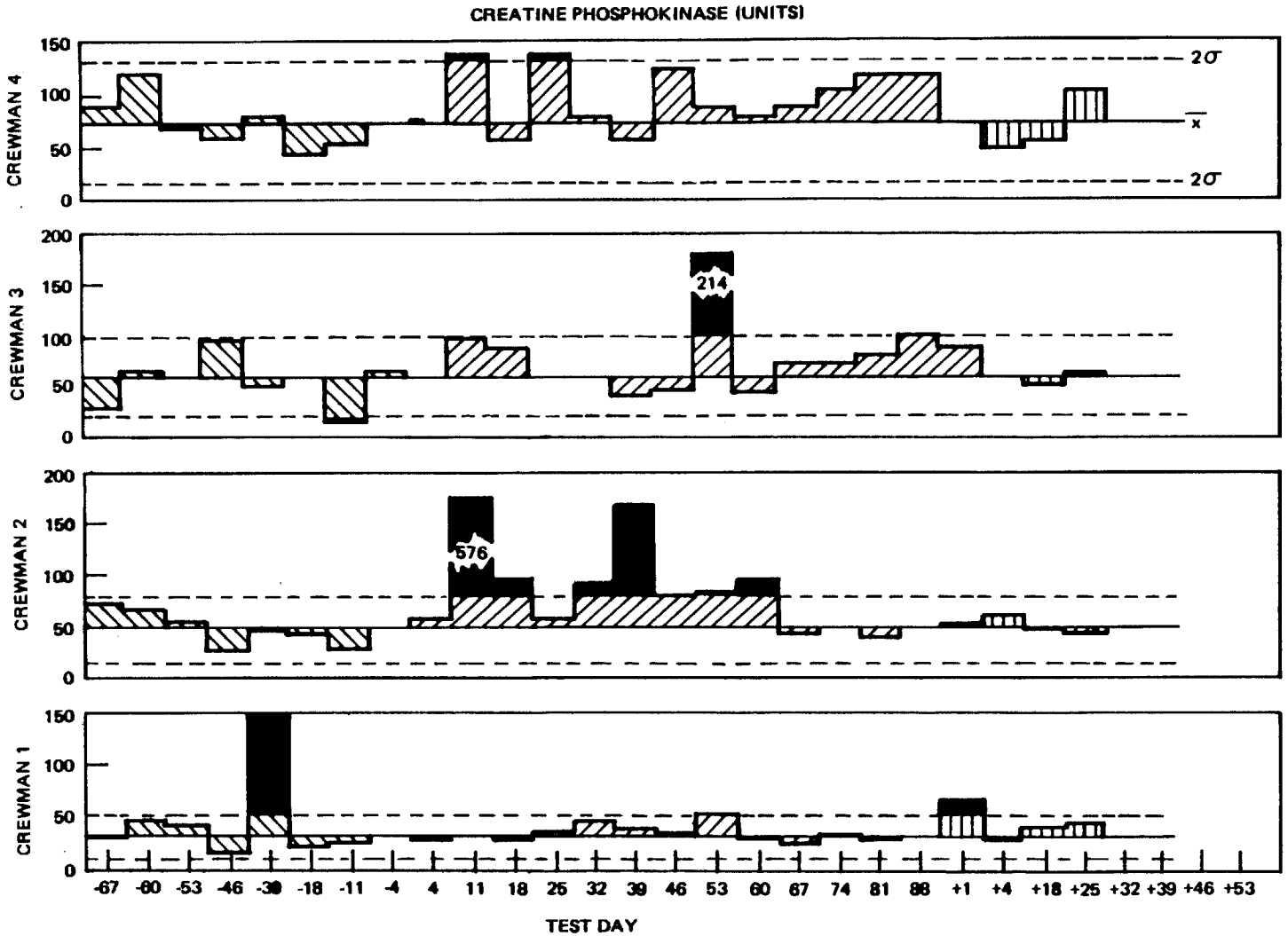
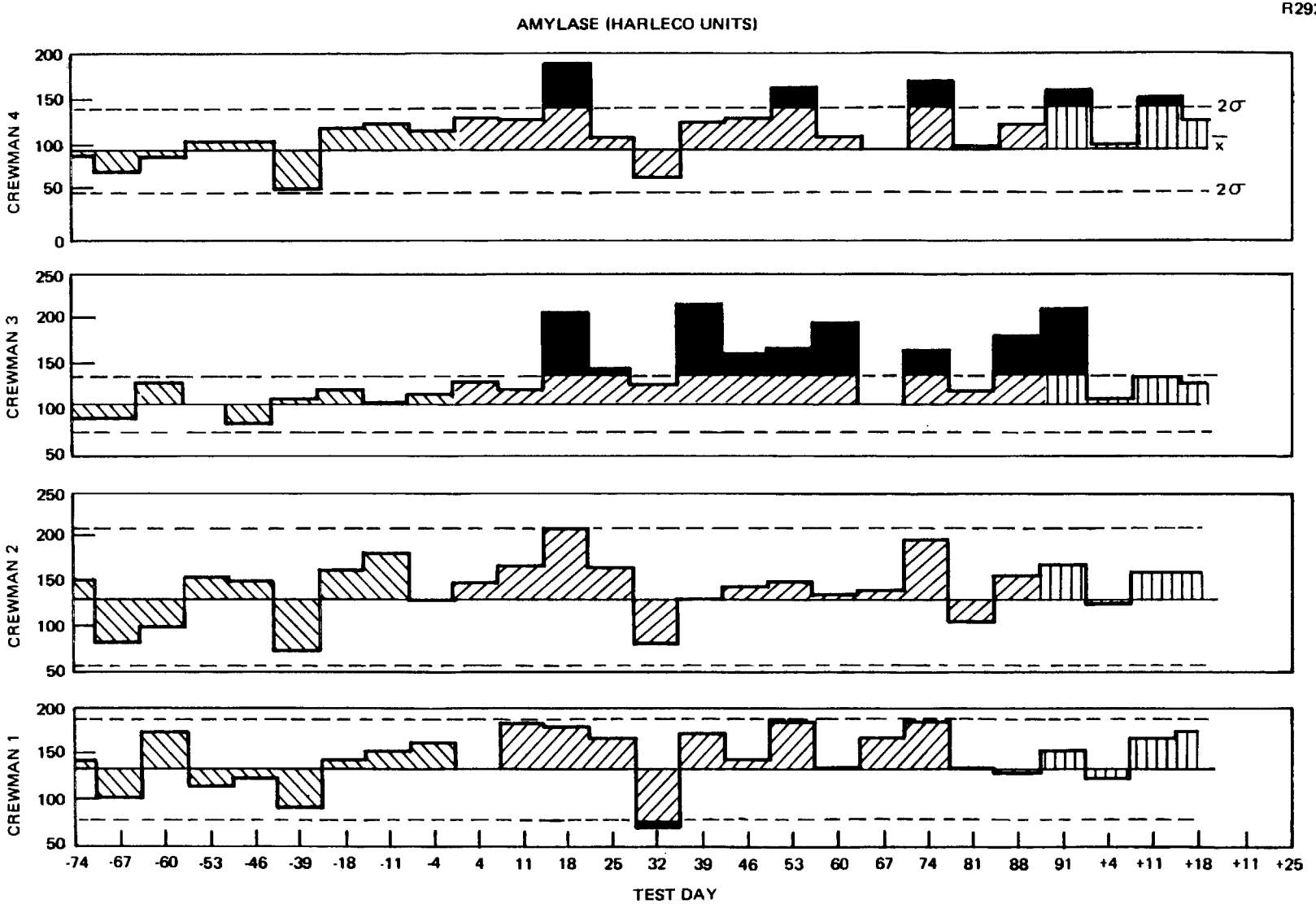
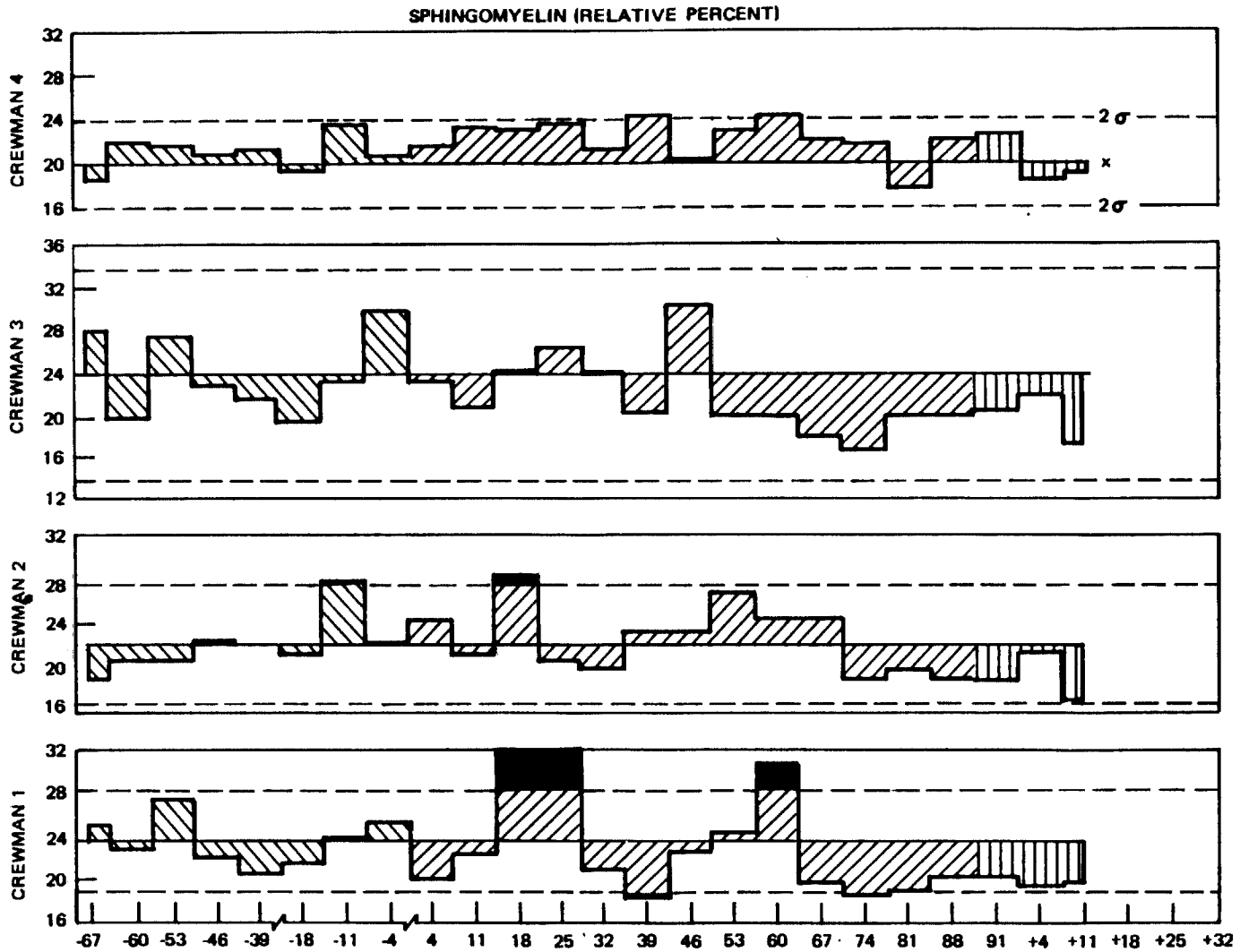


Figure 4-37. Serum Levels of Creatine Phosphokinase Activity



INDICATES PRETEST VALUES, + INDICATES POST-TEST VALUES. SOLID BLACK SHADING INDICATES THOSE VALUES EXCEEDING 2 STANDARD DEVIATIONS FROM THE PRETEST MEANS

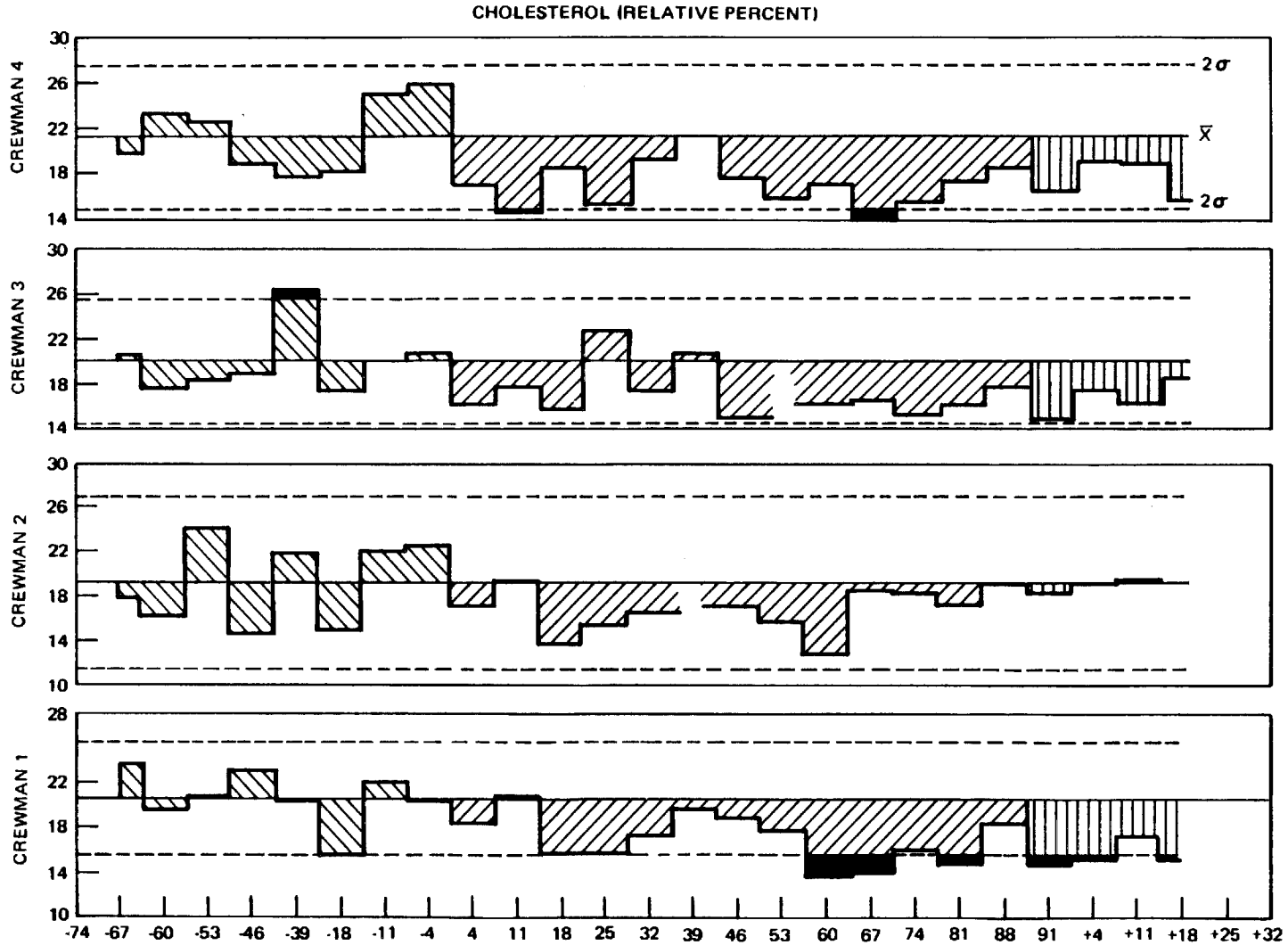
Figure 4-38. Serum Levels of Amylase Activity



- INDICATES PRETEST VALUES, + INDICATES POST-TEST VALUES. BLACK SHADING INDICATES THOSE VALUES EXCEEDING 2 STANDARD DEVIATIONS FROM THE PRETEST MEANS

Figure 4-39. Serum Levels of Sphingomyelin

R292



- INDICATES PRETEST VALUES, + INDICATES POST-TEST VALUES.
BLACK SHADING INDICATES THOSE VALUES EXCEEDING 2
STANDARD DEVIATIONS FROM THE PRETEST MEANS

Figure 4-40. Serum Levels of Cholesterol

In all of the crew members, the values for cholesterol fell during the test and remained low after the test. This could be due in part to diet and exercise, but, without dietary analysis, this concept is only speculative. There have been reports of both a rise and a decline in cholesterol levels associated with exercise.

The sphingomyelin pattern is interesting in all of the crew members. This phospholipid is increased in combat aviators (Reference 4-8). In an earlier study by NMRI of isolation stress (unpublished data—Project RIM), one crew member became very upset emotionally. At this time, his serum sphingomyelin was at these same high levels and remained high for the next day even though the isolation had been terminated. In NMRI hyperbaric experiments on humans, no rise in sphingomyelin has been observed.

The serum lipoproteins were considered to have shown no significant change. These analyses were performed because serum lipids are transported bound to proteins and, if there was a pronounced change in serum lipids, alterations in the lipoprotein pattern might be expected.

Glucose and lactate showed no changes of any significance in this hypobaric environment.

When NMRI noted that the one crew member had an apparent ahaptoglobinemia prior to the test, the test Medical Director was immediately notified. Examination of the crew member, however, did not reveal any abnormalities. Since haptoglobins are the normal mechanism for binding of free hemoglobin, a sudden decrease could indicate a hemolytic episode.

4.5.8.3 NMRI Carboxyhemoglobin (COHb) Analyses

Blood COHb percent saturation varies primarily with the concentration of carbon monoxide (CO) and oxygen in the breathing atmosphere, duration of exposure, and the endogenous production rate (CO produced as a product of bilirubin formation from heme metabolism). It is not unusual, therefore, that the mean crew COHb percent saturation curve during the test (Figure 4-41) tends to follow the simulator atmospheric CO concentration curve (Figure 4-42). Higher standard deviations in mean crew COHb saturation pre- and post-test are attributed to Crewman 2 who smoked occasionally during these periods. The crew COHb and simulator CO concentration curves show two abrupt increases. The first rise is coincident with accumulation of CO in the atmosphere during the first 3 weeks of confinement. The second rise is attributed to the lack of CO scrubbing capacity caused by scheduled shutdown of the toxin burner between test days 67 and 81.

In a report of test results, Rodkey, et al (Reference 4-43) described a method for calculating the concentration of CO in the simulator atmosphere using mean crew COHb percent saturation, total cabin pressure, and oxygen and water vapor concentration. A comparison of calculated versus infrared analyzed SSS CO level at the time of blood sampling reveals that the two methods varied from -7 to +14 ppm CO. The infrared analyses were predominantly on the high

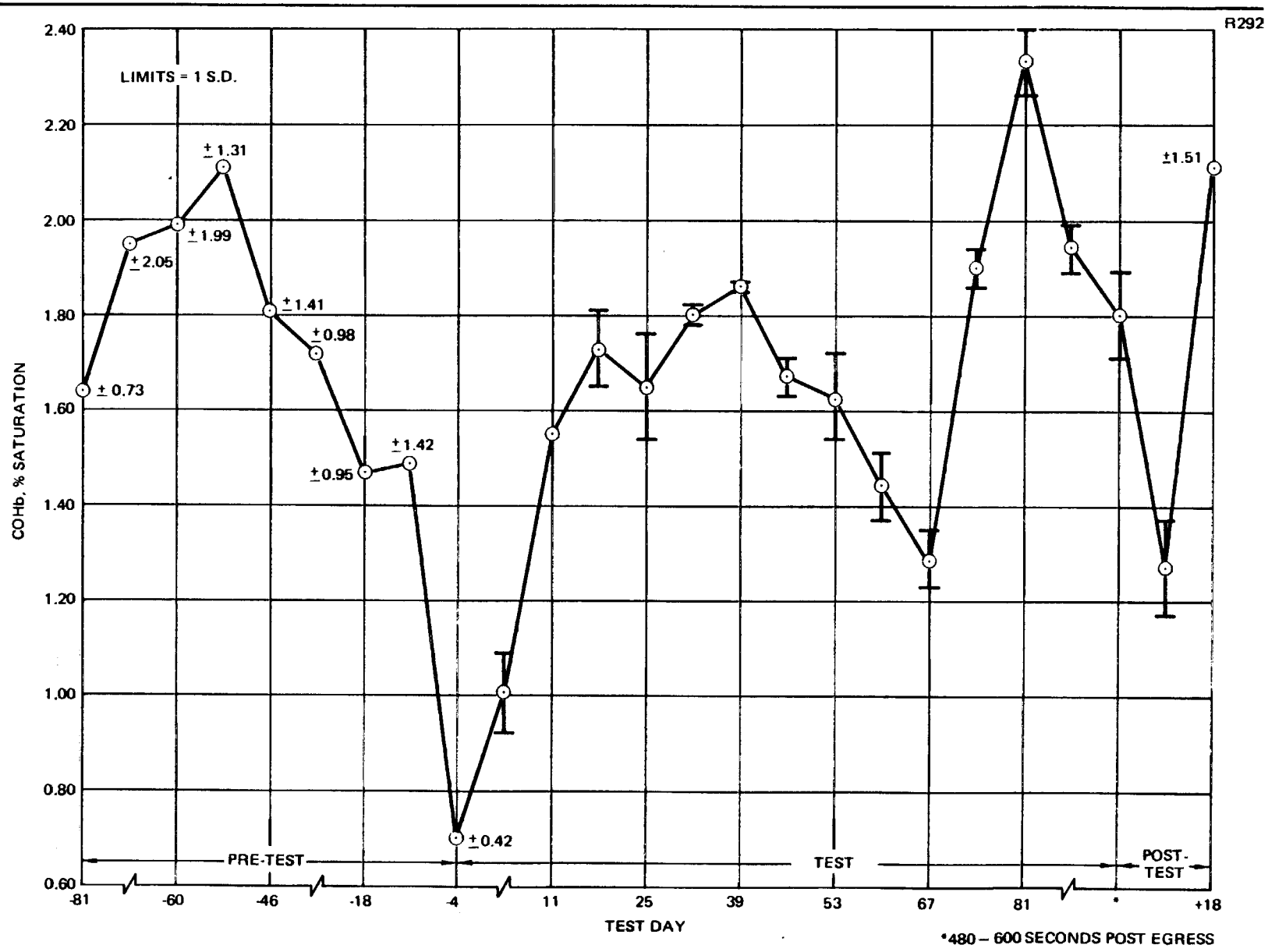


Figure 4-41. Crew Carboxyhemoglobin % Saturation, Mean and Standard Deviation

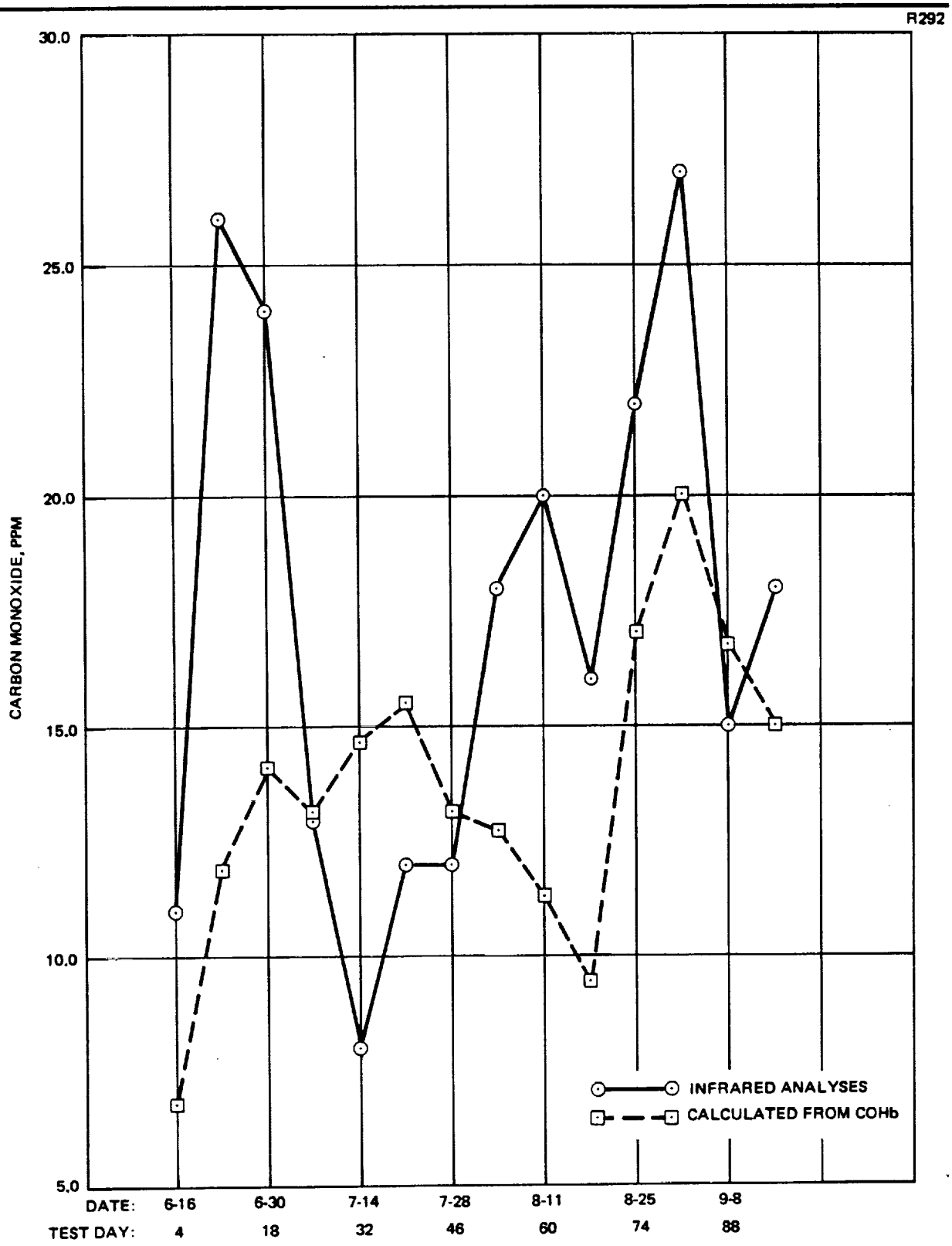


Figure 4-42. Simulator Carbon Monoxide Concentration

side in comparison with calculated values based on the blood data; actual and calculated values differ by a fairly constant ratio only between test days 60 and 81. Early large differences can be attributed to errors associated with readout procedures; a switch from the LIRA meter to a more accurate strip chart (Leeds and Northrup) type of display took place after test day 25. Other small errors, possibly cumulative, such as calibration gas accuracy, scale resolution, meter nonlinearity, print wheel jitter, etc., could account for several ppm CO difference between actual and calculated values.

In a report of the test findings at LRC, Rodkey, et al (Reference 4-44) indicated that the crew mean and standard deviation COHb pretest was within the normal range for nonsmokers (0.80 ± 0.29), crewman 2 being the exception as indicated previously. During the test, all crewmen could be expected to reach nearly identical steady state COHb levels, and was indeed the case (Table 4-10). Also to be expected was the finding that there was significantly less variation between crew members during than before the test.

Figure 4-41 shows that the mean crew COHb level increased sharply from test start until day 39 whereupon it gradually decreased until day 67. Variations in toxin burner (and other) CO scrubbing capacity and/or changes in component offgassing rate during this period are probably responsible for these variations. Between toxin burner shutdown on day 67 and its return to on-line status on day 81, a sharp rise in mean crew COHb of from 1.3 to 2.3 percent was observed. Rodkey, et al, report (Reference 4-44) that approximately 0.60 cm^3 CO/man-hour could be calculated for the CO production rate during this period. This value agrees well with normal endogenous CO production rates which average approximately 0.42 cm^3/man-hour according to Coburn, et al (Reference 4-45).

In conclusion, these results demonstrate that the level of CO in the blood can be used to estimate the concentration of CO in the atmosphere of a closed environment. The reverse calculation may also be made but more sophistication in the carbon monoxide gas analysis technique than was used during this test is required for accurate measurement of the very low ppm levels experienced.

4.5.8.4 Automated Visual Sensitivity Tester

Two separate sets of visual test results were obtained. The first set is composed of complete ophthalmological exams conducted both before the crewmen entered the test chamber and after they left it. (These exams were administered by J. G. Tirico, M. D., Orange, California, on 2 June and 7 September 1970.) No significant differences were found between the two tests. Crewmen 1 and 2 had corrected 20:20 distance acuity while crewmen 3 and 4 had uncorrected 20:30 and 20:20 distance acuity, respectively. All four crewmen had a normal range of accommodation (focus), normal color perception, normal intraocular pressure, normal vertical and horizontal phoria values, and full and normal visual field sensitivity.

Table 4-11 gives the number of times that the automated visual sensitivity tester was used to test each crewman.

Table 4-10

CARBOXYHEMOGLOBIN, % SATURATION

Test Phase	Date	Primary Crew						Backup Crew			
		1	2	3	4	Crew Mean	SD	5	6	Crew Mean	SD
Pretest	3-23-70	1.29	2.74	1.19	1.35	1.64	0.73	2.53	1.45	1.99	0.76
	4-7-70	0.97	5.02	0.84	0.95	1.95	2.05	2.75	0.98	1.87	1.25
	4-14-70	1.04	4.98	0.88	1.05	1.99	1.99	-	1.19	-	-
	4-21-70	1.70	4.06	1.27	1.42	2.11	1.31	3.50	1.02	2.26	1.75
	4-28-70	0.92	3.92	1.21	1.18	1.81	1.41	2.77	1.22	1.99	1.10
	5-5-70	1.34	3.18	1.33	1.04	1.72	0.98	2.87	1.07	1.97	1.27
	5-26-70	1.02	2.88	0.88	1.08	1.47	0.95	2.68	0.93	1.81	1.24
	6-2-70	1.09	2.07	1.31	1.49	1.49	1.42	4.65	1.14	2.90	2.48
	6-9-70	0.52	0.95	0.48	0.85	0.70	0.24	2.31	0.87	1.59	1.02
	$\bar{x}$	1.10	3.31	1.04	1.16			2.99	1.10		
	±SD	0.33	1.32	0.29	0.22			0.77	0.18		
Test	6-16-70	1.11	1.01	0.95	0.95	1.01	0.08	0.41	-	-	-
	6-23-70	1.58	1.56	1.58	1.48	1.55	0.05	-	0.60	-	-
	6-30-70	1.76	1.75	1.80	1.62	1.73	0.08	2.06	-	-	-
	7-7-70	1.77	1.69	1.53	1.59	1.65	0.11	2.18	-	-	-
	7-14-70	1.81	1.81	1.76	1.81	1.80	0.02	-	0.99	-	-
	7-21-70	1.87	1.87	1.86	1.85	1.86	0.01	-	0.61	-	-
	7-28-70	1.72	1.64	1.65	1.66	1.67	0.04	2.50	-	-	-
	8-4-70	1.66	1.67	1.70	1.50	1.63	0.09	-	-	-	-
	8-11-70	1.54	1.37	1.40	1.44	1.44	0.07	3.14	-	-	-
	8-18-70	1.32	1.29	1.20	1.35	1.29	0.06	2.97	-	-	-
	8-25-70	1.85	1.94	1.88	1.93	1.90	0.04	3.09	1.16	2.13	1.36
	9-1-70	2.25	2.42	2.34	2.32	2.33	0.07	1.96	1.13	1.55	0.59
	9-8-70	1.90	2.01	1.90	1.93	1.94	0.05	1.67	-	-	-
	9-11-70*	1.92	1.75	1.71	1.81	1.80	0.09	4.07	0.91	2.49	2.23
	$\bar{x}$	1.72	1.70	1.66	1.66			2.41	0.90		
	±SD	0.28	0.34	0.33	0.33			1.00	0.25		
Post-Test	9-15-70	1.27	1.39	1.15	1.28	1.27	0.10	2.66	-	-	-
	9-29-70	1.51	4.37	1.31	1.25	2.11	1.51	3.15	2.11	2.63	0.74
	10-6-70	0.97	2.41	0.90	0.95	1.31	0.74	2.43	0.80	1.62	1.15
	$\bar{x}$	1.25	2.72	1.12	1.16			2.75	1.46		
	±SD	0.27	1.51	0.21	0.18			0.37	0.93		

*This sample was taken 480 to 900 seconds post-test but reflects COHb % saturation under test rather than ambient environmental conditions

Table 4-11

NUMBER OF TEST PRESENTATIONS

Crewman Number	Pre-90 Day Test				During 90 Day Test			
	Blind Spot Vis. Sen.				Blind Spot Vis. Sen.			
	LE*	RE*	LE	RE	LE	RE	LE	RE
1	1	1	1	1	1	2	1	1
2	1	2	1	2	1	1	1	1
3	3	2	1	2	2	3	3	3
4	3	3	2	2	2	2	2	2

*LE = left eye
*RE = right eye

This number of test administrations is much smaller in each case than had been expected because of an equipment malfunction within the stimulus projector unit located within the closed chamber. Crewman 4 made a number of attempts to repair the malfunction in communication with Ames personnel on the outside of the chamber but was not successful. The last data collection occurred on test day 19.

As an illustration, Figure 4-43 shows the results from the visual sensitivity test for crewman 1 obtained on test day 19 (right eye); it is representative of the data obtained on all four crewmen. In this figure, the center of the pattern indicates where the subject fixated during the test. Each concentric circle is five degrees arc from its adjacent neighbor, thus a region 60-degree arc diameter was tested along each of the meridians (labeled with numbers). The test film used to collect the data of Figure 4-43 did not present the 120-degree meridian, however. Each of the solid lines indicates when the small, white, moving test spot was turned off during testing. The dashed lines parallel to the solid lines indicates when the subject responded to the test spot disappearance by pressing his finger button. The slight offset (in the radial direction) indicates the subject's reaction time to the disappearance of the test spot. The dashed line on the 90-degree meridian from about 15 to 20-degree arc from the fovea was produced because the test spot fell upon the normal blind spot which made it disappear. Except for a small response error* on the 0-degree meridian about 18-degree arc from the fovea, these data indicate fully functioning visual sensitivity and fast reaction times to the offset and onset of the test spot.

*In this instance, the test spot was turned off but the crew member did not press his finger button. This occurs very infrequently and may indicate that the crew member was momentarily distracted from attending to the spot.

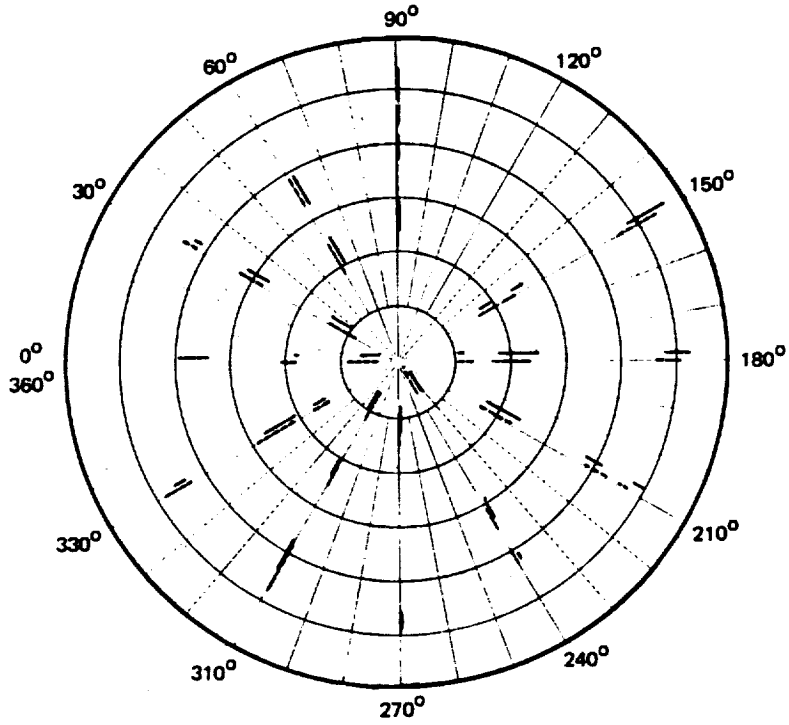


Figure 4-43. Results of Visual Sensitivity Test for Crewman 1

Regarding the primary objective of this investigation, no significant changes were found in the data collected before the 90-day test began and that obtained during the test for any of the four crewmen on either test.

Regarding the secondary objectives, the crew learned how to self-administer the tests in a short time and had no difficulty in attaching and aligning their individual bite boards or making other minor adjustments prior to each day's testing. The principal investigator from NASA, Ames, felt that there may have been some hesitancy on the part of the crew members to take this test. In summary, no significant changes were found between the pretest data and the chamber data on either the ophthalmological exams or the present automated visual sensitivity tester results on any crew member.

4.5.8.5 Isotopes

The results of plasma and blood volume measurements are shown in Table 4-12. The precision of the measurement of plasma volume has a coefficient of variation of less than 1 to 2 percent. Significant differences (increases) in plasma volumes were observed in three of the four crew members. Blood volume determinations were less accurate, but differences may have been measured in two of the test crew members and both controls. However, none of the changes can be regarded as significant since they lie within the range of normal human variation. Nevertheless, since the subjects acted as their own controls, such changes may be considered indicative.

Table 4-12

PLASMA AND BLOOD VOLUMES OF SUBJECTS IN THE 90-DAY TEST OF A SPACE STATION SIMULATOR

	Plasma Volume (cm^3)			Blood Volume (cm^3)			
Subject	Day 0	Day 90	Δ Baseline	Predicted	Day 0	Day 90	Δ Baseline
1	2,905	2,801	-104	4,700	4,663	4,669	+6
2	2,779	2,920	+141	4,350	4,495	4,787	+292
3	3,019	3,222	+203	5,070	5,317	5,370	+53
4	3,586	3,575	-11	5,290	*6,162	5,959	-203
5	2,896	2,834	-62	4,900	4,827	4,645	-182
6	2,580	2,520	-60	4,460	4,433	4,201	-232

*Blood volume is 76.1 cm^3/kg body weight which is well within the normal range of 68 to 88 cm^3/kg after M. B. Cohen, M.D.

Although the changes in plasma volume and blood volume were, at best, marginal, the trend of the combined results may reflect the effects of differences in physical conditioning of the subjects. A prolonged exercise program will generally increase blood volume and plasma volume. Thus, the increase in plasma volume and blood volume in crewman 3 may be the result of his intensive and prolonged exercise program after entering the SSS. Crewman 4 appeared to be the best physically conditioned of the crewmen before the test and his onboard exercise would not, therefore, be expected to affect his plasma volume and blood volume. Crewman 2 increased his exercise program in the mid-30 days of the 90-day test and subsequently maintained a higher ergometer workload. This may have increased his plasma and blood volumes. The control personnel had sedentary jobs during the test which may account for their apparent losses in plasma and blood volume.

Potassium-40 was measured by Dr. N.S. MacDonald in the UCLA total-body counter pre- and post-test in order to determine whole-body potassium. These results are shown in Table 4-13. Total potassium is considered to be an index of lean body mass. The normal coefficient of variation for the precision of the measurement of potassium is 2 to 4 percent. It was the opinion of Dr. MacDonald that test crew members 1 and 2 and control crew member 6 showed a significant loss of whole-body potassium. There was no significant difference between the average changes in the test crew members and those in the control crew members.

Therefore, the same tendencies indicated by plasma and blood volume measurements were reflected by the measurements of potassium-40. Those crewmen

Table 4-13

MEASUREMENT OF WHOLE-BODY POTASSIUM IN SUBJECTS BY COUNTING K-40 WITH THE UCLA TOTAL-BODY COUNTER

	Before		After		90-Day	
Subject	gK*	gK*/kg	gK*	gK*/kg	ΔgK*	Comment
1	158.9	2.75	148.9	2.52	-10.0	Significant loss
2	156.5	2.65	147.2	2.37	- 9.3	Significant loss
3	178.2	2.42	182.4	2.44	+ 4.2	
4	190.4	2.37	191.9	2.39	+ 1.5	
5	164.9	2.37	161.6	2.21	- 3.3	
6	172.2	2.71	162.0	2.67	-10.2	Significant loss

No significant difference between subjects and controls

*After N. S. MacDonald, Ph.D.

showing decreases in total-body potassium indicative of losses in lean body mass also exercised the least during the 90-day test; while those crewmen pursuing a prolonged and rigorous exercise program showed a tendency to maintain or gain lean body mass. If the foregoing observations are valid, the results suggest that a rigorous physical conditioning program is necessary to maintain body compostion in a confined space.

Table 4-14 shows the measurements of TBW of the crew members during the 90-day test. Measurements were made before the test, on test day 61 , and immediately upon egress. Unfortunately, the standard for day 0 was lost enroute to the laboratory so that the absolute values of these measurements are unknown. The day 0 values were calculated from the relative determinations, the specific activity of the original solution, and the dilution factor. As a result, the changes noted in TBW for each crew member are not meaningful. However, a comparison of the relative changes between crew members and controls might have some indicative value since the precision of measurement should be about 1 percent. Thus, analysis of the data with the "t" test for unpaired variates shows that the average gain in TBW for the crew members was greater than gain in TBW for the controls at the 90 percent level of confidence. Consequently, some increase in TBW for the crew may have occurred during the 90-day test, although this conclusion is not in consonance with measurements of plasma volume, total body potassium, changes in physical conditioning or body weight changes.

The application of radiopharmaceuticals or medical measurements was contingent on the radiation dose received by a crewman and the permission of the crew. The calculated radiation exposure from ^{125}I-RISA was 6-mrad whole body radiation for each of the two determinations (Reference 4-46) was calculated by Dr. Cohen. Dosimetry calculations by N. Telfer, M.D., and G. Harwood for the tritium determinations gave a total body dose of less than 10 mrads for the three determinations combined. These calculations accounted for recycling of $^{3}H_2O$ during the 90-day test. The total radiation exposure to each crewman from radiopharmaceuticals was only about 20 percent of the dose that could be allowed to a member of the general population for a comparable time period.

One obvious result of this study was that current methods of measuring body composition and fluid compartments would be inconvenient, traumatic, and subject to uncertainty if the measurements had to be regularly performed in the actual environment of a Skylab or Space Station by inexperienced personnel with onboard equipment and materials. There were significant difficulties in this test with procedures accomplished by experts. Since the health and safety of astronauts may be endangered by changes in body fluid compartments in a zero-g environment, methods of measurement must be developed for use in spacecraft which are accurate, reliable and noninvasive. Recent innovations which measure trace amounts of deuterium oxide in saliva samples by infrared spectophotometry or gas chromatography should be evaluated. The electrical measurement of whole-body impedance at dual frequencies is a promising technique for determination to total body water, extracellular fluid, and intracellular fluid. Prototype measuring systems should be evolved and medically evaluated during future, longer duration, manned, one-g simulations.

Table 4-14

TOTAL BODY WATER OF CREWMEN DURING THE 90-DAY TEST OF AN SSS

Crewman	Day	TBW Predicted*	TBW Change*	Mean Δ TBW*	TBW Measured	TBW Change	Mean Δ TBW
1	0	35.1			35.8		
	61	35.3	$+0.1 \times 10^{-3}$ m^3		44.0	$+6.1 \times 10^{-3}$ m^3	
	90	35.1			39.8		
2	0	36.6			35.9		
	61	37.9	$+0.3 \times 10^{-3}$ m^3		40.4	$+4.9 \times 10^{-3}$ m^3	
	90	37.9		-0.3×10^{-3} m^3	41.4		$+6.0 \times 10^{-3}$ m^3 Subjects
3	0	43.1			42.4		
	61	42.4	-0.6×10^{-3} m^3		47.3	$+5.5 \times 10^{-3}$ m^3	
	90	42.6			48.4		
4	0	45.6			46.2		
	61	44.8	-1.0×10^{-3} m^3		53.3	$+7.4 \times 10^{-3}$ m^3	
	90	44.5			54.0		
5	0	41.4			44.2		
	61	41.8	$+0.7 \times 10^{3}$ m^3		46.7	$+2.2 \times 10^{-3}$ m^3	
	90	41.8		-0.2×10^{-3} m^3	46.0		$+3.0 \times 10^{-3}$ m^3 Controls
6	0	38.5			35.5		
	61	37.4	-1.1×10^{-3} m^3		38.6	$+3.7 \times 10^{-3}$ m^3	
	90	37.4			39.8		

*Predicted from body weight and age
After N. Telfer, M.D.

Net increase 3.0×10^{-3} m^3

To summarize, measurements of plasma volume, blood volume, and total body water with radiopharmaceuticals, and also measurement of total body potassium by natural ^{40}K did not reveal any large changes in whole-body fluid compartments or lean body mass for the test or control crew members during the 90-day manned test in the SSS. Although the changes in body fluids and lean body mass were of marginal significance, the combined results are believed to reflect differences in the physical activity among the crew members. If valid, the results suggest that a rigorous physical conditioning program is necessary to maintain body composition in such a confined space. This study further indicated that improved methods for measuring body fluids and body composition must be developed and tested in future space station simulators if potentially hazardous changes in body fluid compartments are to be adequately monitored for the zero-g environment of long-duration space flight.

4.5.8.6 Physical Conditioning Program

Best results are obtained from the Åstrand-Ryhming nomogram when the working heart rate reaches a steady state between 125 and 170 beats per minute. This was achieved in all cases both before and during the test. The crew gradually increased the workload in the initial, pretest phase of the program as they became more accustomed to the ergometer. In some cases, the workload was further increased during the test at the request of an individual when he felt he could benefit by the higher work output. The oxygen consumption, measured weekly, showed some erratic variations unrelated to work output or heart rate. Because of this, the heart rate – $\dot{V}O_2$ relationship was unacceptable as a predictor of aerobic capacity and the heart rate – work output relationship was used exclusively in nomogram determinations. Weekly averages of work load, heart rate, and maximum $\dot{V}O_2$ are shown in Table 4-15.

The maintenance of physical fitness during the confinement period appeared to be a function both of the fitness level of the subject at the beginning of confinement and the workload level of the exercise performed during the test. Figure 4-44 illustrates the predicted aerobic capacity, shown as weekly averages, for all crew members during the period of confinement. Figure 4-45 is the same bar graph expressed in terms of kilograms of body weight.

Values derived from the Balke Optimal Work Capacity test are shown in Figure 4-46.

Crewman 1 commenced the test in "very good" physical condition, as indicated by his Balke scores. He exercised at a moderate level during the test and maintained his predicted aerobic capacity until the last 2 to 3 weeks when the values appeared to be somewhat reduced. His post-test Balke score, indicating only "average" fitness, was significantly reduced from his pretest values, giving further evidence of a reduced fitness level.

Crewman 2 commenced the test in only "fair" physical condition, as indicated by both his Balke score and his predicted aerobic capacity. During the test, he devised a controlled stepped-up exercise program. During the first 30 days, he refrained from additional exercise and maintained his original ergometer workload of 125 watts. During the mid-30 days, he started a progressively more strenuous calisthenics program and increased his ergometer workload in steps to 175 watts. During the last 30 days he maintained the higher ergometer

Table 4-15

EXERCISE PROGRAM DATA

Exercise Periods	Crewman 1				Crewman 2				Crewman 3				Crewman 4			
	Work Load (watts)	Heart Rate (beats/ min)	Max $\dot{V}O_2$		Work Load (watts)	Heart Rate (beats/ min)	Max $\dot{V}O_2$		Work Load (watts)	Heart Rate (beats/ min)	Max $\dot{V}O_2$		Work Load (watts)	Heart Rate (beats/ min)	Max $\dot{V}O_2$	
Pretest			cm^3/sec	L/min			cm^3/sec	L/min			cm^3/sec	L/min			cm^3/sec	L/min
1	137	141	55.0	(3.3)	100	149	38.4	(2.3)	125	138	53.3	(3.2)	175	147	61.1	(3.7)
2	138	144	53.3	(3.2)	100	143	41.7	(2.5)	150	144	56.6	(3.4)	-	-	-	-
3	-	-	-	-	112.5	154	38.4	(2.3)	150	154	48.4	(2.9)	200	155	61.6	(8.7)
4	137	140	55.6	(3.4)	112.5	153	40.0	(2.4)	150	153	50.0	(3.0)	225	160	63.4	(3.8)
5	-	-	-	-	-	-	-	-	150	157	46.6	(2.8)	225	166	61.6	(3.7)
6	137.5	140	56.6	(3.4)	-	-	-	-	150	158	46.6	(2.8)	225	154	70.0	(4.2)
7	-	-	-	-	125	157	41.7	(2.5)	150	158	46.6	(2.8)	-	-	-	-
Test Weeks																
1	140	147	51.7	(3.1)	125	153	43.4	(2.6)	150	149	53.3	(3.2)	225	155	70.0	(4.2)
2	140	138	58.4	(3.5)	125	149	45.0	(2.7)	150	154	48.4	(2.9)	225	149	75.0	(4.5)
3	140	140	56.6	(3.4)	125	149	45.0	(2.7)	150	151	51.7	(3.1)	225	147	76.7	(4.6)
4	140	137	60.0	(3.6)	125	150	45.0	(2.7)	175	160	51.7	(3.1)	225	151	73.4	(4.4)
5	140	137	60.0	(3.6)	125	148	46.6	(2.8)	175	158	53.3	(3.2)	225	152	71.7	(4.3)
6	140	141	56.6	(3.4)	150	155	48.4	(2.9)	175	159	53.3	(3.2)	225	153	70.0	(4.2)
7	140	136	60.0	(3.6)	150	153	50.0	(3.0)	175	160	51.7	(3.1)	225	153	70.0	(4.2)
8	140	138	58.4	(3.5)	175	158	53.3	(3.2)	175	158	53.3	(3.2)	225	153	70.0	(4.2)
9	140	140	56.6	(3.4)	175	157	53.3	(3.2)	175	162	50.0	(3.0)	225	149	75.0	(4.5)
10	140	137	60.0	(3.6)	175	158	53.3	(3.2)	175	156	55.0	(3.3)	225	155	68.4	(4.1)
11	140	141	56.6	(3.4)	175	160	53.3	(3.2)	175	156	55.0	(3.3)	225	152	71.7	(4.3)
12	140	142	55.0	(3.3)	175	163	51.7	(3.1)	175	157	55.0	(3.3)	225	154	70.0	(4.2)
13	140	143	55.0	(3.3)	175	160	53.3	(3.2)	175	154	56.6	(3.4)	225	151	73.4	(4.4)

Heart rate values = Average of 5 runs per week
Work load = Ergometer setting in watts
Max VO_2 (Aerobic capacity) = Predicted values from nomogram (Figure 4-6)

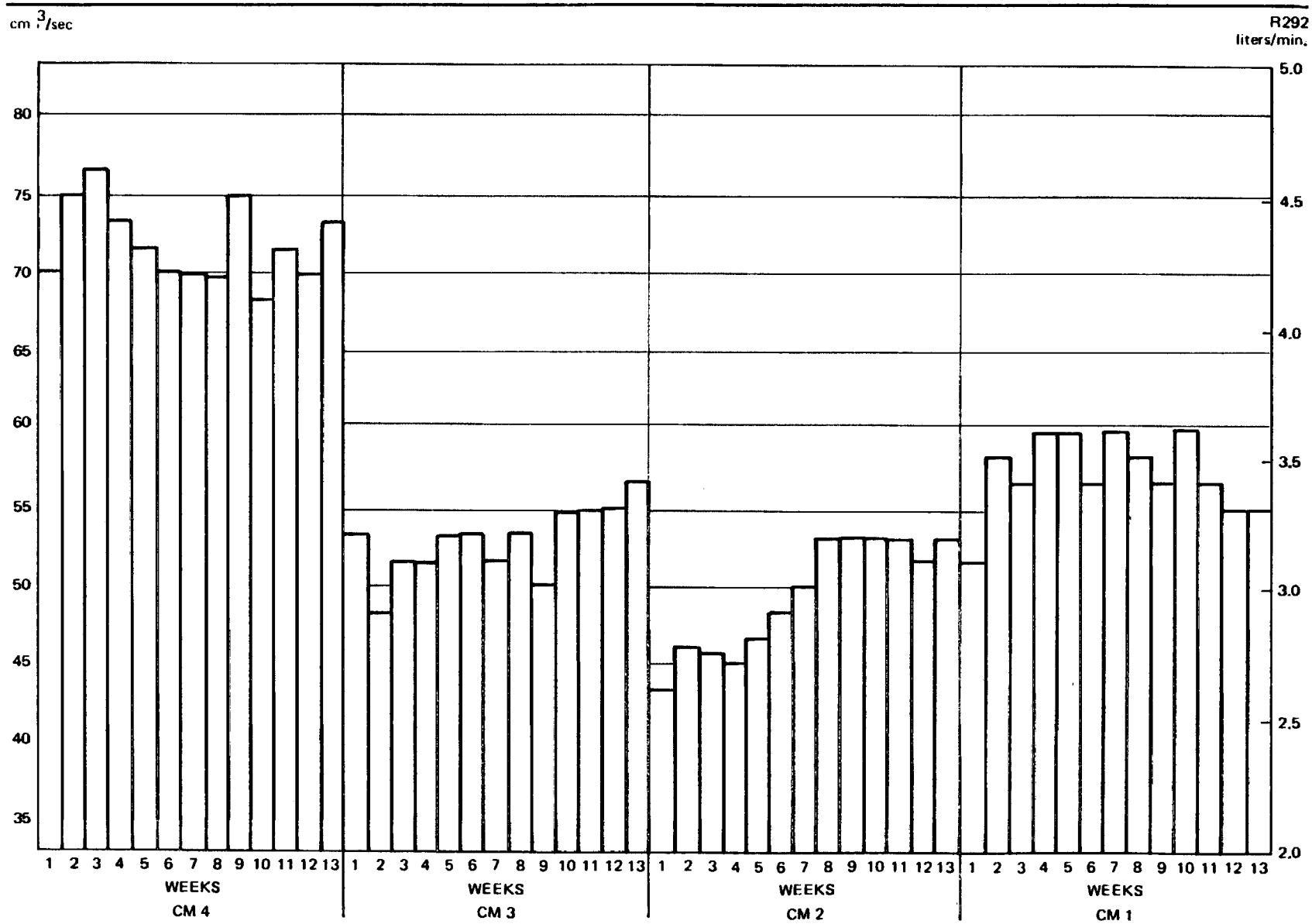


Figure 4-44. Total Aerobic Capacity (Maximal O_2 Consumption)

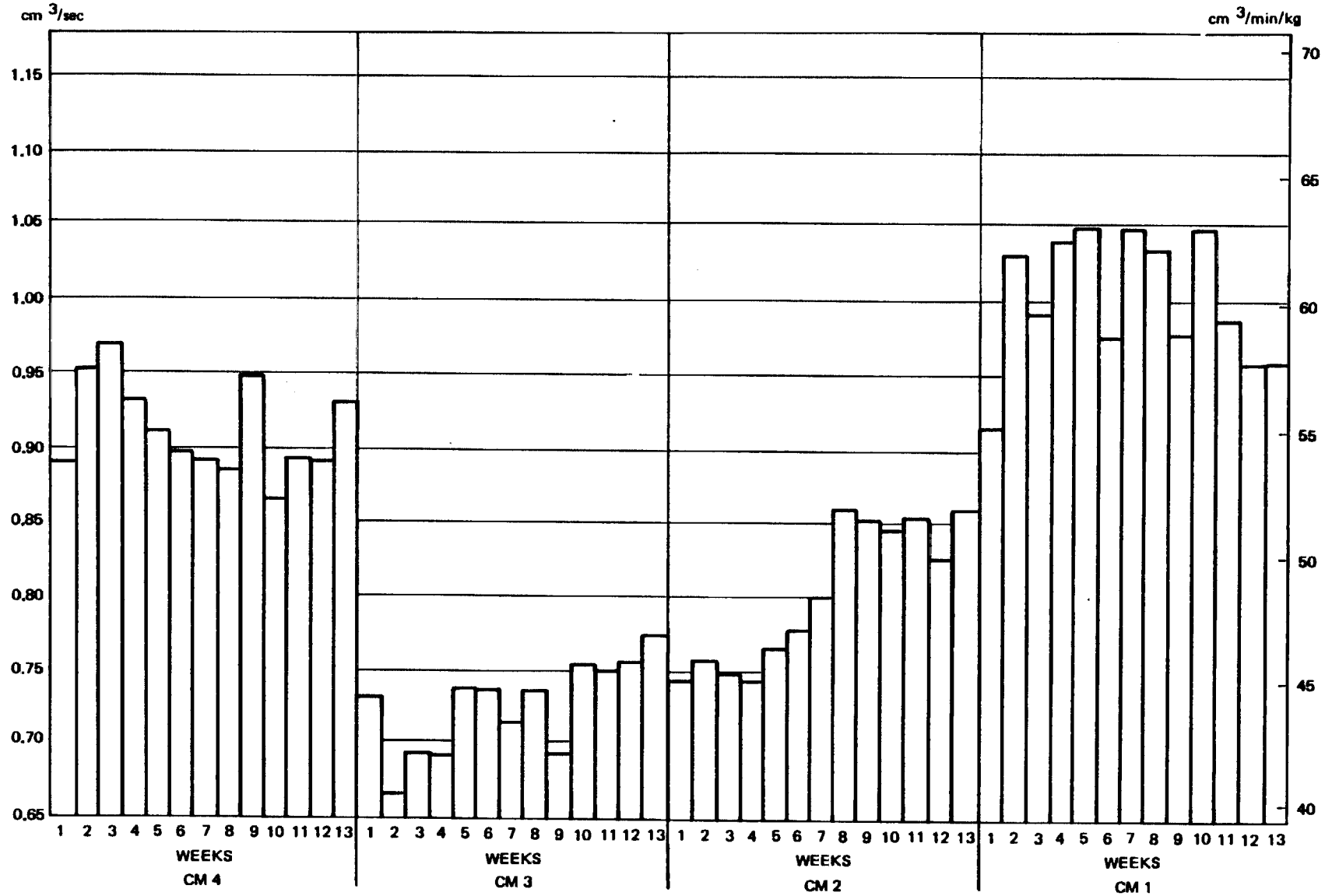


Figure 4-45. Aerobic Capacity (Maximal O_2 Consumption) in Relation to Body Weight

(TREADMILL SPEED = 3.5 MPH, TERMINATION HEART RATE = 180 BEATS/MIN)

CREWMAN	TIME	WEIGHT (kg)	TIME ON TREADMILL (min)	FINAL MINUTE OF EXERCISE		BALKE INDEX (% OF AVERAGE)
				TOTAL WORK (kg-m/min)	WORK/kg OF BODY WEIGHT (kg-m/min/kg)	
4	PRE-RUN >	81.7	22	1688	20.3	120
	POST-RUN >	80.5	25	1887	23.2	135
1	PRE-RUN >	58.9	20	1103	18.8	109
	POST-RUN >	58.9	17	940	16.0	93
3	PRE-RUN >	73.7	18	1248	16.9	98
	POST-RUN >	74.1	18	1252	16.9	98
2	PRE-RUN >	59.2	16	888	15.0	87
	POST-RUN >	61.9	18	1043	16.9	98

Figure 4-46. Balke Optimal Work Capacity Test

setting, but additional exercise was minimal. This program adjustment was sufficient to increase his predicted maximum $\dot{V}O_2$ 9.9 cm^3/sec (0.6L/min.) or 23 percent and his fitness as indicated by the Balke score from "fair" to "good."

Crewman 3 adjusted his workload once during the confinement period to maintain a "heavy" workload during his exercise periods and to prevent excessive pedal rates seen at the lower setting. His predicted aerobic capacity increased slightly during the test and his post-test Balke score was unchanged from the pre-test value, both indicating a "good" fitness level.

Crewman 4 exercised for the 90-day period at a workload level rated as "strenuous." This exercise regimen maintained his high aerobic capacity during the test and improved his "excellent" Balke score.

During the test, crewmen 3 and 4 supplemented their ergometer exercise with calisthenics. This very probably was responsible for the maintenance of lean body mass in these two crewmen in contrast to crewmen 1 and 2 who showed a significant loss (see Section 4.5.8.5).

It is concluded, from the results of the physical fitness program that cardiorespiratory fitness can be maintained during confinement by means of 15 minutes of exercise per day on the bicycle (pedal mode) ergometer if the workload level is in the "hard" to "strenuous" range ($\dot{V}O_2$ = 2,000 to 3,000 cm^3/min) but that additional calisthenics may be necessary to maintain overall muscle tone and prevent a reduction in lean body mass.

4.6 MICROBIOLOGY

The 90-day test afforded an unusual opportunity to assess possible modifications in normal human and environmental microflora during an extended simulation study in a closed environmental system. These changes are potentially detrimental to crew health and/or systems operation during long-duration manned spaceflight. Major objectives were to determine: (1) gross quantitative and qualitative shifts in the microflora of the crew members and SSS surfaces, atmosphere, and subsystem components; (2) transmission between crew members and within the SSS subsystems; (3) buildup of equipment/subsystem microflora; and (4) effectiveness of the oxygen and water loops in maintaining acceptable levels of microbial contamination. The data reflect the dynamic interaction of crew and life support system microflora in a truly "closed system", for materials were passed out only by means of an autoclave-airlock.

4.6.1 Collection and Passout of Samples

To obtain reliable samples, the crew members were trained to collect and handle specimens using consistent sampling methods and aseptic techniques. Samples of the crew and environmental surfaces were taken once a week, just before passout. Air samples were taken every 2 weeks approximately 24 hours before passout, while the potable water was usually monitored every 48 hours. To maximize laboratory recovery of fastidious microorganisms, the following sequence of swab collection was observed before the weekly passout: surfaces, nose, axilla, toe web, perineum, and throat. To maintain a microbiologically closed system, the autoclave in the pass-through port was operated (for 30 minutes at 121°C and 15 psig) after each weekly passout and within 12 hours of the next scheduled passout. A summary of the sampling procedures for the entire test is presented in Table 4-16.

4.6.2 Laboratory Processing of Samples

Transport of specimens from the SSS to the nearby laboratory was made as quickly as possible. There was a maximum period of 1/2 hour between collection and primary incubation for nasopharyngeal organisms (throat swabs were processed first) and of 1-1/2 hours for dermal anaerobes.

For primary isolation from swabs, plates of general and selective media were streaked in a specific manner and sequence (Table 4-17). After incubation, growth was quantitatively described by a scoring system so that gross comparisons could be made during the test. Up to six morphologically different colonies were picked from a plate for subsequent identification.

Table 4-16

SUMMARY OF MICROBIOLOGICAL SAMPLING PROCEDURES

Sample	Location or Type	Method	Schedule	
			Sampling	Passout
Crew	Throat, nose, axilla, perineum, and toe web	Cotton swab moistened with physiological saline	Weekly	Weekly
	Feces	Special sampler provided with G. E. commode. Sample frozen at -5°C on board until passout	As required	Earliest passout
	Urine	Aliquot of 24-hour collection. Sample frozen at -5°C on-board until passout	As required	Earliest passout
	Throat wash	Physiological saline gargle	As required	Earliest passout
	Serum	Vacutainer collection	Weekly	Weekly
Surfaces	10 x 10 cm areas in the food management and hygiene compartments	Cotton swabs moistened with Casein Soy Broth	Weekly	Weekly
	5 x 5 cm areas: Spirometer inlet, commode seat, floor under bunks, recreation table top, microwave oven, refrigerator, urinal, clothes washer and dryer, counter tops and floors, storage areas, thermal control ducts, door handle, VD-VF boiler rim, air return duct, vacuum cleaner, commode vacuum line, heat exchanger, psychomotor tester	Cotton swabs moistened with Casein Soy Broth	Post-test	None
Air	Equipment (forward) and crew (aft) compartments	Reyniers samplers run for 1 hour at 0.028 m^3 (1 ft^3) of air per minute. Casein Soy Agar plates incubated on board at 35°C for 24 hours	Every 2 weeks, day before passout	Every 2 weeks
Potable and wash water	Sample ports: 1) Holding tanks 1 and 2 2) Potable use tanks 3 to 6 3) Wash water tanks 7 and 8 4) VD-VF condensate, B-84 5) Potable dispensers-Apollo hot, Apollo cold, MDAC cold 6) Wash water faucet—hot position, cold position	10 cm^3 water filtered through Millipore Field Monitor (0.45 micron)*; membrane cultured with ampouled Casein Soy Broth and incubated at 35°C for 48 hours prior to colony counts. Sample port flushed initially with 50 to 100 cm^3 water to be sampled; water sample collected in Whirl-Pak bag**	Every 48 hours or as required	Weekly, monitors showing growth
	Same sample ports as listed above	LRC bacterial sensor experiment: 0.5 cm^3 water sample made alkaline (pH 12) with NaOH and injected into bacterial sensor	Coincident with field monitor samples	None
	Apollo hot potable water dispenser	250 cm^3 water collected in Whirl-Pak bag***	Every 2 weeks	Earliest passout
Water, waste management, thermal control, food management, and atmosphere and humidity control subsystem components	Wicks, ion exchange resins, charcoal, filters, fecal bags, garbage, food trays, coolant and condensate water, etc.	Immersion of a small portion of material in Casein Soy Broth and Brewer Thioglycollate media	Post-test	None

*Millipore Catalog No. MHBG 03700
**Scientific Products Catalog No. B1205-6
***Scientific Products Catalog No. B1205-18

Table 4-17

PRIMARY CULTURAL CONDITIONS FOR CREW AND SURFACE MICROFLORA

Swab Sample		Agar Medium[1]	Organisms of Interest	Incubation 37°C for 24 Hours (Exceptions Noted)
Throat	1)	Blood (Sheep)*	Staphylococcus aureus and beta-hemolytic streptococci	Aerobic
	2)	Staphylococcus No. 110	Staphylococcus aureus	Aerobic
	3)	Filde Enrichment	Hemophilus influenzae	Aerobic
	4)	Thayer-Martin (pre-warmed to 37°C)	Neisseria meningitidis	Aerobic (5 to 10% CO_2)
Nose	1)	Blood (Sheep)*	Staphylococcus aureus and beta-hemolytic streptococci	Aerobic
	2)	Staphylococcus No. 110	Staphylococcus aureus	Aerobic
Axilla, Perineum, and Toe Web	1)	Blood (Sheep)*	Total flora and Staphylococcus aureus	Aerobic
	2)	Staphylococcus No. 110	Staphylococcus aureus	Aerobic
	3)	Serum Tellurite	Gram-positive bacteria	Aerobic
	4)	Tellurite Glycine	Staphylococcus aureus	Aerobic
	5)	Eosin Methylene Blue	Gram-negative bacteria	Aerobic
	6)	Sabouraud Dextrose	Fungi	Aerobic 37°C for 24 hours or 22°C for 7 days
	7)	Brewer Thioglycollate	Quantitation of total flora	Anaerobic 35°C for 3 days only
	8)	Blood (Sheep)	Facultative and obligate anaerobes	Anaerobic 35°C for 3 days only
Surfaces	1)	Casein Soy*	Total flora	Aerobic
	2)	Staphylococcus No. 110	Staphylococcus aureus	Aerobic
	3)	Blood (Sheep)	Staphylococcus aureus	Aerobic
	4)	MacConkey	Enteric bacteria	Aerobic
	5)	Sabouraud Dextrose	Fungi	Aerobic 37°C for 24 hours or 22°C for 7 days

*Plates streaked from the swabs in order listed

Note 1. All agar media from Hyland, Div. of Travenol Laboratories, Inc., Costa Mesa, California

4.6.2.1 Throat and Nasal Swabs

The Blood and Staphylococcus No. 110 agar plates were examined for colonies of Staphylococcus aureus and both alpha- and beta-hemolytic streptococci. Different colonies were picked and subcultured, as outlined in Figure 4-47. As a result, some of the isolates were identified as Group A beta-hemolytic streptococci or Diplococcus pneumoniae in the laboratory, while coagulase-positive cultures were shipped to the Medical College of Virginia for phage typing.

Certain neisseria-like colonies on the Thayer-Martin plates were selected for further testing as shown in Figure 4-47. Primary isolates on Filde medium were hemophilus-like, but attempts to identify them as Hemophilus influenzae were unsuccessful. Procedures to recover this organism were discontinued after test day 53.

4.6.2.2 Dermal Swabs

As summarized in Table 4-17, culture media streaked from the dermal swabs were incubated anaerobically as well as aerobically. Different colonies appearing to be staphylococci and other aerobic bacteria, anaerobes, and fungi were subcultured as diagrammed in Figure 4-48. Coagulase-positive staphylococci were sent to the Medical College of Virginia for phage typing, and various aerobes and facultative anaerobes were shipped to the Langley Research Center for identification. A group of fungal-type isolates was held in the MDAC laboratory for future identification.

4.6.2.3 Feces, Urine, and Throat Wash

Fecal, urine, and throat wash samples for virus and mycoplasma analysis were collected from each crewman once pretest and once during the test (test day 88). Fecal samples were collected using specially designed samplers provided for this purpose with the commode. Urine samples were provided as aliquots of 24-hour collections made the day before pass-through. Both fecal and urine samples were held frozen (-5°C) on board until pass-through. Physiological saline was used for throat washing and was gargled by the crew immediately before pass-through. All sample materials were packed in dry ice for shipment to the Lunar Receiving Laboratory, NASA Manned Spacecraft Center, Houston, Texas.

4.6.2.4 Serum Samples

Serum from clotted blood samples was frozen at -70°C for contingency testing and for future immuno-assays at NASA Ames Research Center.

4.6.2.5 Surface Samples

Casein Soy Broth-moistened swabs were used to sample 10 by 10 cm marked surfaces in the food management and hygiene areas. The surface sampled was then cleaned with 1:750 Zephiran (Winthrop Laboratories, New York City) after weekly passout. The swabs were streaked for primary isolation as summarized in Table 4-17. Various colonies were picked and streaked out

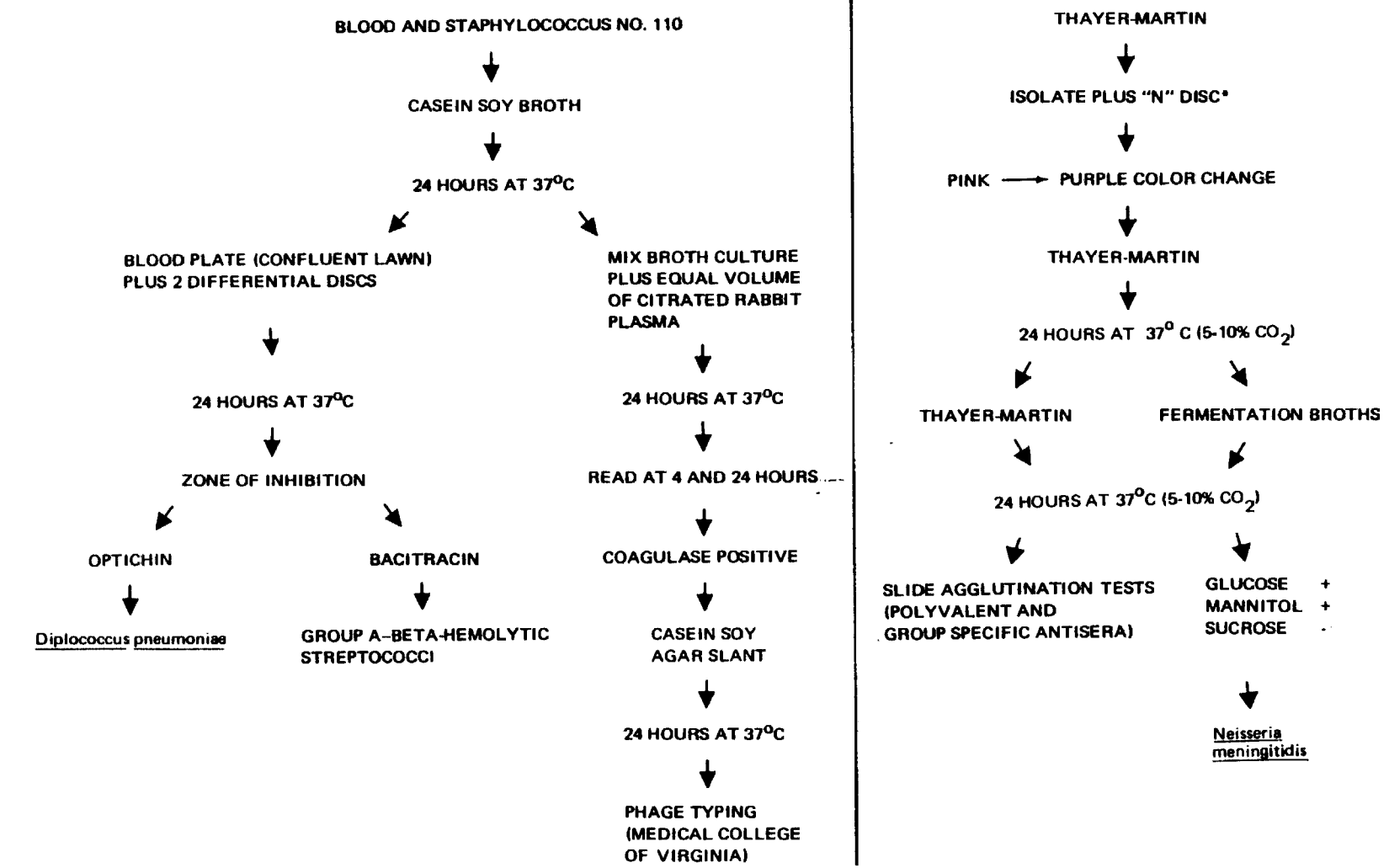


Figure 4-47. Identification Schemes for Primary Throat and Nasal Isolates

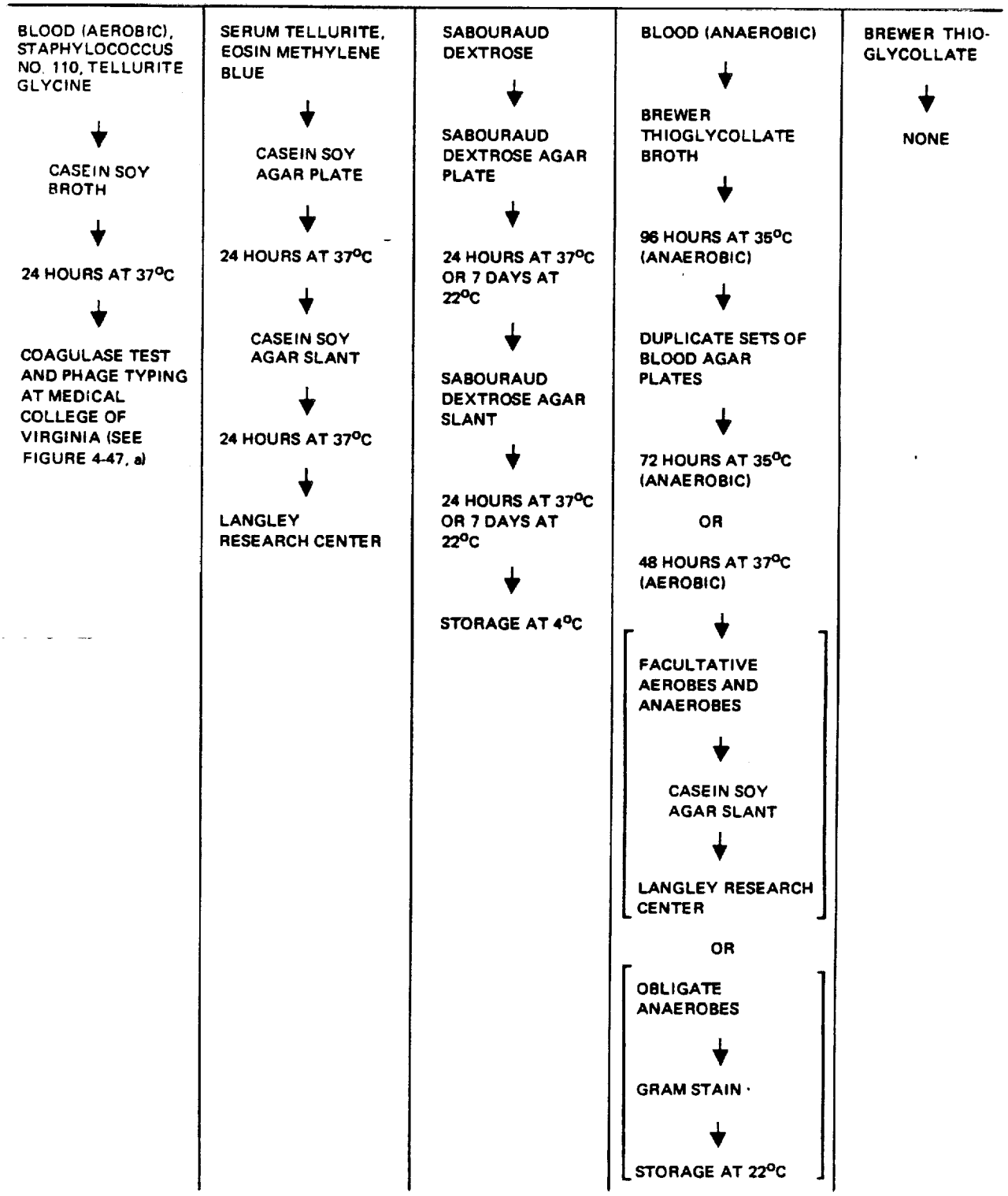


Figure 4-48. Identification Schemes for Dermal Isolates on Primary Isolation Media

on Casein Soy Agar before shipment to LRC. Hemolytic colonies on Blood Agar and isolates on Staphylococcus No. 110 Agar were transferred to Casein Soy Broth for coagulase testing (see Figure 4-47) and shipment to the Medical College of Virginia for phage typing. Fungal-type isolates were checked for purity then stored at 4°C in the MDAC laboratory for future identification.

Immediately following crew egress, areas of hardware components were swabbed, sampling 5 by 5 cm areas wherever possible. The swabs were streaked out as summarized in Table 4-18. Various colonies were picked and transferred to Casein Soy Agar slants, for shipment to LRC. Organisms appearing to be beta-hemolytic staphylococci or streptococci, and D. pneumoniae were identified according to the procedures in Figure 4-47. Suspected fungi were stored on Sabouraud Dextrose Agar slants at 4°C.

4.6.2.6 Subsystem Components

Selected components of the humidity control, waste management, and the potable and wash water recovery subsystems were aseptically removed and sampled as soon as possible after crew egress. The components which were assayed are listed in Section 4.6.3.6. Approximately equivalent weights, sizes, or volumes, as the case may be, of samples were used to inoculate tubes of Casein Soy and Brewer Thioglycollate Broths (see Table 4-18). After incubation, the broth cultures were subcultured onto plates of media identical to those used for post-test assay of surfaces (see Section 4.6.2.5). Isolates were picked for identification as described above for post-test surface samples.

4.6.2.7 Air Samples

Casein Soy Agar plates used in the Reyniers samplers were passed out every 2 weeks and incubated an additional 24 hours at 37°C. A colony count of bacterial-type isolates was made. The plates were held at 22°C for 7 more days before the fungal-type colonies were counted. Bacterial colonies were transferred to Casein Soy Agar slants and sent to LRC. All fungal-types were stored on Sabouraud Dextrose Agar slants at 4°C for future identification.

4.6.2.8 Water Samples

Millipore Field Monitors

Millipore Field Monitors which showed growth on board were passed out every week. Isolates were picked and subcultured on Casein Soy Agar for subsequent identification at LRC.

Virus Studies

Potable water samples (250 cm^3) were periodically taken from the Apollo hot water dispenser and passed out. The samples were frozen to -70°C and then shipped in dry ice to the Medical College of Virginia for viral studies

Table 4-18

PRIMARY CULTURAL CONDITIONS FOR POST-TEST SAMPLES OF HARDWARE COMPONENT SURFACES AND SUBSYSTEM COMPONENTS

Sample		Culture Medium[1]	Organisms of Interest	Incubation
Swabs of hardware component surfaces	1)	Casein Soy Agar*	Total flora	Aerobic 37°C for 24 hours
	2)	Blood (Sheep) Agar	Staphylococcus aureus and beta-hemolytic streptococci	Aerobic 37°C for 24 hours
	3)	Sabouraud Dextrose Agar	Fungi	Aerobic 37°C for 5 days 22°C for 5-7 days
	4)	Blood (Sheep) Agar	Total flora	Anaerobic 35°C for 3 days
Portions of hardware subsystem components	1)	Casein Soy Broth**	Total flora	Aerobic 37°C for 24 hours
		Agar media 1, 2, 3 above	Same as above	Same as above
	2)	Brewer Thioglycollate Broth**	Total flora	Anaerobic 37°C for 24 hours
		Agar medium 4 above	Same as above	Same as above

*Plates streaked from the swabs in order listed.
**Sample portions immersed in broth tubes. After incubation period, plates of agar media (1-4 above) were inoculated from the broth cultures for colonial isolation.

Note 1. All media from Hyland, Div. of Travenol Laboratories, Inc., Costa Mesa, California

by H. P. Dalton, Ph. D., Department of Clinical Pathology. Samples were obtained once pretest and on test days 25, 39, 53, 67, and 81. Virus was concentrated from the water samples by both membrane chromatography and hydroextraction techniques. Three host cell culture systems were employed: primary rhesus monkey kidney (PRMK), human epidermoid carcinoma-2/ heteroploid (H. Ep. 2), and human embryonic lung/diploid (WI-38). Concentrates from each technique were cultured in duplicate in all three host cell systems.

LRC Bacterial Sensor Experiment

A chemiluminescent method for rapid detection of bacterial contamination of the potable and wash water recovery subsystems was evaluated during the test. The detection method utilized was a modification of the luminol-perborate system described in Reference 4-47. The detection principle is based upon measurement of light emission resulting from microbial cytochrome C activation of luminol (5-amino-2, 3-dihydro-1, 4-phthalazinedione) in the presence of sodium perborate. Verification of the experimental detection method during the test was accomplished by correlating sensor response with a viable cell count obtained on the same water sample using Millipore Field Monitor culturing techniques.

The instrumentation (Figures 4-49 and 4-50), as designed by Dr. J. R. Wilkins (NASA-LRC), consisted of a light-tight reaction chamber/photocell and shutter assembly located inside the simulator and a Model 520-M Photovolt amplifier and Honeywell Electronik 194 strip chart recorder located outside the simulator. Operation of the sensor was a two-man procedure; one of the crew members (1) prepared the water samples for injection while an outside monitor zeroed the meter and strip chart recorder between injections. Typical procedures on board involved aseptic collection of water samples, making the sample highly alkaline (>pH 11) with NaOH, filling the reaction chamber with luminol-dextrose/sodium perborate/sodium hydroxide reaction mixture, and injecting the water sample (0.5 cm^3) into the reaction chamber. Typical outside procedures involved warmups and calibration of the amplifier and recorder, setting the range or sensitivity of the amplifier, and zeroing out residual luminescence between injections of sample or fresh additions of reaction mixture. The elapsed time between samples varied between 30 and 600 seconds depending upon the magnitude of the chemiluminescent response and the number of samples ready for injection. For comparison with the bacterial sensor response, a 10 cm^3 aliquot of the same water sample was filtered through a Millipore Field Monitor, then filter-cultured with ampouled Casein Soy Broth and incubated for 48 hours at 36°C. The number of bacteria/cm^3 of original sample was calculated by counting the number of colonies on the membrane filter and dividing by the volume of water filtered.

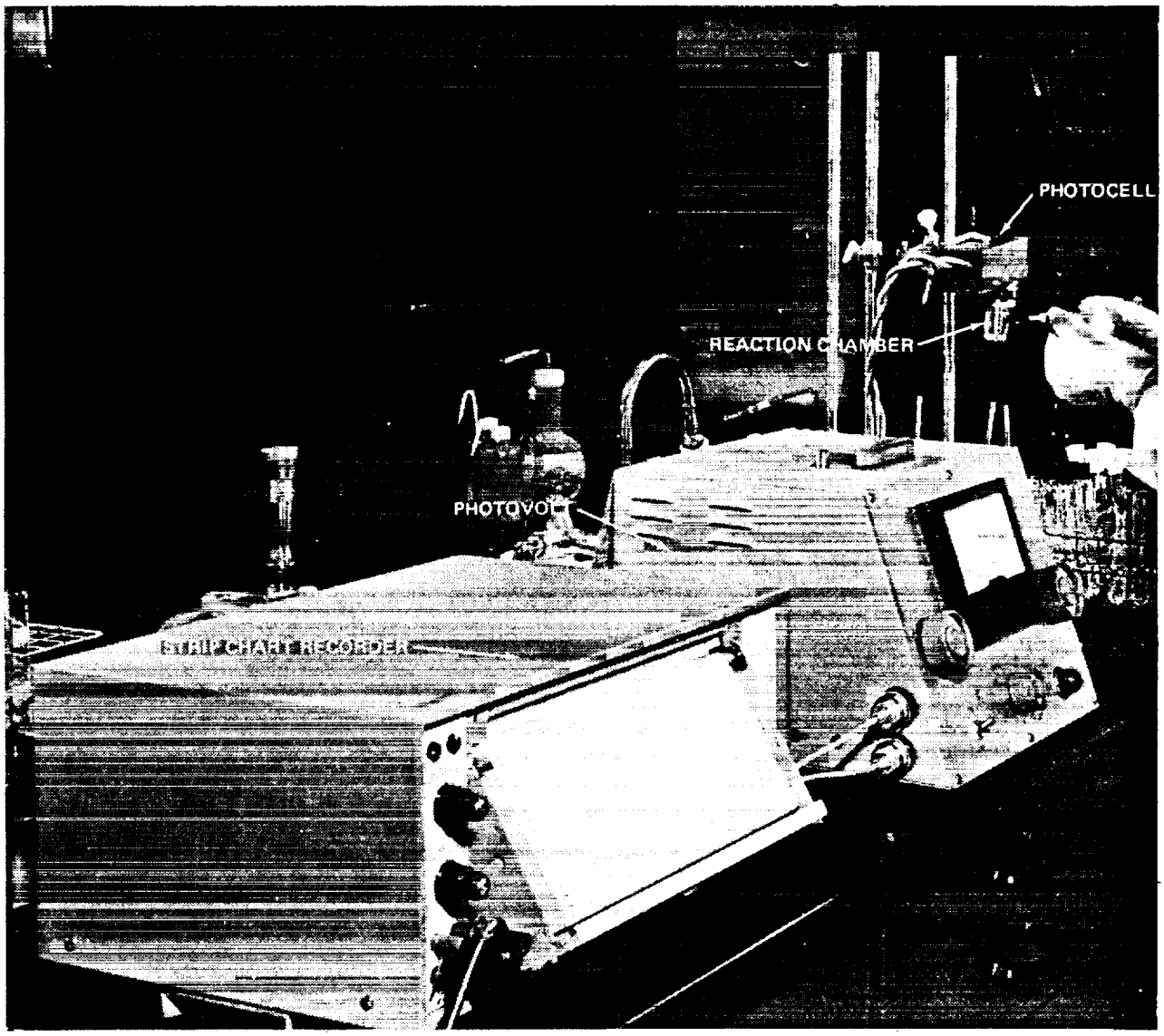


Figure 4-49. Bench Test Setup Bacterial Sensor Experiment

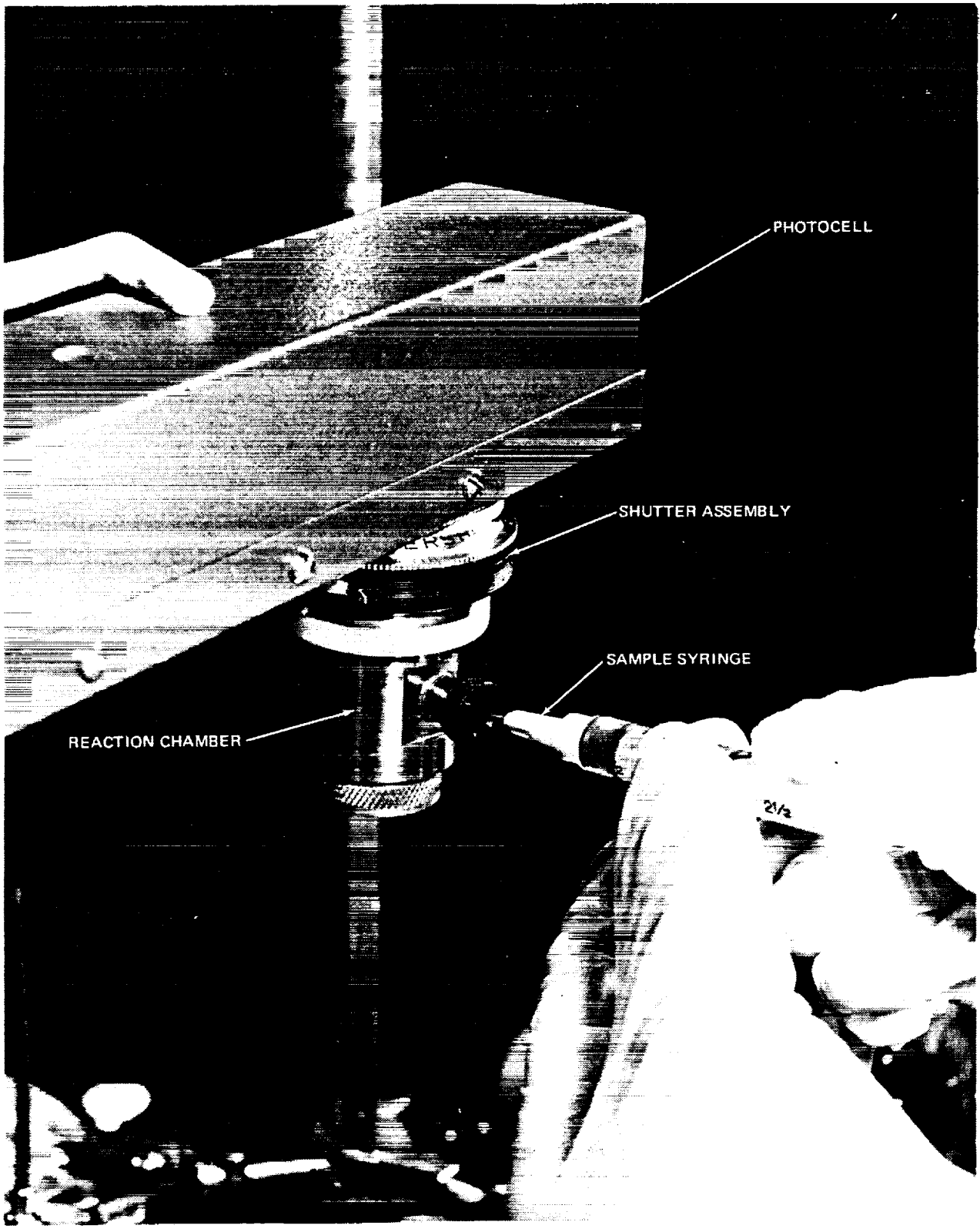


Figure 4-50. Onboard Setup Bacterial Sensor Experiment

4. 6. 3 Results

After the identification of all isolates selected during the 90-day test was completed, data were analyzed for quantitative and qualitative changes in flora indigenous to the crew, their environment, and life support systems. Possible occurrences of cross infection, buildup, and equipment deterioration were especially investigated.

4. 6. 3. 1 Throat and Nasal Swabs

Aerobic flora of the throat and nose which were of particular interest medically, viz., S. aureus, beta-hemolytic streptococci, N. meningitidis and D. pneumoniae, were isolated as indicated in Table 4-19. H. influenzae was not recovered during the first 53 days of the test. Thereafter, isolation procedures for this organism were discontinued.

Although an attempt was made to phage-type S. aureus isolates at the Medical College of Virginia, they were all found to be non-typable. Differential sensitivity tests were then applied, but all cultures were found to be sensitive to the 12 antibiotics tested. Consequently, no "markers" were available to investigate cross-infections. Generally, it was observed that crewman 1 was lacking S. aureus until the last few weeks of the test when this organism appeared regularly in his throat. Crewman 2 was a carrier; S. aureus was constantly present in his throat and nose samples. Crewmen 3 and 4 also harbored this organism in both nose and throat; however, it was not as consistently recovered from them as it was from crewman 2.

Beta-hemolytic streptococci were isolated from only crewman 1 on the 4th, 60th, and 67th test days. Oral erythromycin was administered to this man from the 70th to the 79th test day. His throat swab on test day 74 indicated an elimination of not only the beta-hemolytic streptococci but of all other flora except a beta-hemolytic strain of Neisseria sicca. By test day 81, N. sicca was his predominant isolate among others, viz., alpha-hemolytic Gram-positive cocci and S. aureus. N. sicca continued to outnumber other organisms until the end of the test. Samples obtained 18 days after egress indicated that alpha-hemolytic Gram-positive cocci once again outnumbered N. sicca.

Crewman 3 was a carrier of N. meningitidis throughout the test. There were relatively few colonies isolated from his throat during pretest sampling and the first 2 weeks of the test. However, heavy and confluent growth was obtained on the Thayer-Martin plates for every sampling time thereafter (test days 18 through 88 and post-test 18). Serological typing revealed that crewman 3 was a carrier of both Group B and C. N. meningitidis was not recovered from any other crewman except crewman 1 on test days 25 and 32. Since serotyping was not performed, it is unknown whether there was a transfer of this organism from crewman 3 to 1.

Table 4-19

RECOVERY OF S. AUREUS, BETA-HEMOLYTIC STREPTOCOCCI, N. MENINGITIDIS, AND D. PNEUMONIAE FROM THE NOSE AND THROAT

	Crewman		Test Day														
			-4	4	11	18	25	32	39	46	53	60	67	74	81	88	+18
(A)	1	N)															
		T)		X									X		X	X	X
	2	N)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		T)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	3	N)					X								X		
		T)		X	X	X	X	X	X	X	X	X	X	X	X	X	X
	4	N)		X		X	X	X		X	X	X	X	X	X	X	X
		T)		X		X	X	X	X				X		X		X
		N:Nose T:Throat															
(B)	1			X								X	X				
	2																
	3																
	4																
		Throat															
(C)	1						X	X									
	2																
	3		X	X	X	*	X	X	X	X	X	X	X	X	X	X	X
	4																
		Throat															
(D)	1		X	X	X	X	X	X	X	X	X		X	X		X	X
	2		X	X	X	X		X	X	X	X	X	X	X	X	X	X
	3		X	X	X	X	X	X		X	X	X	X	X	X	X	X
	4		X	X	X	X	X	X	X	X	X		X	X	X	X	X
		Throat															

X Organism recovered
* Sample lost
(A) Staphylococcus aureus
(B) Beta-hemolytic streptococci
(C) Neisseria meningitidis
(D) Diplococcus pneumoniae

Finally, Table 4-19 shows that D. pneumoniae was consistently present, with a few exceptions, in the throats of all crew members.

4.6.3.2 Dermal Swabs

Aerobic Flora

All dermal samples yielded Staphylococcus epidermidis at every sampling. Microorganisms intermittently isolated were S. aureus, species of Micrococcus, Aerococcus, Sarcina, Corynebacterium, Bacillus, and various Gram-negative bacteria. The recovery of these aerobes is summarized in Table 4-20. Mycological results are omitted due to incomplete identification.

Generally, an individual profile of aerobes was displayed for each man's axilla, perineum, and toe web. Of special interest was the comparative recovery of S. aureus from the nasopharynx and skin. Although crewman 2 was a carrier of nasopharyngeal S. aureus (see Table 4-19), it was recovered less frequently from his dermal sites than from crewman 4's. Crewman 1 and 3 yielded S. aureus rarely and only during the last half of the test. It was isolated earliest (before the 5th week) and most frequently from crewman 4.

Anaerobic Flora

Comparisons of growth scores on Brewer Thioglycollate Agar showed no gross changes in the level of dermal anaerobes during the test. The number of obligate anaerobes recovered from each site and sampling is presented in Table 4-21. The axilla and perineum of all crewmen usually yielded more anaerobes than the toe web. The lowest growth scores on Brewer Thioglycollate Agar were obtained from crewman 3's samples. His hygienic practices during the midportion of the test, viz., cleansing his feet with 1:750 Zephiran and treating them with Tinactin (Schering Corp., Bloomfield, N. J.) were reflected in extremely low scores for the toe web. The highest growth scores were consistently obtained from crewman 4's swabs.

Generally, individually characteristic profiles for types per crewman and dermal site were observed for both facultative and obligate anaerobes. A large majority of the facultative anaerobes were identified as S. epidermidis. As previously indicated, this organism was recovered from all aerobic plates at every sampling (Table 4-20). Other facultative anaerobes isolated were members of the following genera (which were also isolated under aerobic conditions): Micrococcus, Sarcina, Bacillus, and Corynebacterium. Most of the obligate anaerobes have been identified as diphtheroids. Crewman 4's swabs from all three sites were not only the most heavily contaminated but also yielded the greatest variety of colonial types on Blood Agar. Three anaerobes unique to crewman 4's perineum were identified as a clostridium, a diphtheroid, and Bacteroides melaninogenicus.

Table 4-20

RECOVERY OF AEROBIC BACTERIA FROM DERMAL SITES

Crewman	Site	Test Day														
		-4	4	11	18	25	32	39	46	53	60	67	74	81	88	+18
Staphylococcus aureus																
1	A									X						
	P									X						
	TW							X		X				X		
2	A							X		X					X	
	P												X	X		
	TW						X	X		X		X	X			
3	A															
	P											X	X			
	TW											X				
4	A			X			X	X		X	X		X			
	P							X	X		X			X		X
	TW		X	X					X	X						X
Staphylococcus epidermidis																
1	A	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	P	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	TW	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2	A	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	P	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	TW	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
3	A	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	P	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	TW	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
4	A	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	P	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	TW	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Micrococcus sp.																
1	A		X		X									X		
	P															X
	TW					X				X				X		
2	A															
	P				X	X	X							X		
	TW			X	X	X					X	X				
3	A		X		X											
	P				X	X	X					X				X
	TW			X	X	X								X		
4	A			X	X		X	X	X			X		X		
	P									X						
	TW		X		X							X			X	
Aerococcus sp.																
1	A			X		X	X					X		X		
	P															
	TW				X		X					X				
2	A				X											
	P				X		X					X	X	X		
	TW				X		X					X				
3	A				X							X				
	P			X			X			X		X				
	TW			X								X				
4	A						X			X				X		
	P			X	X		X									
	TW			X	X											
Sarcina sp.																
1	A						X								X	
	P					X				X						
	TW	X	X	X	X	X				X						
2	A					X										
	P				X											
	TW					X					X					
3	A				X	X										
	P															
	TW	X		X		X										
4	A				X	X				X						
	P							X		X		X	X			
	TW				X			X							X	
Corynebacterium sp.																
1	A			X						X	X	X				
	P	X			X		X									
	TW											X				
2	A										X					
	P				X		X	X								
	TW				X											
3	A															
	P				X					X		X				
	TW										X	X	X			
4	A	X				X				X						
	P		X					X								
	TW							X			X					
Bacillus sp.																
1	A									X		X	X			
	P	X	X	X				X					X			
	TW			X												
2	A		X					X								
	P			X	X				X	X	X	X	X			
	TW		X	X											X	
3	A							X			X					
	P	X														
	TW															
4	A	X					X	X								
	P	X										X	X		X	
	TW												X	X		
Gram-negative bacteria																
1	A			X			X									
	P	X							X		X					
	TW															
2	A												X	X		
	P		X						X				X	X		
	TW															
3	A															
	P													X		
	TW															
4	A								X			X				
	P		X	X			X	X	X	X		X	X	X		
	TW	X												X		

A = Axilla, P = Perineum, TW = Toe Web, X = Organism recovered

Table 4-21

NUMBER OF DIFFERENT TYPES OF OBLIGATE ANAEROBES FROM DERMAL SITES

Crewman	Site	Test Day														
		-4	4	11	18	25	32	39	46	53	60	67	74	81	88	+18
1	A	-	0	1	1	1	1	2	2	2	1	0	2	0	1	2
	P	1	-	1	1	1	0	2	1	2	1	1	0	2	1	2
	TW	1	-	0	0	1	0	0	0	0	0	0	0	1	0	0
2	A	1	1	0	0	0	1	1	0	1	0	0	1	2	1	0
	P	2	0	1	1	1	0	1	1	1	1	1	1	1	1	1
	TW	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	A	0	0	1	2	0	2	1	2	3	1	1	2	1	2	1
	P	0	0	1	0	0	0	0	0	1	1	0	5	1	1	1
	TW	1	0	0	0	0	0	0	1	3	0	0	0	0	0	0
4	A	0	0	0	2	1	1	1	1	2	1	2	3	1	1	1
	P	4	3	4	5	3	3	3	3	4	4	3	3	3	4	3
	TW	2	1	0	0	0	0	0	0	1	1	0	0	1	0	0

A = Axilla
P = Perineum
TW = Toe web
- = Sample lost
O = None recovered

4. 6. 3. 3 Feces, Urine, and Throat Wash

Although fecal, urine, and throat wash samples were shipped to and analyzed at the Lunar Receiving Laboratory at NASA-MSC, no data have been obtained.

4. 6. 3. 4 Serum Samples

As indicated in Sections 4. 5. 1 and 4. 5. 7, selected samples of serum were assayed during the test for ASO (antistreptolysin O) titer. Sera for additional immuno-assays are being held frozen (-70° C) in the Medical Laboratory.

4. 6. 3. 5 Surface Samples

Gross quantitation of microbes recovered during the 90-day test from surfaces in the food management and hygiene areas showed that the hygiene area was generally more contaminated throughout the test (Figure 4-51). These results are not unexpected because the food management area was cleaned at least once per week with Zephiran while the hygiene area was cleaned only sporadically.

The recovery of various bacterial isolates from SSS surfaces is indicated in Table 4-22. With one exception, S. epidermidis was recovered on every sampling date from both areas. S. aureus was found mainly in the hygiene area during the last few weeks of the test and in the food management area

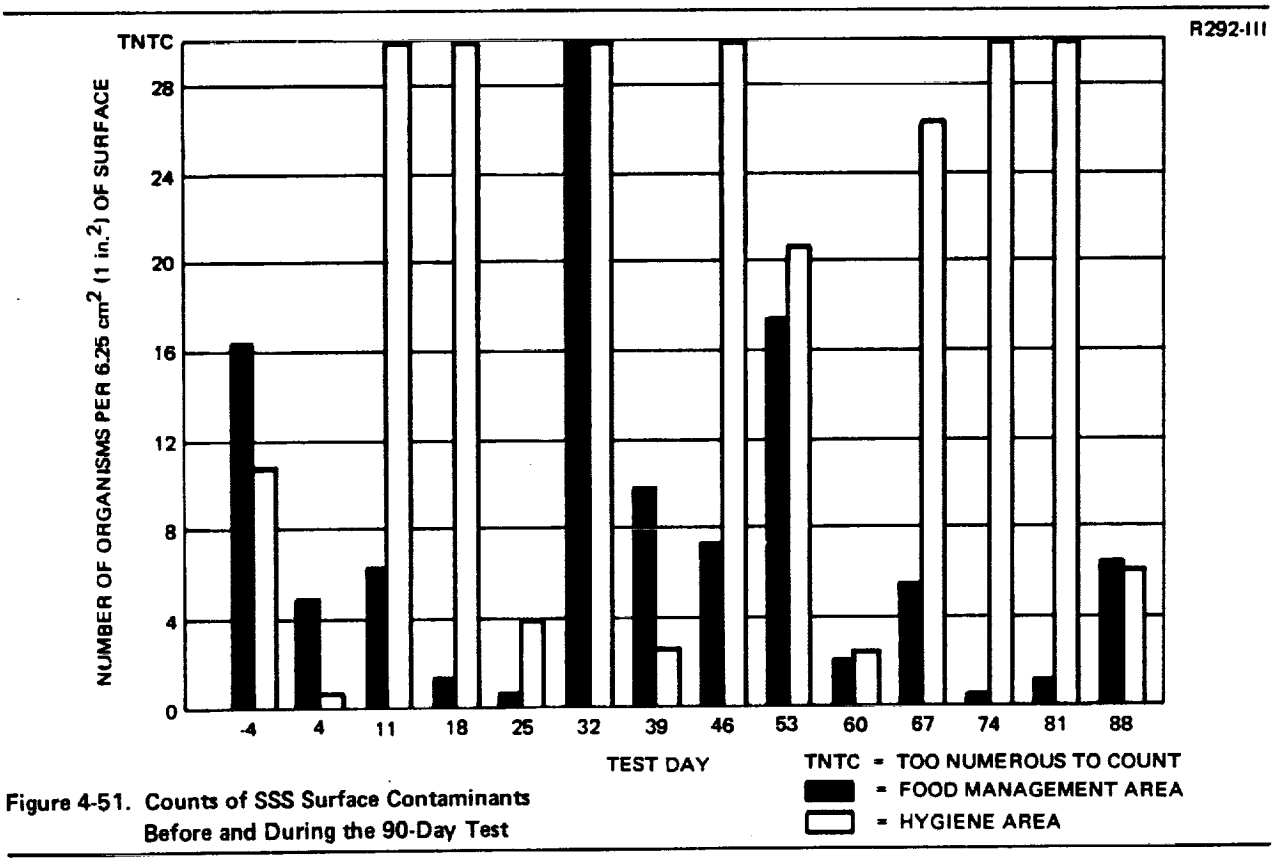


Figure 4-51. Counts of SSS Surface Contaminants Before and During the 90-Day Test

Table 4-22

RECOVERY OF BACTERIA FROM SSS SURFACES

Isolate	Site	Test Day														
		-4	4	11	18	25	32	39	46	53	60	67	74	81	88	+18
Staphylococcus epidermidis	FM	X	X	X	X	X		X	X	X	X	X	X	X	X	X
	H	X	X	X	X	X	X	X	X	X		X	X	X	X	X
Staphylococcus aureus	FM									X						
	H										X	X	X		X	
Bacillus sp.	FM	X		X				X	X	X	X	X				
	H					X	X	X			X	X	X		X	
Sarcina sp.	FM	X		X			X				X			X		
	H									X	X			X		
Aerobacter sp.	FM						X									
	H			X					X	X			X	X		
Micrococcus sp.	FM			X	X											
	H			X	X					X	X					
Alcaligenes sp.	FM						X									
	H				X	X	X		X							X
Pseudomonas sp.	FM						X									
	H						X		X	X	X					

Area sampled = 10 x 10 cm
FM = Food management area
H = Hygiene area
X = Organism recovered

only once. Other contaminants included Bacillus sp., Sarcina sp., Micrococcus sp., Corynebacterium bovis, Aerobacter sp., Alcaligenes sp., and Pseudomonas sp. The Gram-negative types were restricted to the hygiene area except for test day 32 when the largest number of surface contaminants for the food management area was obtained (see Figure 4-51).

The location of 35 surfaces swabbed immediately after the test is indicated in Figure 4-52. Levels and types of aerobic and anaerobic isolates are presented in Tables 4-23 and 4-24. Table 4-23 shows that aerobic (bacterial and fungal-type*) contaminants were found on 31 of the 35 surfaces sampled. Aerobic bacterial counts ranged from 0 to 46.0 colonies per 6.25 cm^2 of surface while fungal-types ranged from 0 to 40.5 colonies per 6.25 cm^2. Obligate anaerobes were recovered from 19 surfaces but were not quantitated.

No contaminants were recovered from the following samples: VD-VF vacuum line, potable water condensate separator, and potable water condensate separator - GN_2 line. Except for the floor under the port bunks, bacterial contaminants exceeded fungal-types. Surfaces exhibiting low levels of bacteria (<2.0/6.25 cm^2) included the: wick evaporator counter top, recreation table top, Aircoustat door handle, spirometer inlet, commode vacuum line, and thermal control duct grill sample 3. Highly contaminated surfaces included: interior of vacuum cleaner hose, urine collector debris screen, urine measurement volumetric cylinder, floor under urine phase separator, floor under psychomotor tester right pedal, and thermal control duct grill sample 1 (air return).

Table 4-24 indicates that Staphylococcus epidermidis was the predominant surface contaminant recovered after the test, as it was during the test. A majority of the sample sites also yielded one or more species of Bacillus. Ten surfaces were contaminated with species of Micrococcus, eight with Sarcina, and seven with Aerococcus viridans. Corynebacterium bovis was recovered only from the thermal control duct shelf (air return) and Clostridium sp. only from the thermal control duct 4.

Gram-negative enteric types were recovered from only five surfaces. Pseudomonas sp. and Aerobacter aerogenes were isolated from the floor under the urine phase seperator and species of Pseudomonas, Alcaligenes, and Aerobacter from the thermal control duct grill sample 1 (air return). Pseudomonas sp. was also isolated from the vacuum cleaner hose and Alcaligenes sp. from the floor under the port bunk. An unusual organism, Acinetobacter mallei, was recovered from the urine collector debris screen. This organism, bright lemon-yellow in colonial pigmentation, grew confluently on Casein Soy and Sabouraud Dextrose Agars.

As indicated in Table 4-24, all aerobic bacterial isolates were grouped according to staining characteristics and morphology. Gram-positive cocci accounted for approximately 54 percent of the total number; Gram-positive

*Fungal-type counts were derived from the total number of colonies on Sabouraud Dextrose Agar. Preliminary screening of these isolates has shown that some of the isolates initially thought to be fungi are actually bacteria. This should be kept in mind when reviewing the fungal (actually fungal-type) data.

FORWARD (EQUIPMENT) COMPARTMENT

PORT	STARBOARD
POTABLE H_2O CONDENSATE SEPARATOR	AIRCOUSTAT DOOR HANDLE
POTABLE H_2O CONDENSATE SEPARATOR, GN_2 LINE	STOWED VD-VF BOILER RIM
WICK EVAPORATOR COUNTER TOP	* VACUUM CLEANER HOSE, INTERIOR
VD-VF VACUUM LINE	FLOOR UNDER PSYCHOMOTOR TESTER, RIGHT PEDAL
VD-VF LOWER SHIELD, TOP SURFACE	
COUNTER BEHIND SABATIER REACTOR	
THERMAL CONTROL DUCT GRILL, SAMPLE 1	
THERMAL CONTROL DUCT GRILL, SAMPLE 2	
THERMAL CONTROL DUCT AIR RETURN, SHELF	

AFTER (CREW) COMPARTMENT

PORT	STARBOARD
CLOTHES DRYER DRUM, INTERIOR	FREEZER COUNTER TOP
CLOTHES WASHER DRAIN FILTER	FOOD STORAGE AREA 74, SHELF
CLOTHES DRYER COUNTER TOP	FLOOR UNDER BUNK
MICROWAVE OVEN SHELF, INTERIOR	
MICROWAVE OVEN REAR COUNTER TOP	
RECREATION TABLE TOP	
REFRIGERATOR EGG TRAY	
MDAC COLD H_2O DISPENSER OUTLET	
SPIROMETER INLET	
THERMAL CONTROL DUCT GRILL, SAMPLE 3	
THERMAL CONTROL DUCT GRILL, SAMPLE 4	
THERMAL CONTROL DUCT GRILL 4, TOP CORNER	
STORAGE AREA 1, REAR CORNER	
COMMODE SEAT, EXTERIOR	
COMMODE VACUUM LINE	
URINE COLLECTOR DEBRIS SCREEN	
VOLUMETRIC CYLINDER, INTERIOR (URINE MEASUREMENT)	
FLOOR UNDER URINE PHASE SEPARATOR	
FLOOR UNDER BUNK	

* NOTE: VACUUM CLEANER USED THROUGHOUT SIMULATOR, BUT STOWED IN FORWARD COMPARTMENT.

Figure 4-52. Location of Post-Test Surface Samples

Table 4-23
POST-TEST SURFACE CONTAMINATION LEVELS

Surface Sampled	No. aerobes/6.25[1] cm^2	
	[2]Bacterial	[3]Fungal-type
VD-VF vacuum line	0	0
Potable water condensate separator	0	0
Potable water condensate separator, GN_2 line	0	0
*Stowed VD-VF boiler (lower rim)	0	0
Commode vacuum line	0.3	0
Thermal control duct grill–sample 3	0.3	0
Wick evaporator counter top	0.5	0
Aircoustat door handle	0.5	0
Recreation table top	1.0	0
Spirometer inlet	2.0	0
Clothes washer drain filter (interior)	2.0	0.8
Thermal control duct grill–sample 4	3.0	0.3
Thermal control duct grill–sample 2	5.5	1.0
Food storage area (74) shelf	5.5	3.5
Microwave oven shelf (interior)	7.0	1.3
Refrigerator egg tray	9.5	1.8
Floor under starboard bunk	12.0	2.3
Thermal control duct grill 4, top corner	12.0	4.5
Storage area 1, rear corner	14.0	4.0
Clothes dryer counter top	19.0	19.0
VD-VF lower shield, top surface	19.5	4.5
Freezer counter top	21.8	7.8
MDAC cold water dispenser outlet (interior lip)	25.0	11.3
Floor under port bunk	27.0	40.5
Clothes dryer drum (interior)	33.0	9.0
Counter behind Sabatier reactor	37.0	12.7
Thermal control duct air return, shelf	45.5	4.0
Commode seat (exterior)	45.5	20.8
Microwave oven rear counter top	46.0	10.0
Vacuum cleaner hose (interior, housing end)	TNTC	11.0
Urine collector debris screen	TNTC	TNTC
Volumetric cylinder, urine measurement (interior lip)	TNTC	TNTC
Floor under urine phase separator	TNTC	TNTC
Floor under right pedal of psychomotor tester	TNTC	TNTC
Thermal control duct grill–sample 1	TNTC	TNTC

Increasing bacterial contamination ↓

Notes: 1 Approximate area for surfaces not of flat configuration.

2 Bacterial Levels–from total number of colonies on Casein Soy Agar after 24 hours at 37°C.

3 Fungal Levels–from total number of colonies on Sabourand Dextrose Agar after 5 days at 37°C. Some of these isolates later proved to be bacteria, not fungi.

TNTC=too numerous to count

*Further incubation yielded isolates, as indicated in Table 4-26.

Table 4-24

MICROBIAL TYPES RECOVERED FROM SSS SURFACES POST-TEST

Site	Gram-positive: Cocci: Micrococcaceae: Staphylococcus epidermidis	Gram-positive: Cocci: Micrococcaceae: Staphylococcus aureus	Gram-positive: Cocci: Micrococcaceae: Micrococcus sp.	Gram-positive: Cocci: Micrococcaceae: Sarcina sp.	Gram-positive: Cocci: Streptococcaceae: Aerococcus viridans	Gram-positive: Rods: Corynebacterium bovis	Gram-positive: Rods: Clostridium sp.	Gram-positive: Rods: Bacillus subtilis	Gram-positive: Rods: Bacillus firmus	Gram-positive: Rods: Bacillus cereus	Gram-positive: Rods: Bacillus coagulans	Gram-positive: Rods: Bacillus stearothermophilus	Gram-positive: Rods: Bacillus brevis	Gram-positive: Rods: Bacillus sphaericus	Gram-positive: Rods: Bacillus megaterium	Gram-positive: Rods: Bacillus lentus	Gram-positive: Rods: Bacillus licheniformis	Gram-negative: Rods: Alcaligenes sp.	Gram-negative: Rods: Pseudomonas sp.	Gram-negative: Rods: Aerobacter aerogenes	Gram-negative: Rods: Acinetobacter mallei	Other: Obligate anaerobe(s)	Other: Fungal-types
Stowed VD-VF boiler (lower rim)	X						X			X		X											
Thermal control duct grill–sample 3							X																
Wick evaporator counter top	X																					X	
Aircoustat door handle	X																					X	
Recreation table top	X		X	X			X															X	
Spirometer inlet	X	X	X																				
Clothes washer drain filter (interior)	X																					X	X
Thermal control duct grill–sample 4	X		X			X		X			X											X	X
Thermal control duct grill–sample 2	X		X					X														X	X
Food storage area 74 (shelf)	X	X	X																				X
Microwave oven shelf (interior)	X						X		X							X						X	X
Refrigerator egg tray				X																		X	X
Floor under starboard bunk	X		X				X	X	X														X
Thermal control duct grill, 4, top corner	X						X							X								X	X
Storage area 1, rear corner			X	X			X	X			X			X					X			X	X
Clothes dryer counter top	X				X				X														X
VD-VF lower shield, top surface	X	X		X									X			X						X	X
Freezer counter top	X	X		X			X															X	X
MDAC cold water dispenser outlet															X			X	X				X
Floor under port bunk	X	X						X	X					X				X					X
Clothes dryer drum (interior)	X				X			X														X	X
Counter behind Sabatier reactor	X																					X	X
Thermal control duct air return, shelf	X					X			X													X	X
Commode seat (exterior)	X		X																			X	X
Microwave oven, rear counter top	X			X	X		X	X		X												X	X
Vacuum cleaner hose (interior, housing end)		X	X		X														X				X
Urine collector debris screen				X	X															X			X
Volumetric cylinder, urine measurements (interior lip)												X										X	X
Floor under urine phase separator	X	X		X															X	X			X
Floor under right pedal of psychomotor tester	X	X	X		X				X														X
Thermal control duct grill–sample 1	X			X				X										X	X	X		X	X

X = organism recovered
Area sampled = 5 cm x 5 cm, wherever possible

rods, 36 percent, and Gram-negative rods, 10 percent. Puleo, et al. (Reference 4-49) reported quite similar results for bacterial isolates from interior command module surfaces while Apollo 6 was located at Launch Complex 39A. The average number of aerobic surface bacteria in the Apollo spacecraft was approximately 47 organisms per 6.25 cm^2. This level is comparable to the number of aerobes recovered from only 3 of the 35 post-test SSS surface samples (Table 4-23). The majority of samples (26) yielded an average of only 10 aerobes/6.25 cm^2. As in other confinement studies (Reference 4-50), the highest levels of contaminants were found in samples from the personal hygiene, waste management, and thermal control systems. Despite heavy contamination in these areas, few pathogens were recovered during and post-test; the majority of the isolates were either saprophytes or dermal flora indigenous to the crew. Organisms recovered from 35 surfaces post-test were essentially the same as those isolated from 2 surfaces sampled weekly and from atmospheric samples taken biweekly during the test.

4.6.3.6 Subsystem Components

Potable and Wash Water Reclamation Systems

Quantitative and qualitative results for post-test samples of water subsystem components are presented in Tables 4-25 and 4-26. The broth growth scores provide only a gross estimation of contamination levels since sample quantity was only estimated. Figure 4-53 diagrams the sequence of multifilter elements through which the water was pumped prior to storage in heated use tanks. As discussed in Section 2, various elements of both multifiltration systems were replaced over the course of the test. Consequently, the types and quantities of organisms isolated post-test only reflect the post-installation history of a multifilter element. Elements of the wash water unit were replaced more frequently than those in the potable water unit.

As indicated in Table 4-25, ion-resin and carbon columns in both potable and wash water subsystems were sampled at 3 or 4 equally spaced intervals within the column packing to determine contaminant distribution. No consistent pattern for either type or level of contamination was found except for a greater incidence of fungal-type isolates from the wash water unit and an absence of Pseudomonas sp. from the potable water unit. As with the wick evaporator system (Table 4-26), the majority of multifilter element contaminants were Bacillus sp.

Of the two systems, the potable water multifiltration unit yielded lower levels and fewer types of contaminants. Bacillus firmus and Bacillus sphaericus were the only two organisms isolated from more than one site within a potable water multifilter element and from two elements in series. Ion-resin 1 yielded only Bacillus firmus and an obligate anaerobe, ion-resin 2 only Bacillus sphaericus. Fungal-types were not recovered from either resin bed. Carbon column 1 was heavily contaminated at the inlet with

Table 4-25

POST-TEST RECOVERY OF MICROBIAL CONTAMINANTS FROM THE POTABLE AND WASH WATER MULTIFILTRATION UNITS

	Component	Broth Growth Scores		Gram-positive														Gram-negative			Other
				Cocci				Rods										Rods			
		Aerobic	Anaerobic	*Micrococcus* sp.	*Staphylococcus epidermidis*	*Staphylococcus aureus*	*Sarcina* sp.	*Corynebacterium equi*	*Bacillus firmus*	*Bacillus macerans*	*Bacillus brevis*	*Bacillus circulans*	*Bacillus megaterium*	*Bacillus subtilis*	*Bacillus cereus*	*Bacillus sphaericus*	*Pseudomonas* sp.	*Alcaligenes* sp.	*Actinobacillus* sp.	Obligate anaerobe(s)	Fungal-types
POTABLE WATER SYSTEM MULTIFILTRATION UNIT	Carbon 1 inlet	+3	+3	XX				X												X	
	Carbon 1 midstream	+1	+3					X									X		X	X	
	Carbon 1 outlet	+1	+4					X													
	Mixed Ion-Resin (1) inlet	+2	+2					X											X		
	Mixed ion-resin (1) midstream	0	+2								no growth on subculturing										
	Mixed ion-resin (1) midstream	0	+1								no growth on subculturing										
	Mixed ion-resin (1) outlet	0	+1								no growth on subculturing										
	Cation resin (2) inlet	+1	+1												X						
	Cation resin (2) midstream	0	+1								no growth on subculturing										
	Cation resin (2) outlet	+1	+1												X				X		
	Carbon 2 inlet	+1	+2		XX	XX									X						
	Carbon 2 midstream	+1	+1												X						
	Carbon 2 midstream	+1	+3								X	XX					X				
	Carbon 2 outlet	+3	+3											X					X	X	
WASH WATER SYSTEM MULTIFILTRATION UNIT	Pall filter pore size 30μm top	+1	+2								XX					X				X	
	Pall filter pore size 30μm middle	+1	+2							XX						X				X	
	Pall filter pore size 30μm bottom	+1	+3						XX							X				X	
	Pall filter pore size 3μm top	+1	+3							X								X		X	
	Pall filter pore size 3μm middle	+1	+2													X		X		X	
	Pall filter pore size 3μm bottom	+1	+2					X										X		X	
	Pall filter pore size 1μm top	+1	+4													X				X	
	Pall filter pore size 1μm middle	+1	+1													X				X	
	Pall filter pore size 1μm bottom	+1	+1													X		X		X	
	Carbon 1 inlet	+1	+4				X				XX									X	
	Carbon 1 midstream	+1	+4													X			X	X	
	Carbon 1 midstream	+1	+4	XX								XX				X				X	
	Carbon 1 outlet	+1	+4													X			X	X	
	Mixed ion-resin inlet	+4	+3											X		X				X	
	Mixed ion-resin midstream	+2	+2					X						X		X				X	
	Mixed ion-resin midstream	+1	+4					X												Y	
	Mixed ion-resin outlet	+2	+3											X			X		X	X	
	Cation resin inlet	+3	+2											X			X			X	
	Cation resin midstream	+4	+4				X						X	X	X					X	
	Cation resin midstream	+2	+3									X								X	
	Cation resin outlet	+2	+2								X						X			X	
	Carbon 2 inlet	+2	+4													X			X	X	
	Carbon 2 midstream	+2	+1					X												X	
	Carbon 2 midstream	+3	+4					X						X						X	
	Carbon 2 outlet	+2	+4											X					X	X	

0 = no growth in broth
+1 — +4 = growth scores used to indicate increasing broth turbidity

X = organism recovered
XX = organism recovered on anaerobic primary isolation plate

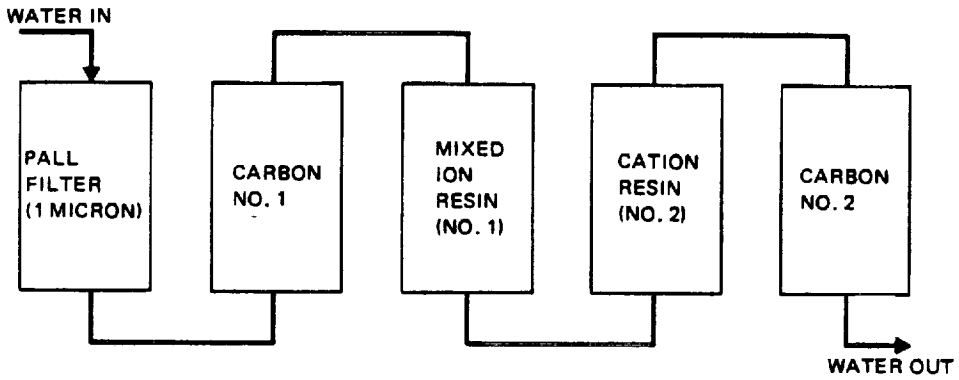
Table 4-26

POST-TEST RECOVERY OF MICROBIAL CONTAMINANTS FROM POTABLE AND WASH WATER SUBSYSTEM COMPONENTS

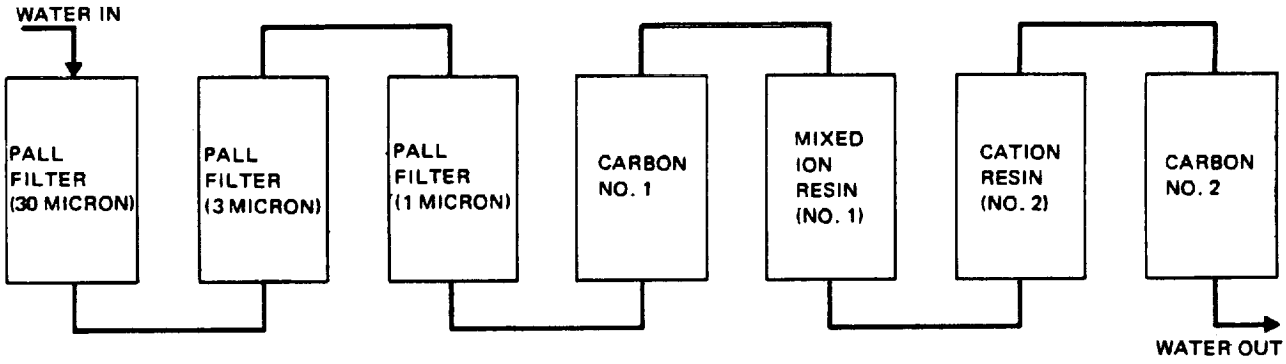
Component	Broth Growth Scores		Gram Positive												Gram Negative				Other
			Cocci		Rods										Rods				
	Aerobic	Anaerobic	Micrococcus/Staphylococcus epidermidis	Sarcina lutea	Corynebacterium equi	Bacillus sp.	Bacillus firmus	Bacillus macerans	Bacillus brevis	Bacillus megaterium	Bacillus subtilis	Bacillus lentus	Pseudomonas aeruginosa	Alcaligenes sp.	Escherichia coli	Unidentified rods	Obligate anaerobe (s)	Fungal-types
VD-VF Boiler 1 Residue	+1	+2	No growth on subculturing															
VD-VF Boiler 2 Residue	+1	+4	No growth on subculturing															
Pretreated Urine Residue*	+3	+2									XX	X						X
Wick Evaporator Wick 1	+1	+1	XX				X				X							
Wick Evaporator Wick 2	+3	0					X											
Wick Evaporator Wick 3	+4	+4	X					XX			X			X				X
Wick Evaporator Wick 4	+3	0					X											
Wick Evaporator Wick 5	+2	+1							XX		X							X
Carbon Air Filter Inlet	+1	–				X									XX			
Carbon Air Filter Mid-stream	+1	+1								X					XX			X
Carbon Air Filter Outlet	+1	+1		X														
Carbon Air and Humidity Condensate Overflow	+1	+4						XX										
Thermal Control Heat Exchanger Condensate	+4	0					X											X
Silica Gel and Humidity Condensate	+2	+2											X		X	X		X
Isotope Capsule Storage Tank Water	+2	+3			X					XX			X					X
Hygiene Sink Water	–	+3						XX										

+1– +4 = growth scores indicating increasing broth turbidity
X = organism recovered
XX = organism recovered from Blood Agar anaerobic plate

Notes: All water samples = 10 $(cm)^3$
*From temporary urine storage container



POTABLE WATER MULTIFILTRATION UNIT



WASH WATER MULTIFILTRATION UNIT

Figure 4-53. Potable and Wash Water Multifiltration Units

Staphylococcus epidermidis and fungal-types; at mid-stream with Bacillus firmus, Alcaligenes sp., fungal-types, and an obligate anaerobe; and at the outlet side with Bacillus firmus only. Carbon column 2 showed heavy contamination at the outlet with Bacillus subtilis, fungal-types, and an obligate anaerobe, while the inlet and mid-stream samples yielded only scanty growth scores for Staphylococcus aureus, Bacillus sphaericus and Sarcina sp. The only Gram-negative enteric isolated was Alcaligenes sp. found midstream in both carbon columns.

A greater variety of Bacillus sp. was isolated from elements of the wash water multifilter unit than from the potable water unit and a corresponding rise was observed in the number of isolates from multiple sites in individual filters. Bacillus subtilis, Pseudomonas sp., Alcaligenes sp., and fungal-types were recovered from two or more adjacent filter elements. The greatest variety of organisms was isolated from the resin beds and carbon column 1.

Fecal Collection System

Assay results for components of the fecal collection system are summarized in Table 4-27. Analysis of the Purafil (Marbon Chemicals Div. of Borg-Warner Corp., Washington, W. Va.) odor control canister contents revealed the pellets to be sterile at all three sample sites. Isolates from the stored fecal bag were unusual and could not be identified by the LRC. The fecal bag in use at the end of the test contained Bacillus macerans, Bacillus licheniformis, and Bacillus cereus. Several fungal-types were isolated from both bags. No obligate anaerobes were recovered.

Stored Waste

Waste materials were categorized accoring to capacity as a source of microbiological contamination, noxious odor, and combustible material. Food packaging materials, which comprised the bulk of waste and fit into all three categories, were further classified as dry or wet waste. Dry waste consisted primarily of outer packaging materials associated with the freeze-dried food program. Low in moisture content and highly combustible, they were returned to their original stowage configuration in the form of foil-wrapped bundles.

Wet waste consisted primarily of those items which were or had come in contact with readily bio-degradable materials such as reconstituted freeze-dried food, urine spills, exudates of the oronasal cavities, etc. Wet waste was either placed in size No. 2 cans, sprayed with 8-hydroxy quinoline sulfate (8-quinolinol) and hermetically sealed, or it was sprayed with 8-quinolinol and stored in aluminum boxes. The latter technique was used only for disposal of several thousand used plastic food trays generated during the test.

Table 4-27

POST-TEST RECOVERY OF MICROBIAL CONTAMINANTS FROM SSS FECAL COLLECTION SYSTEM

Component	Isolates
Odor control filter (Purafil pellets, top, middle, and bottom intervals)	No growth
Stored fecal bag contents	Aerobic isolates were not identified. S. epidermidis from anaerobic plates. Fungal-types
In-use fecal bag contents	Bacillus macerans Bacillus licheniformis Bacillus cereus Fungal-types

Note: No obligate anaerobes were recovered.

Analysis of representative samples from each type of stored waste is presented in Table 4-28. More microbial types and higher levels of contaminants were recovered from wet than dry waste. In contrast to the complete absence of contaminants on used food trays, contents of hermetically sealed wet waste cans yielded up to four different organisms. Storage time may have a bearing on the recovery patterns observed with the canned wet waste since only sporeformers such as Bacillus circulans and fungal-types were isolated from cans filled early in the test. In addition, the crew members indicated that not all cans were as heavily sprayed with 8-quinolinol as they should have been considering the quantity of material to be treated. As expected, the types of organisms recovered from stored waste were similar to those found in the SSS atmosphere and on surfaces during the test. The complete absence of obligate anaerobes cannot be explained at this time.

4.6.3.7 Air Samples

Microbial contamination levels in the SSS atmosphere were low throughout the test (see Table 4-29). Bacterial counts ranged from 0.02 to 3.0 airborne viable particles/0.028m^3, while fungal counts were even lower, ranging from zero to 0.23. Slightly higher counts for bacterial types were obtained in the forward (equipment) than the aft (crew) section on eight of the ten sample sets.

Table 4-28

POST-TEST RECOVERY OF MICROBIAL CONTAMINANTS FROM STORED WASTE

Component		Broth Growth Scores: Aerobic	Broth Growth Scores: Anerobic	Gram-positive: Cocci: *Staphylococcus epidermidis*	Gram-positive: Cocci: *Staphylococcus aureus*	Gram-positive: Cocci: *Aerococcus viridans*	Gram-positive: Rods: *Corynebacterium striatum*	Gram-positive: Rods: *Bacillus sp.*	Gram-positive: Rods: *Bacillus coagulans*	Gram-positive: Rods: *Bacillus circulans*	Gram-positive: Rods: *Escherichia coli*	Gram-negative: Rods: *Aerobacter aerogenes*	Gram-negative: Rods: *Pseudomonas aeruginosa*	Other: Fungal-types
Dry Waste (not quinolinol treated)	*Foil-wrapped bundle No. 1	0	0											
	2	0	+4	X X										
	3	0	+0											
	4	+2	+4	X X				X						X
	5	+3	0						X		X			X
	6	0	0											
Wet Waste (quinolinol treated)	**Hermetically sealed can No. 1	+3	+3							X				X
	2	0	+3				no growth on subculturing							
	3	+4	+4		X X						X X	X		X
	4	+2	+4		X		X							
	5	+3	+3				X		X					X
	6	+4	+4	X	X	X								X
	***Aluminum storage box No. 1	0	0											
	2	0	0											
	3	0	0											
	4	0	0											
	5	0	0											

*Freeze-dried food wrappers and cans, waste paper and gauze, test tubes.
**Can tops and bottoms, plastic tubing, wipes, jelly and condiment containers, table scraps.
***Used food trays.

0 = no growth
+1 → +4 = growth scores used to indicate increasing broth turbidity
X = organism recovered
XX = organism recovered from anaerobic plates (Blood Agar)
Note: no obligate anaerobes recovered

Table 4-29

NUMBER OF VIABLE PARTICLES PER 0.028 M^3 (1 FT^3) IN THE SSS ATMOSPHERE

	Equipment Compartment		Crew Compartment	
Test Day	Bacterial	Fungal	Bacterial	Fungal
-1	0.07	0	0.016	0.02
3	0.70	0	0.160	0
17	1.92	0.05	1.050	0.03
31	1.00	0.03	1.220	0.02
45	0.73	0.12	2.070	0.23
59	1.83	0	1.670	0
73	3.00	0.08	0.830	0.07
80	2.87	0	2.130	0
87	2.57	0.03	0.900	0.05
+4	0.12	0	0.020	0

Note: Forward and aft Reyniers samplers were operated simultaneously at 1 ft^3 of air per minute for 1 hour.

As shown in Table 4-30, S. epidermidis was the predominant bacterial contaminant in the atmosphere, just as it was the chief contaminant on SSS surfaces (Table 4-22) and the most common isolate from dermal sites (Table 4-20). Other surface and dermal isolates found in the atmosphere were S. aureus and species of Micrococcus, Aerococcus, Sarcina, Bacillus, and Corynebacterium.

During the period that the catalytic toxin burner was inoperative (days 67 to 81), colony counts increased slightly in the equipment area. Moreover, there was a corresponding increase in the number of different bacterial types recovered in the same section; i. e., Alcaligenes sp., Neisseria catarrhalis, Enterobacter Group B, and Proteus mirabilis were not isolated until the tenth week of the test. Although it is possible that the toxin burner may have had a direct or indirect influence upon the recovery of airborne contaminants,

Table 4-30

TYPES OF BACTERIA RECOVERED FROM SSS ATMOSPHERE

Isolate	Test Day									
	-1	3	17	31	45	59	73	80	87	+4
Staphylococcus epidermidis	F	F, A	F, A	F, A	F, A	F, A	A	A	F, A	F, A
Staphylococcus aureus				F			F, A		F	
Micrococcus sp.		F		F	F	F, A	F		F, A	
Aerococcus sp.	F						F	F		
Aerococcus viridans			F, A							F
Sarcina sp.	F, A	A		F	F, A		F, A			
Bacillus sp.		F		F	A	A	F	A	F	F, A
Corynebacterium sp.		A						F	F, A	F, A
Corynebacterium bovis		F, A	F, A	F						
Neisseria catarrhalis								F	F	
Alcaligenes sp.							F, A	F	F, A	
Enterobacter group B								F		
Proteus mirabilis								F		

F = Forward (equipment) section
A = Aft (crew) section

this question cannot be resolved due to the lack of continuous sampling shortly before, during, and shortly after toxin burner shutdown.

4.6.3.8 Water Samples

Throughout the 90-day test, the crewmen drank water that met the biological requirements established by the National Academy of Sciences (Reference 4-48). A maximum of 10 viable microorganisms per cm^3 was allowed.

Millipore Field Monitors

The Millipore bacterial analysis technique provided adequate onboard surveillance of potable and wash water systems. A compilation of all microbial counts is presented in Figures 2-30 and 2-31 of the final report on the water management system (Section 2.2). Contamination levels ranged from zero to "too numerous to count". The latter were shown to be due either to incorrect sampling procedure or they indicated actually contaminated water. Remedial action to purify the water in these instances is discussed in Section 2.2.

Most of the microbial contaminants found in the potable water system were recovered from unprocessed water at sample port B-84, which was located directly downstream of the VD-VF condenser. Species of Alcaligenes were consistently isolated. Pseudomonas sp. were sporadically recovered, and S. aureus was evident only during the last 3 weeks of the test. Alcaligenes sp. were isolated during the two instances that the heated holding tanks were found to be contaminated.

Contaminants in the wash water system were Alcaligenes sp., Pseudomonas sp., and Bacillus sp. The latter organism was recovered from a rayon felt retaining pad removed from a carbon column of the wash water system on test day 39. It was never recovered from the potable water system. It is remarkable that the most predominant dermal organism, Staphylococcus epidermidis, was recovered only once from wash water samples.

Medical College of Virginia Virus Studies

Analyses on potable water samples performed at the Medical College of Virginia were negative for virus on all samples provided using the concentration techniques and host cell culture systems previously described. Polio Virus Type 1 (10 $TCID_{50}$) controls were positive for each test. A cytopathogenic effect (CPE), nonviral in etiology, was observed in the WI-38 and H. ep. 2 host cell culture systems for water samples obtained on test days 53, 67, and 81. This effect was most pronounced on the WI-38 cell line and was attributed to the probable presence of bacterial endotoxins in those samples of water. The investigators reported that WI-38 cells are very sensitive to endotoxin (i.e., to as little as 0.002 microgram of Salmonella abortus-equi endotoxin) and that the CPE was equally expressed with both types of concentration techniques employed for these tests.

LRC Bacterial Sensor Experiment

The results of the experiment revealed that the bacterial sensor was not consistent in detecting either the presence or the absence of bacterial contamination in the water samples. Both a sensor and a field monitor analysis was performed for 63 of the 106 samples of water obtained for this experiment during the test. Of these 63 samples, only 6 (approximately 10 percent) showed a strong sensor response (sensor reading over 10 photometer units) coincident with high (too numerous to count) field monitor counts. Conversely, 38 of these samples showed moderate to strong sensor responses coincident with field monitor counts of less than 1.0 organism/cm^3 of sample. Complicating the problem was the finding that of the 63 samples analysed this way, only a small fraction injected in duplicate yielded data points within a few photometer units of each other. On several occasions, injection of the sample caused a reproducible negative or below zero response (quenching effect).

Lack of reproducibility with a majority of the samples appears to be related to the lack of control of injection speed and sample volume injected; neither parameter is adequately controlled by manual techniques. One cause for the quenching effect can probably be attributed to the presence of trace quantities of benzalkonium chloride (Zephiran) routinely used for disinfecting the table tops and occasionally during the early test period for rinsing sensor syringes. This material caused a pronounced quenching of the chemiluminescent reaction when added to samples of water initially having a high sensor reading. Since quenching reactions also occurred long after the use of this disinfectant for syringes was discontinued, it is possible that other quenching materials may have been present in the water samples.

The most plausible explanation for the preponderance of positive sensor responses and low correlating viable cell counts is the presence of dead cells or dead cell products in these samples which can catalyze the chemiluminescent reaction. It was known pretest that the reaction is catalyzed by dead as well as living cells. As indicated above, the viral studies at Medical College of Virginia also showed evidence of the presence of bacterial endotoxins in the last three samples of Apollo hot water via the expression of a cytopathogenic effect (CPE) on two of the three viral host cell culture systems employed. It is theorized that water sampled from heated (72°C) tanks and dispensers may have had sufficient prior storage at lower temperature in the condensate tanks to allow bacterial growth, and subsequent multifiltration was unable to completely remove the soluble and heat stabile bacterial endotoxins. Although it is also possible that high sensor readings may have been due to inorganic catalysts in the water (Reference 4-47), a negative potassium thiocyanate test for ferric ion was obtained on one specific "false positive" sample, and analyses of water passed out of the simulator routinely during the test indicated very low inorganic ion contamination.

It may be concluded from this experiment that more research is needed to determine the identity of interfering materials that cause false positive and negative responses in the chemiluminescent reaction. Methods for removing interfering materials and for concentrating cells before analysis should be developed along with automated rather than manual procedures for handling of sample and reaction mixtures.

4.6.4 Discussion

4.6.4.1 Crew Sampling

Possible changes in the microflora indigenous to the manned SSS were surveyed during the 90-day test. Since the microflora originated solely from the crewmen, original atmosphere, surfaces, and all life support systems, the SSS represented a microbiologically closed system during the 90-day test. Most of the sampling and assay methods emphasized the isolation of medically-significant bacteria and fungi. However, the recovery spectrum was widened by the use of: general as well as selective growth media, both aerobic and anaerobic incubation and outside laboratory tests for viruses and mycoplasmas. In addition to representing the longest study in the space program of men in a closed environmental loop, the data from this test are enhanced by these features: (1) the autoclave in pass-through; (2) lack of a quarantine period prior to crew ingress (so that cross-infections potentially began at test outset); (3) inclusion of "off the street" microbial types with no pretest clean room requirements; (4) rapid processing of samples for recovery of fastidious types; and (5) post-testing of selected hardware and subsystem components, for study of secondary contamination sources, deterioration effects and contamination control measures.

Crew sampling quantitation involved only gross estimates, since oronasal swabbing and most dermal sampling procedures are subject to wide variability. The growth rating system was useful, however, in determining relative proportions of types isolated per agar plate and in making rough comparisons between weekly samples. The most striking results were: (1) increase of N. meningitidis in crewman 3's throat, (2) elimination of beta-hemolytic streptococci from crewman 1's throat after antibiotic treatment, (3) unusually heavy anaerobic contamination of crewman 4's dermal sites, and (4) decrease in crewman 3's toe web counts during treatment of athlete's foot.

Due to constraints in time, manpower and expense, identification of all isolates was prohibitive. Consequently, recovery and identification schemes for nasopharyngeal and dermal samples represented a clinical microbiology approach. Laboratory results provided a continuous surveillance to the test Medical Director of pathogenic foci, e.g., (1) crewman 1's beta-hemolytic, streptococcal throat infection; (2) carriers—crewman 2 of S. aureus in the nose and throat and crewman 3 of N. meningitidis; and (3) crewman 3's athlete's foot infection.

Types recovered were representative of microflora indigenous to humans and environment. Unfortunately, neither phage typing nor antibiotic sensitivity could be used to trace transmission of S. aureus as planned. It was not only isolated from nasopharyngeal and dermal sites but also from the surfaces, atmosphere, and potable water supply. A marker system for S. epidermidis might have been even more productive since it was more widely distributed. That S. epidermidis was most frequently recovered from not only dermal sites, as expected, but also from the environment (surfaces, atmosphere, and wash water) clearly identifies the source of most SSS contaminants—the occupants. Dermal anaerobes were isolated throughout the test, with individual profiles indicated for each crew member; the number of obligate anaerobes remained rather constant.

4. 6. 4. 2 Environmental Sampling

During the 90-day test, surface samples yielded S. epidermidis and other aerobic microflora indigenous to human skin. Even though the method of quantitation was gross, the hygiene compartment was judged to be more heavily contaminated than the food management area. These results underscore the need for a scheduled cleanup of the living quarters with special attention paid to contamination control in the hygiene compartment.

Although more frequent sampling would have better defined the observed fluctuations in airborne contamination, no significant buildup was evident in the cabin atmosphere. Gram-positive and Gram-negative rod and fungal levels remained low throughout the test, and therefore the need for a clean room type of environment prior to crew ingress is not particularly corroborated by this test. These common environmental contaminants were probably transferred into the simulator pretest from the area outside the test facility. Given suitable environmental conditions, fungal proliferation within the simulator could be an important factor not only in crew health, but also in materials and subsystem deterioration.

Post-test surface and component sampling results amplified the finding during the test that the crew members were a major source of surface and atmospheric contaminants. The distribution of surface organisms post-test was quite uniform as was the dispersion of aerosols during the test as reported by the DOT/Transportation Systems Center (References 4-51 and 4-52). Uniform distribution of airborne particles was probably established as early as the third test week, a finding confirmed by atmosphere and surface sampling performed by the crew. The latter data indicate that over 90 percent of all microbial types to be isolated during the test had already been recovered by test day 18.

Although the hygiene compartment was more heavily contaminated than the food management area, the microbial types recovered at these 2 sample sites were essentially similar throughout the test and mirrored isolates from 35 widely distributed surfaces sampled post-test. Despite the lack of submicron filters in the thermal control unit, no buildup of viable particles in the cabin atmosphere was noted during the test. However, post-test sampling of thermal control ducts revealed that viable particles were retained by the grill work; the highest levels were found on the shelf and grill of the cabin air return to the thermal control unit. Other sites where airborne contaminants were probably scrubbed include the silica gel/molecular sieve beds, toxin control burner, carbon air filter, solid amine beds, and humidity control condenser. The extent of scrubbing that each subsystem might have effected on the overall airborne contamination level is not known.

Post-test sampling of various subsystem components showed that the types of microflora recovered were similar to those found on surfaces, in the atmosphere, and in water samples during the test. No particular pattern was observed for either level or type of contamination except that wash water multifilter elements were more heavily contaminated with more types of

microflora than comparable components in the potable water system. In addition, it was unusual to find such a scatter in recovery from various elements of the wash and potable water multifiltration units. It is possible that lack of a uniform distribution of types in these components may be attributed to sampling error; a larger sample size and/or samples taken from more than three or four sites would be preferable. As in previous tests conducted by this department, Pseudomonas sp. and Alcaligenes sp. were recovered as predominant bacterial contaminants of potable and wash water recovery systems. It is entirely possible that the body cleansing agent, Basic H (Shaklee Products, Haywood, Calif.), which lacked an antibacterial additive, was the prime source of these 2 contaminants. LRC post-test assays showed that Basic H contained up to $10^5/cm^3$ of these bacteria.

Disinfection of stored wet waste was not as satisfactory as expected. The same finding was observed for stored and in-use fecal bag contents. Although each type of waste was treated with a different disinfectant [Wescodyne (West Chemical Products, Inc., Long Island, N. Y.) for fecal material and 8-quinolinol for stored wet waste], the lack of sterility was not attributed to a lack of specificity for the organisms present, but was more probably due to incomplete or inadequate spraying. A similar reason is offered for the lack of contamination control in the hygiene compartment by too infrequent or inadequate use of Zephiran. These findings indicate an appreciation for not only the time versus concentration effects of anitmicrobial action but also the cost effectiveness of a single antimirobial agent that would be appropriate for overall contamination control.

4.6.5 Conclusions

No changes were seen in the SSS microecology of significance to crew health or safety. The results generally support the growing body of evidence that ground based closed tests do not markedly affect the microecological balance or host sensitivity to microorganisms. Future long-duration tests should include more reliable marker systems for following possible cross-transmission of common organisms. Improvements are required for rapid on-board water and atmosphere microbial load monitoring.

4.7 CONCLUSIONS AND RECOMMENDATIONS

Review of the results of the medical and microbial studies conducted during the 90-day test lead to the general conclusion that the test environment was medically benign. Additional general conclusions are as follows:

A. 90 days of confinement caused no perceptible physiologic alterations, but exercise programs must be improved to prevent losses in lean body mass.

B. Biochemical determinations show promise in identifying low-level stresses.

C. Radioisotope energy sources impose no serious problems in application to manned systems.

D. Radiological health criteria and monitoring instrumentation require more development to prevent unnecessarily expensive application of superfluous safety factors.

E. No psychophysiological responses to the low CO_2 experienced in this test were observed.

F. Low-level CO_2 exposure for over 45 days resulted in no perceptible biochemical alterations. Exposure to prolonged peaks of CO_2 superimposed on continous low-level CO_2, however, resulted in apparent calcium-phosphorus metabolism alterations.

G. Microbiological findings support the growing body of evidence that ground-based closed chamber tests do not markely affect the microorganisms or the hosts' sensitivity to them.

4.7.1 Medical Operations

Medical operations were smooth and no serious medical problems were encountered. The one significant medical treatment for a streptococcal infection exemplified the need to provide for acute problems which can be safely solved, allowing mission completion. Medical coverage was more than adequate during the test. Fulltime coverage was supplied by contract physicians, but operational requirements still dictated the presence of the Medical Director each day of the test. Crew selection procedures were adequate in view of the fact that no significant medical problems were encountered. Several small problems recurrent during the test suggest that pretest medical histories were insufficiently detailed.

4.7.1.1 Conclusions

The following conclusions are reached:

A. Operations were smooth, procedures were adequate and no medical problems of significance were encountered, except for the streptococcal infection in one crew member which was managed without compromising the test.

B. Provisions for onboard medical treatment were adequate for this test.

C. Pretest medical selection was adequate in ruling out potentially disabling problems but inadequate to rule out recurring minor problems.

4.7.1.2 Recommendations

The following recommendations are made:

A. Onboard medical supplies should be sufficient to allow safe, definitive treatment of acute problems without jeopardizing mission success. This requires a thorough analysis of most probable contingencies and provision for those which can be managed in the manner described.

B. Medical coverage should be provided primarily by full-time members of the staff conducting the test. Only in this way can operational and medical requirements be met cost effectively. The test-imposed patient-doctor relationship also dictates daily contact between crew members and responsible test medical personnel.

C. Pretest medical selection criteria should continue to emphasize potentially disabling conditions. For tests of this duration or longer, however, histories should be sufficiently detailed to rule out chronic or recurrent minor problems which through discomfort and increasing annoyance could equally compromise the test.

4.7.2 Basal Signs and Skin Fold Measurements

Daily, waking, vital signs were obtained on all crew members. The manual techniques employed for heart rate and blood pressure were marginally satisfactory and provided no data of significance. Oral temperatures were of value in following diurnal rhythm changes. Skin fold measurements, once familiarization with the technique was established, accurately reflected trends in body weight.

4.7.2.1 Conclusions

The following conclusions were drawn:

A. Daily pulse rate and blood pressure measurements appear to be unnecessary in long-duration tests. Daily body weight and oral temperature measurements contributed meaningful data.

B. The skin fold caliper appears to be useful in following nutritional status trends but training pretest must be more thorough.

4.7.2.1 Recommendations

The following recommendations are made:

A. Daily body weight and body temperature measurements should be retained in long-duration tests.

B. Skin fold measurement techniques should be studied further for use in evaluating nutritional status in long-duration missions.

4.7.3 Clinical Blood Chemistry and Hematology

These tests were accomplished every other week. No changes of clinical significance were observed, but certain sampling problems were encountered. The major problem involved sampling following too closely on exercise periods and out of context with altered circadian rhythms. As a consequence, false positive results in comparison to pretest baselines imposed unnecessary anxiety upon the monitoring staff. However, use of the subject as his own control allowed observations not otherwise possible if clinical limits of "normality" were the only guidelines. These observations were of particular interest in following trends in certain serum enzymes correlated with observed stressful operational periods. Use of outside crew members as laboratory controls was of value in interpreting some apparent biochemical changes.

4.7.3.1 Conclusions

The following conclusions were drawn:

A. Clinical blood studies revealed no significant medical problems. Sampling frequency was inadequate to establish significant trends in response to low-level stress or to detect acute problems except by chance.

B. Sampling in two crew members was not keyed to altered diurnal rhythms resulting in "false alarms" when test data were compared to pretest samples.

C. Use of pretest baseline data allowed each subject to be his own control except for the diurnal rhythm problem.

D. Outside laboratory controls are of value in interpreting data obtained on the test crew but only in detecting processing problems.

4.7.3.2 Recommendations

The following recommendations are made:

A. Clinical biochemistries should be selected to cover a wide variety of organ systems for developing pathology. Sampling frequency in tests such as this one should be increased using micro techniques. Onboard biochemical analysis capability for selected parameters should be considered for contingency use at least.

B. Sampling for blood chemistry and hematology should be scheduled in consonance with the individual's diurnal rhythm. All samples should be obtained in a fasting, basal state regardless of other scheduling problems.

C. The use of outside samples for processing control is highly recommended and should be expanded in future tests. If possible, these controls should include samples from an experimental control crew on the same regimen (including work hours, exercise and diet) as the test crew.

4.7.4 Routine Urinalysis and Urine Chemistry

Routine urinalyses revealed no clinically significant changes. Differences in urine solids production between the night crew and the day crew were observed. These differences are apparently related to body weight and suggest that urine chemistry should be expressed on a metabolic mass basis. We have not expressed urine data in this manner because of a lack of pretest baselines in urine chemistry and because of a lack of any other data on urine parameters so expressed. Review of sodium-potassium excretion ratios (Na^+/K^+) suggested that this simple measurement may be of value in following circadian cycle shifts and trends in psychophysiological stress. Other urine data pertinent to the CO_2 study are discussed in Section 4.7.9.1.

4.7.4.1 Conclusions

The following conclusions are drawn:

A. Routine urinalyses revealed nothing of clinical significance.

B. Gross differences in urine solids production between the night and day crews were observed and apparently were accounted for by body weight differences.

C. Na^+/K^+ excretion in urine appears to be useful in following circadian changes and stress reactions.

4.7.4.2 Recommendations

The following recommendations are made:

A. Although routine urinalyses did not reveal changes, this procedure remains of value in screening for pathology and should be continued in future tests.

B. Urinary excretion rates should be corrected for body or metabolic mass. Adequate pretest data should be obtained in future tests to establish baselines and individual control limits without recourse to laboratory or clinical "normal" values.

C. The Na^+/K^+ in urine should be evaluated further as a simply obtained biochemical correlate of postural or other stress.

4.7.5 Radiological Monitoring

Approximately 1/3 kw in heat from five capsules containing $^{238}PuO_2$ was used to power the VD-VF water recovery system. Radiation doses received by the test crew were well below acceptable levels and below pretest predictions (for a worst case). No radiation exposure problems were encountered and there were no evidence of leakage from the radioactive isotope capsules. There were no difficulties encountered in handling the hot capsules. Pretest analysis of crew timelines and capsule handling procedures allowed a more realistic protection program in this test which can still be improved upon through further analysis and certain equipment improvements.

4.7.5.1 Conclusions

The following conclusions are drawn:

A. Radioisotope energy sources can be considered completely acceptable for manned systems.

B. Current tendencies toward excessive protective measures may be unnecessarily impeding application of radioisotope energy sources. Protective measures may be optimized through proper design and procedures and a thorough analysis of crew activities to allow accurate exposure predictions.

C. Several improvements in devices and procedures were identified as a direct result of this test.

4.7.5.2 Recommendations

The following recommendations are made:

A. Prototype instrumentation must be designed, constructed, and tested to monitor for leakage of radioactivity onboard manned space vehicles.

B. Some features that should be incorporated in the design of the air monitor and survey meter are:

1. A capability for electronic discrimination between an alarm caused by instrument malfunction and one resulting from radioactivity.

2. Warning indicators of radioactivity level, radioactivity release rate (air monitor), and instrument failure.

3. Built-in radioactive calibration sources, electronic calibration and elective indications of critical voltages.

4. Interchangeable rate meters, detector assemblies and some electronic components.

C. Prototype instruments and prototype systems using radioisotopes should be evaluated in simulators before use in vehicles. This allows development of procedures and analysis of crew activity schedules both leading to optimization on protective measures and minimization of expensive safety factors necessary without these evaluations.

D. Safety design criteria for integrating radioisotope energy sources into life support systems must be developed. Analyses suggested in the paragraph above will contribute to these criteria.

E. Heat control mechanisms should be developed to minimize heat source handling.

4.7.6 Electrocardiography (ECG)

Weekly two-lead ECG tracings were obtained from each crew member. No clinically significant changes occurred and no trends in ECG parameters were observed. An apparent rhythm change was observed in one crew member but further investigation revealed it to be a normal variant present before the test but missed on the pretest clinical ECG.

4.7.6.1 Conclusions

No significant electrocardiographic changes were observed.

4.7.6.2 Recommendations

In future tests crew members should be subjected pretest to long (3 to 5 minute) ECG tracings obtained with the test equipment. These tracings should reveal the presence of random events and provide baselines for the test. Long tracings obtained standing and tracings during respiratory maneuvers (breath-holding, hyperventilation, and valsalva) would be helpful also.

4.7.7 Pulmonary Spirometry

A forced vital capacity volume-flow ($\dot{V}$-V) loop was obtained on each crew member each week. No significant changes were observed during the test except for enhanced respiratory flow at reduced barometric pressure. This enhancement was expected from pretest observations during an altitude checkout of the SSS.

4.7.7.1 Conclusions

The following conclusions are drawn:

A. No changes were observed in pulmonary volumes during the 90 days of confinement.

B. The $\dot{V}$-V technique is simple, fast and of significant value in assessment of pulmonary function, especially in situations where pulmonary irritants are potential problems and baseline recordings are available.

4.7.7.2 Recommendations

A capability for assessing pulmonary function and volumes should be available throughout any test in which pulmonary irritants in the atmosphere are a potential problem. The spirometric technique used in this test shows promise in fulfilling this requirement in every way and should be considered for application in extended space missions.

4.7.8 Contingency Samples

Residual serum and urine samples from scheduled sampling periods were held frozen for contingency use. On occasion, portions of these samples were used to perform unscheduled procedures, chief among these was determination of ASO titers in the crew at the time of the streptococcal incident. These samples are still being held. It is expected that the urine will be used to follow up Na^+/K^+ patterns with 17 ketogenic steroid determinations and with hydroxyproline analyses in support of the CO_2 study. Serum will probably be used for immuno-assays to evaluate crew immunological status over the course of the test.

4.7.8.1 Conclusions

Contingency samples appropriately stored were of value in obtaining unscheduled analyses during the test. These samples are also of value in follow-up studies in cases of unpredicted observations.

4.7.8.2 Recommendations

Contingency sample storage is a recommended procedure for future tests.

4.7.9 Special Studies

The special studies supplementing the basic medical program included evaluation of biochemical responses to CO_2 exposure, a crew experiment on sleep respiratory and heart rate responses to various CO_2 levels, special analysis of biochemical correlates of stress and carboxyhemoglobin by the NMRI, an evaluation of an automated visual sensitivity tester (NASA-Ames), radioisotope studies of plasma volume, total body water and total body potassium and an evaluation of physical conditioning during confinement. These studies were completed with total crew cooperation but were limited by the pass-out schedule.

4.7.9.1 Carbon Dioxide Studies

The carbon dioxide exposure history reveals a slowly rising mean Pco_2 during the test with significant prolonged peaks during the last 45 days as compared to the first 45 days. Blood samples analysed at the USNSMC, Groton, Connecticut, reveal no apparent changes in venous plasma or red blood cell pH, bicarbonate or electrolytes not seen also in outside controls. Analyses of these data have not been completed by USNSMC personnel, however, and these are our preliminary judgments. Serum samples analyzed by the MDAC contract laboratory reveal depression of serum calcium (Ca^{++}) during the last half of the test with concomitant increases in serum phosphorus (P). These changes probably reflect CO_2 storage in response to peaks of CO_2 exposure superimposed on a chronic low-level exposure. Twenty-four hour urine samples did not reveal changes reflecting any alteration in acid-base balance. No psychomotor or physiological changes were seen at any level of CO_2 exposure. Sleep respiratory rates and heart rates (crew experiment) were unaffected by levels of Pco_2 of 4.15 to 9.2 mm Hg.

Conclusions

The following conclusions are drawn:

A. At levels of P_{CO_2} ranging from 2.8 mm Hg (374 N/m^2) to 11.2 mm Hg (1495 N/m^2), there were no apparent alterations in acid-base balance as reflected in venous plasma and erythrocytes or in urine. Red blood cell chemistry was apparently unaltered.

B. No changes in Ca^{++}-P metabolism were evident at generally low levels of CO_2 but recurrent prolonged peaks superimposed on continuing low CO_2 were associated with significantly depressed serum Ca^{++} and elevated serum P.

C. No psychomotor or physiologic parameters were effected at any level of CO_2.

D. Current Skylab CO_2 limits (<5.5 mm Hg) appear to be realistic and should not cause detectable biochemical changes if intermittent higher level exposures are prevented.

Recommendations

The following recommendations are made:

A. Long-duration exposures to rigidly controlled low CO_2 are required to explicate the Ca^{++}-P effects seen in this test.

B. Interactions of low-level CO_2 effects on Ca^{++}-P with zero g must be evaluated in detail. The instability in Ca^{++}-P caused by both of these stresses, though apparently acting in opposite directions, may create special problems in Ca^{++} control even at very low levels of CO_2, e.g., less than 3.5 mm Hg (465 N/m^2).

C. It would appear on the basis of this test that flight crew members subjected to chronic low level CO_2 should not be additionally subjected to intermittent high levels. The exact control limits cannot be defined for complete biochemical control, i.e., in preventing any adaptive change in response to CO_2 as measurable by current techniques.

4.7.9.2 NMRI Serum Analyses

Blood samples were sent to personnel at the NMRI for analysis of potential biochemical correlates of stress. In general, the data indicated no marked alteration that could be interpreted as a response to a hazardous condition. Sporadic alterations were seen which have been correlated with psychological data.

Conclusions

A. The NMRI analyses corroborated the clinical impression that the SSS environment was essentially benign.

B. Certain biochemical analyses show promise as correlates of psychological stress.

Recommendations

Analyses should continue correlating biochemical alterations with low-level stresses. These analyses should include selection of the most reliable correlates and evaluation of the correlates in predicting critical stress levels.

4.7.9.3 NMRI Carboxyhemoglobin (COHb) Analyses

Blood COHb determinations at the NMRI demonstrated that the level of CO in the blood can be used to estimate the concentration of CO in the atmosphere of a closed environment. The reverse calculation can be made but more sophistication in the CO gas analysis technique is required for accurate measurement of the low levels experienced in this test. The CO atmospheric buildup rate during toxin burner shutdown suggests that the only significant source of CO in the SSS was normal endogenous production in the crew.

Conclusions

A. Blood COHb can be used to estimate atmospheric CO levels.

B. The SSS crew was the primary source of CO during this test.

Recommendations

Current gas analysis techniques require improvement for long-term reliable evaluation of atmospheric CO. CO is the most hazardous potential contaminant in the Skylab program and since no toxin burner is currently planned for that program, reliable sensors would seem most important.

4.7.9.4 Automated Visual Sensitivity Tester (AVST)

This equipment was planned primarily for experimental evaluation since no changes in visual sensitivity as measured by the AVST were expected. Good pretest data were obtained, but early equipment malfunctions on board allowed only a few evaluations during the test. The last data available were obtained on test day 19. Crewman 4 and Ames personnel attempted repairs but were unsuccessful.

Conclusions

No significant changes were found in the pretest data, the test data or post-test visual examinations.

Crew training and procedures were adequate for this experiment.

Recommendations

Continued development with expansion of capabilities into peripheral field and low-light level evaluations would significantly enhance the value of the AVSS in long duration manned tests.

4.7.9.5 Isotope Studies

Plasma volume was measured with RISA pre- and post-test. Total body water by tritium oxide dilution was determined pre-, mid-, and post-test. Whole body potassium 40 was determined pre- and post-test. The total body water determination pretest was compromised technically and the results are suspected. Plasma volumes and derived blood volumes increased in the crew members who also improved their physical (cardiovascular) fitness. Two crew members who performed the least additional whole-body exercise also lost lean body mass as measured by potassium 40 determinations. Current techniques in measuring body fluid compartments are complex and almost totally unrealistic for in-flight use.

Conclusions

The following conclusions are drawn:

A. Ergometer exercise alone does not appear to be sufficient in maintaining lean body mass.

B. Plasma volume increases were seen in crew members who improved cardiovascular fitness.

C. The procedures used in this test are difficult to control even in the hands of experts. They are not suitable for in-flight determinations.

Recommendations

Body water compartments and trends in those compartments must be measured accurately to follow the responses to hypodynamic environments. Improved (simplified, atraumatic, safe, and reliable) techniques must be developed. In view of the known effects in short-term zero g on body water. these measurements would appear to be extremely important for longer duration missions.

4.7.9.6 Physical Conditioning Program

Crew members exercised (normally) 5 days a week at a preset load on the pedal mode bicycle ergometer. Ad lib, additional, exercise was permitted and ergometer work loads were adjusted upwards for crew members who were improving in heart rate response and desired the extra exercise. One crew member who exercised at a submaximal load on the ergometer and performed no additional exercise was less fit post-test than pretest. The other crewmen either remained at the same level or improved.

Conclusions

The following conclusions are drawn:

A. Exercise on the bicycle ergometer once a day is adequate to maintain a given level of cardiovascular fitness if the exercise is in the "hard" to "strenuous" range.

B. Additional exercise appears to be required to maintain overall muscle tone and prevent a reduction in lean body mass (see Section 4. 7. 9. 5).

Recommendations

Exercise programs in prolonged confinement require more study. Consideration should carefully be given to whole body exercisers. Exercise regimes should be programmed to increase gradually the work load level, maintaining it in the hard to strenuous range.

4. 7. 10 Microbiology Program

The main objectives of the microbiology study were to assess changes in crew and environmental microflora which were potentially detrimental to crew health and/or function of life support systems and to monitor effectiveness of the water reclamation and atmosphere regeneration systems. Significant features were the microbiologically closed conditions, effected by the autoclave in the passout air lock and the record length of the simulation study.

Samples collected by crew members, using consistent and aseptic techniques, were passed out at weekly intervals. The MDAC laboratory was responsible for collection of specimens, primary isolation, gross quantitation and limited identification. Both general and selective culture media were used for recovery of major pathogenic aerobic bacteria, fungi and anaerobes (from dermal sites and post-test surfaces and subsystem components). Fungal-type isolates were stored for future identification in the MDAC laboratory. Bacterial cultures requiring extensive taxonomic work were submitted to the LRC. Special tests were performed at the Medical College of Virginia (phage typing of coagulase-positive staphylococci and virus isolation from potable water) and MSC – Lunar Receiving Laboratory (mycoplasma and virus studies on feces, urine and pharyngeal washings).

The nasopharynegeal and dermal (axilla, perineum, and toe web) microflora were sampled with swabs before (-4th day), during (weekly), and after (+18th day) the test. The recovery of Staphylococcus aureus, beta-hemolytic staphylococcus, Neisseria meningitidis, Diplococcus pneumoniae, and Hemophilus influenzae from the nose and throat was emphasized. No unusual quantitative and qualitative shifts were observed except for the increase in crewman 3's throat growth scores to a maximum on day 18 and remaining at that level through test days 88 and + 18. Procedures for isolation of H. influenzae were discontinued after 53 days of nonrecovery. Beta-hemolytic streptococci in the throat of crewman 1 were eliminated after administration of erythromycin during the 10th to 11th week of the test. Marker systems (phage typing and antibiotic sensitivity) for coagulase-positive staphylococci were not obtainable, precluding transmission studies.

Dermal samples showed individual profiles of indigenous microflora throughout the test. Staphylococcus epidermidis was the predominant aerobe and facultative anaerobe. Other major types were S. aureus, species of Micrococcus, Aerococcus, Sarcina, Corynebacterium, Bacillus, and various Gram-negative bacteria. Obligate anaerobes were primarily diphtheroids. No gross changes in levels of dermal anaerobes were observed, except a significant decrease in crewman 3's toe web samples during the test mid-portion, reflecting treatment of his "athlete's foot" with Zephiran and Tinactin.

Swab samples of surfaces in the hygiene area were usually more contaminated than in the food management area, probably due to more regular housekeeping practices in the latter. Significant buildups of contamination were found on test days 11, 18, 32, 46, 74, and 81. Gram-negative types were restricted to the hygiene area except on day 32, when the food management area was the most heavily contaminated. Most isolates were S. epidermidis; others were S. aureus and species of Bacillus, Sarcina, Micrococcus, Aerobacter, Alcaligenes, and Pseudomonas. No remarkable bacterial and fungal buildups were observed for surfaces and hardware subsystem components sampled post-test.

During the test, atmosphere samples were taken every two weeks, using onboard Reyniers samplers in the forward (equipment) and aft (crew) compartments. Total counts (bacterial and fungal) remained at low levels throughout the test (ranging from 0.02 to 3.0 airborne viable particles/ $0.03 m^3$). During catalytic toxin burner shutdown (10th to 12th week), sampling was not continuous enough to detect higher levels, if they occurred, or to verify an increase in the number of types isolated during this period. Most frequently isolated was S. epidermidis. Atmospheric microflora also included S. aureus, and species of Micrococcus, Aerococcus, Sarcina, Bacillus, Corynebacterium, Neisseria, Alcaligenes, Enterobacter Group B, and Proteus.

Potable and wash water supplies were continuously monitored onboard by the crew members, using Millipore Field Monitor techniques and an LRC-furnished bacterial sensor. Contamination levels in the drinking water consumed by the crew members met National Academy of Sciences requirements. Contaminated monitors and samples of potable water were passed out weekly. Viral detection studies on the latter were negative. Bacterial contaminants in the potable water system included Alcaligenes sp. (predominant), Pseudomonas sp. (sporadic), and S. aureus (during the last 3 test weeks). Wash water isolates were species of Alcaligenes, Pseudomonas, and Bacillus and, on occasion, the ubiquitous S. epidermidis.

4.7.10.1 Conclusions

The following conclusions are drawn:

A. No changes were seen in the SSS microecology of significance to crew health or to life support subsystems.

B. Observations from this test suggest that long-duration one-g isolation does not markedly affect microecological balance or host sensitivity to microorganisms.

C. Potable water that was consumed met National Academy of Science recommendations for microbial contamination limits.

D. Potable water monitoring techniques employed in this test were adequate but slow.

E. More positive microbial control methods compatible with water management subsystems are required for entire potable water production and distribution systems.

F. There was no evidence of significant crew interchanges of microorganisms. Marker systems were not available for confirming a possible transfer of Staphylococcus aureus.

G. Surfaces and subsystem components sampled post-test showed no significant buildups in bacterial and fungal populations.

H. The crew was the main source of air, surface, and water bacterial contamination. Preliminary results suggest that the source of fungal populations of the SSS was not the crew.

4.7.10.2 Recommendations

The following recommendations are made:

A. Additional marker systems are required to accurately follow interchanges of common organisms.

B. Microbial control systems should be developed for entire water management systems, including subsystems for distribution and sampling.

C. Improved (more rapid, more qualitative) methods for onboard monitoring of microbial loads in air and water are required for future long duration tests.

D. Preliminary results of fungal screening suggest that final preparations for future simulator tests should be performed under clean room conditions.

E. Improvement of physical/chemical techniques for treatment of stored waste is necessary for greater contamination control.

REFERENCES

1-1. J. K. Jackson, M. S. Bonura, and D. F. Putnam. Evaluation of a Closed Cycle Life Support System During a 60-Day Manned Test. SAE Paper 680741, SAE Journal, 1969, pages 2832-2850.

1-2. M. S. Bonura, et. al. 60-Day Manned Test of a Regenerative Life Support System with Oxygen and Water Recovery, Part I, Engineering Test Results. McDonnell Douglas Astronautics Company, NASA Report CR-98500, December 1968.

1-3. E. H. Taliaferro, et. al. 60-Day Manned Test of a Regenerative Life Support System with Oxygen and Water Recovery, Part II, Aerospace Medicine and Man-Machine Test Results. McDonnell Douglas Astronautics Company, NASA Report CR-98501, December 1968.

1-4. J. N. Pecoraro, A. O. Pearson, G. L. Orake, and J. R. Burnett. Contribution of a Developmental Integrated Life Support System to Aerospace Technology. AIAA Paper No. 67-924, presented to AIAA Fourth Annual Meeting at Aneheim, California, October 23-27, 1967.

1-5. Statement of Work, Operational 90-Day Manned Test of a Regenerative Life Support System. NASA Langley Research Center Document L12-9636-A, February 28, 1969.

1-6. L. J. Baranek. Noise Reduction. McGraw-Hill, New York, New York, 1960.

1-7. E. A. Mechtly. The International System of Units. NASA Document SP-7012, 1964.

2-1. Preliminary Results from an Operational 90-Day Manned Test of a Regenerative Life Support System. NASA SP-261, November 1970.

2-2. L. G. Barr. Test Report—Five Day Manned Test. McDonnell Astronautics Company (MDAC) MDC-G0396, May 1970.

2-3. Water Quality Standards for Long Duration Manned Space Missions, Report of the ad hoc Committee of the National Academy of Sciences, National Research Council, Space Sciences Board. September 1967.

2-4. Standard Methods for the Examination of Water and Waste Water. American Public Health Association, 11th Edition, 1960, New York.

2-5. R. E. Shook and E. C. Thomas. Urine Output Parameters for Space Cabin Environments. MDAC Paper 10069, April 1969.

2-6. D. F. Putnam. Composition and Concentrative Properties of Human Urine. MDAC Report DAC-61125-F1, June 1970.

2-7. Perry. Chemical Engineers Handbook. 4th Edition, pages 4-12.

2-8. Space Station Simulator Facilities Operation Manual. MDAC Drawing 1T33499, March 1970.

2-9. Operation and Maintenance Manual for Water Electrolysis System. Allis-Chalmers Advanced Electrochemical Products Division, Greendale, Wisconsin 53129, June 1970.

2-10. Instruction Manual for Electrolytic Oxygen Generator. Lockheed Missiles and Space Company, Sunnyvale, California, May 1970.

2-11. J. K. Jackson. Development of Automatic Controls for a Two-Gas Atmosphere Supply System. Presented to the 26th Annual Scientific Meeting of the Aerospace Medical Association, New York City, New York, April 1965.

2-12. Instruction Manual, Models 500/550/510 Microwave Oven. Litton Industries, Atherton Division, page 25.

2-13. Control of Hazards to Health from Microwave Radiation. Department of the Army Technical Bulletin, TBMED 270/Dept. of the Air Force Manual AFM 161-7, December 1965.

2-14. H. J. Suroviec. Microwave Oven Radiation Hazards in Food-Vending Establishments. Arch. Environmental Health, Volume 14, March 1967, pages 469-472.

2-15. L. B. Arnoldi (BG/Medical Director, Division of Occupational Medicine). Microwave Oven Hazards. Inter-facility Memorandum, NASA Headquarters, Washington, D. C., June 24, 1968.

2-16. R. V. Decareau. Microwave Ovens Are Innocent Until Proven Guilty. Microwave Energy Applications Newsletter, Volume 11, No. 3, May-June 1969, page 2.

2-17. M. Rosenstein, W. A. Brill, and C. K. Showalter. Radiation Exposure Overview—Microwave Ovens and the Public. OCS 69-1, July 1969. U. S. Department of Health, Education and Welfare; Department of Radiological Health, Rockville, Maryland.

2-18. Symposium on the Biological Effects and Health Implications of Microwave Radiation. Richmond, Virginia. September 17-19, 1969.

2-19. R. H. Finch, Secretary, H. E. W. H. E. W. Surveys of R. F. Emissions. HEW News Release, January 5, 1970. U. S. Department of Health, Education and Welfare.

2-20. R. I. Bruder (Vice President, Litton Industries). Statement Before a Special Meeting on Microwave Ovens Called by the Secretary of HEW, Washington, D. C., January 12, 1970.

2-21. U. S. Industry Officials Plan Nationwide Survey of Microwave Ovens. The Wall Street Journal. January 13, 1970.

2-22. Radio Frequency Leakage. Technical Bulletin TB68-0027. Litton Industries, Atherton Division, Minneapolis, Minnesota, January 16, 1970.

2-23. L. J. Hardeman. Microwave Oven Leakage: Federal Regulations Soon. Microwaves, February 1970, page 17.

2-24. A. Auerbach. Radiation Check of Microwave Ovens Set. Los Angeles Times, Los Angeles, California. May 13, 1970.

2-25. Proposed Rule-Making. Microwave Ovens. Federal Register, Volume 35, No. 100. Friday, May 22, 1970.

2-26. R. E. King. Operational Readiness Inspection Committee Report for the Operational 90-Day Manned Test of a Regenerative Life Support System. MDAC Report MDC G1037, July 1970.

2-27. Bureau of Radiological Health Bulletin. Microwave Cooking Oven Standards Issued. Volume IV, No. 21, Monday, October 12, 1970.

3-1. E. K. E. Gunderson. Personal and Social Characteristics of Antarctic Volunteers. Journal of Social Psychology, 1964, Vol. 64, pages 325-332.

3-2. E. K. E. Gunderson and P. D. Nelson. Biographical Predictors of Performance in an Extreme Environment. Journal of Psychology, 1965, Vol. 61, pages 59-67.

3-3. E. K. E. Gunderson, and J. L. Mahan. Cultural and psychological Differences Among Occupational Groups. Journal of Psychology, 1966, Vol. 62, pages 287-304.

3-4. R. E. Doll, and E. K. E. Gunderson. Hobby Interest and Leisure Activity Behavior among Station Members in Antarctica. Unit Report No. 69-34, Navy Medical Neuropsychiatric Research Unit, San Diego, California, September 1969.

3-5. Project RIM: Design and Implementation, MF12.524.003-1005D. Report 2, NMRI, Bethesda, Maryland, 1970.

3-6. R. H. Rahe, J. Mahan, R. J. Arthur, and E. K. E. Gunderson. Epidemiology of Illness in Naval Environments. I. Illness types, distribution, severities, and relationship to life change. Military Medicine, 1970, Vol. 135, pages 443-452.

3-7. R. H. Rahe, J. Mahan, and R. J. Arthur. Prediction of Near-Future Health Change from Subjects' Preceding Life Changes. Journal of Psychosomatic Research, 1970, Vol. 14, pages 401-406.

3-8. G. E. Seymour, and E. K. E. Gunderson. Attitudes as Predictors of Adjustment in Extremely Isolated Groups. Journal of Clinical Psychology, in press (Accepted for the July 1971 issue).

3-9. Buros (ed). Personality Tests and Reviews. Gryphon Press, New York 1970. (Including an index to Mental Measurements Yearbook.)

3-10. Standard for Human Factors Engineering Design Criteria. MSFC-STD-267A.

3-11. J. A. Zelik, et al. Post-Test Background Noise Measurements in a Ninety-Day Run Space Station Simulator. MDAC Report MDC G0767, January 1971.

3-12. S. Smith. Studies of Small Groups in Confinement, in Sensory Deprivation. Fifteen Years of Research, J. P. Zubek (Ed), Appleton-Centry-Crafts, New York, 1969.

3-13. J. S. Seeman, and E. H. Taliaferro. Medical and Behavioral Aspects of Long-Term Manned Space Cabin Test. McDonnell Douglas Paper 10006, May 1969.

3-14. Project RIM: Observational Data Collection, MF12.524.003-1005D. Report 3, NMRI, Bethesda, Maryland, 1970.

3-15. Technical Report, Space Station Mission Simulation Mathematical Model. General Dynamics, Fort Worth, Texas. NASA CR-66316, 27 March 1967.

3-16. Broadening the Application of a Space Station Mission Simulation Mathematical Model. General Dynamics, Fort Worth, Texas. FZM 6013 NASA CR-66680, 31 May 1968

3-17. Broadening the Application of a Space Station Mission Simulation Mathematical Model (Addendum). General Dynamics, Fort Worth, Texas. MR-0-233, 1 November 1968.

3-18. 60-Day Manned Test of a Regenerative Life Support System with Oxygen and Water Recovery; Part II: Aerospace Medicine and Man-Machine Results. NASA CR-98501, December 1968.

3-19. J. R. Cox, and R. C. Bilger. Suggestion Relative to the Standardization of Loudness-Balance Data for the TDH-39 Earphone. Journal of the Acoustical Society of America, 32:1081-1960.

3-20. I. J. Hirsh. The Measurement of Hearing. New York, 1952, McGraw-Hill, page 105.

3-21. J. E. Kruel, J. C. Nixon, K. D. Kryter, D. W. Bell, J. S. Lang, and E. D. Schubert. A Proposed Clinical Test of Speech Discrimination. Journal of Speech and Hearing Research, Vol. II, pages 536-552, 1968.

3-22. A. Rechtschaffer, et al. A Manual of Standardized Terminology, Technique and Scoring System for Sleep Stages of Human Subjects. Public Health Service, U. S. Government Printing Office, Washington, D. C. 1968, National Institute of Health Publication No. 204.

3-23. J. W. Cooley, and J. W. Tukey. An Algorithm for the Machine Calculation of Complex Fourier Series. Mathematics of Computation, Vol. 19, No. 90, pages 297-301, April 1965.

3-24. S. S. Viglione. Applications of Pattern Recognition Technology. Chapter IV, Adaptive and Learning Systems. Fu and Mendel (eds), Academic Press, New York, 1970.

3-25. As cited by Dalton, N. N. and Kern, J. C. in Glycerol, Edited by Miner, C. S. and Dalton, N. N., American Chemical Society Monograph Series, Reinhold Publishing Company, New York, 1953.

3-26. Cremer, M. Munch. med. Woch., 49, 944 (1902).

3-27. Catron, L. F. and Lewis, H. B., J. Biol. Chem., 84, 553 (1929).

3-28. Johnson, V., Carlson, A. J. and Johnson, A., Amer. J. Physiol, 103, 517 (1933).

3-29. Young, D. R., Pelligra, R., Shapira, J., Adachi, R. R. and Skrettingland, K., J. Applied Physiology 23, 734 (1967).

3-30. S. Smith. Studies of Small Groups in Confinement. In Sensory Deprivation: Fifteen Years of Research. New York, Appleton-Century-Crofts, 1969.

3-31. F. J. Roethlisberger, and W. J. Dickson. Management and the Worker. Harvard University Press, Cambridge, Massachusetts, 1939.

3-32. Kurt Lewin. A Dynamic Theory of Personality. McGraw-Hill Book Company, New York, 1935.

3-33. G. Lindzey, and E. Aronson. Handbook of Social Psychology. Volumes 1–5. Addison-Wesley, Reading, Massachusetts, 1968 (Second Edition).

3-34. R. M. Chambers. Problems and Research in Space Psychology. NADC-MA6145, Aviation Medical Acceleration Lab., U. S. Naval Air Development Center, Johnsville, Pennsylvania, April 1962.

3-35. W. W. Haythorne, I. Altman, and T. I. Myers. Emotional Symptomatology and Subjective Stress in Isolated Pairs of Men. J. Exp. res. in Pers., 1966, Vol.1, pages 290-305.

3-36. R. F. Bales. Interaction Process Analysis. Addison-Wesley, Reading, Massachusetts, 1950.

3-37. H. R. Jex, J. D. McDonnell, and A. V. Phatak. A Critical Tracking Task for Manual Control Research. IEEE Trans., Vol.HFE-7, No. 4, December 1966, pages 138-145.

3-38. H. R. Jex, J. D. McDonnell, and A. V. Phatak. A Critical Tracking Task for Man-Machine Research Related to the Operator's Effective Delay Time; Part 1. Theory and Experiments with a First-Order Divergent Controlled Element. NASA CR-616, November 1966.

3-39. J. D. McDonnell, and H. R. Jex. A Critical Tracking Task for Man-Machine Research Related to the Operator's Effective Delay Time; Part II. Experimental Effects of System Input Spectra, Control Stick Stiffness, and Controlled Element Order. NASA CR-674, January 1967.

3-40. H. R. Jex, and R. W. Allen. Research on a New Human Dynamic Response Test Battery; Part I. Test Development and Validation; Part II. Psychophysiological Correlates, Proceedings of the 6th Annual Conference on Manual Control, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, 7-9 April 1970, pages 743-777.

3-41. H. R. Jex, and R. W. Allen. A Psychomotor Task Battery for Manual Control Performance: Development, Validation, and Some Psychophysiological Correlates. Systems Technology, Inc., Technical Report 175-1, January 1970.

3-42. D. T. McRuer, L. G. Hofmann, and H. R. Jex, et al. New Approaches to Human-Pilot/Vehicle Dynamic Analysis. AFFDL-TR-67-150, February 1968.

4-1. A. A. Kelton. Radiation Safety Manual for Utilization of $^{238}PuO_2$ Capsules in a Manned Test of a Space Station Simulation. McDonnell Douglas Report No. G-0190, March 1970.

4-2. Clinical Spirometry. Instructions for the use of the Collins respirometer and for calculations and interpretation of data in pulmonary function and basal metabolism testing. Published by Warren E. Collins, Inc., Boston, Massachusetts.

4-3. C. F. Consolazio, R. E. Johnson, and L. J. Pecora. Physiological Measurements of Metabolic Functions in Man. McGraw-Hill Book Company, New York, 1963.

4-4. D. W. Dery, L. Wiener, and E. Hendler. The Presentation of Flow-Volume Loops. Presented at the 38th Annual Scientific Meeting of the Aerospace Medical Association, Washington, D. C., April 1967.

4-5. K. E. Schaefer. Environmental Physiology of Submarines and Spacecraft. Arch. Envir. Health, Vol. 9, pages 320-331, 1964.

4-6. K. E. Schaefer, G. Nichols, Jr., and C. R. Carey. Acid-Base Balance and Blood and Urine Electrolytes of Man During Acclimatization to CO_2. J. Appl. Physiol., Vol. 19, pages 48-58, 1964.

4-7. H. A. Glatte, Jr., G. J. Motsay, and B. E. Welch. Carbon Dioxide Tolerance Studies. USAF School of Aerospace Medicine, SAM TR-67-77, September 1967.

4-8. B. D. Polis, E. Polis, J. DeCani, H. P. Schwarz, and L. Dreisbach. Effect of Physical and Psychic Stress on Phosphatidyl Glycerol and Related Phospholipids. Biochem. Med., Vol. 2 (4), pages 286-312, 1969.

4-9. G. M. Adams, and T. L. Sallee. An Improved One-Dimensional Thin-Layer Chromatographic Separation of Serum Phospholipids. J. Chromatog. Vol. 49, pages 552-554, 1970.

4-10. T. L. Sallee, and G. M. Adams. An Improved One-Dimensional Thin-Layer Chromatographic Separation of Neutral Lipid Classes. J. Chromatog., Vol. 51, pages 544-547, 1970.

4-11. R. P. Noble. Electrophoretic Separation of Plasma Lipoproteins in Agarose Gel. J. Lipid Res., Vol. 9, pages 693-700, 1968.

4-12. A. L. Babson, and G. E. Phillips. A Rapid Colorimetric Assay for Serum Lactic Dehydrogenase. Clin. Chim. Acta., Vol. 12, pages 210-215, 1965.

4-13. H. J. Hohorst. Methods of Enzymatic Analysis. pages 266-270, H. Bergmeyer (Ed.), Academic Press, 1965.

4-14. M. Novak. Colorimetric Ultramicro Method for Determination of FFA. J. Lipid Res., Vol. 6, pages 431-433, 1965.

4-15. R. F. Haines, J. W. Fitzgerald, and S. A. Rositano. Development of An Automated Visual Sensitivity Tester. NASA-TN (in press), August 1970.

4-16. M. F. Armaly. Ocular Pressure and Visual Fields: A ten-year follow-up study. Arch. Opthal., Vol. 81, pages 25-40, 1969.

4-17. C. C. Beehler, N. L. Newton, J. F. Culver, and T. Tredici. Ocular Hyperoxia. Aerospace Med., Vol. 24, pages 1017-1020, 1963.

4-18. E. M. Roth. Selection of Space Cabin Atmospheres. Space Sciences Reviews, Vol. 6, pages 452-492, 1967.

4-19. H. A. Saltzman, L. Hart, H. O. Sieker, and E. Duffy. Retinal Vascular Response to Hyperbaric Oxygenation. J. Amer. Med. Assoc., Vol. 191, pages 290-292, 1965.

4-20. S. A. Brandis. The Influence of Bromine and Caffein on the Light Sensitivity of the Eye and Heat Regulation in High Environmental Temperature. Fiziologicheskii Zhurnal, SSSR, Vol. 46, pages 489-494, 1960 (in Russian)

4-21. A. T. Kissen. Effects of Hyperthermia on Peripheral Dark Adaptation Rates. J. Appl. Physiol., Vol. 18, pages 600-602, 1963.

4-22. D. McK. Kerslake. The Effects of Thermal stress on the Human Body, A Textbook of Aviation Physiology, pages 409-440, Gillies, J. A. (Ed.). Permagon Press, New York, 1965.

4-23. J. Bellows, and D. Nelson. Cataract Produced by Anoxia. Arch. Opthal., Vol. 31, pages 250-252, 1944.

4-24. C. Berger, R. A. McFarland, M. H. Halperin, and J. I. Niven. The Effect of Anoxia on Visual Resolving Power. Amer. J. Psych., Vol. 56, pages 395-407, 1943.

4-25. T. D. Duane. Observations on the Fundus Oculi During Blackout. Arch. Opthal., Vol. 51, pages 343-355, 1954.

4-26. R. A. McFarland, and J. N. Evans. Alterations in Dark Adaptation Under Reduced Oxygen Tensions. Amer. J. Physiol., Vol. 127, pages 37-50, 1939.

4-27. R. A. McFarland and M. H. Halperin. The Relations Between Foveal Visual Acuity and Illumination Under Reduced Oxygen Tension. J. Gen. Physiol., Vol. 23, pages 631-630, 1939-40.

4-28. W. R. Pierson. Night Vision and Mild Hypoxia. Aerospace Med., Vol. 38, pages 993-994, 1967.

4-29. R. W. Sullivan, and H. C. Vykukal, K. H. Hyatt, R. F. Haines, and W. R. Vetter. Effects of Orbital Deconditioning on Crew/Passenger Tolerance to Orbiter Reentry Acceleration. Presented at Space Shuttle Technology Conference, NASA—Lewis Research Center, Cleveland, Ohio, July 17, 1970.

4-30. P.-O. Åstrand, and I. Rhyming. A Nomogram for Calculation of Aerobic Capacity (Physical Fitness) from Pulse Rate During Submaximal Work. J. Appl. Physiol., Vol. 7(2), pages 218-221, 1954.

4-31. B. Balke. Correlation of Static and Physical Endurance. I. A Test of Physical Performance Based on Cardiovascular and Respiratory Responses to Gradually Increased Work. USAF School of Aviation Medicine, Project No. 21-32-004, Report No. 1, Randolph AFB, Texas, April 1952.

4-32. E. M. Neptune, Jr., R. E. Danziger, T. L. Sallee, and D. E. Uddin. Some Biochemical Determinations on Serum from Crewmen Participating in a 90-Day Space Station Simulator Test. Presented at the 90-Day Manned Test Symposium, Langley Research Center, Hampton, Virginia, November 17-18, 1970.

4-33. O. F. Trout. Spirometry Loop Technique, Langley Symposium, op. cit., 1970.

4-34. R. Saucer. Complex Coordinator, Langley Symposium, op. cit., 1970.

4-35. H. A. Glatte, Jr., and B. E. Welch. Carbon Dioxide Tolerance: A Review. USAF School of Aerospace Medicine, Review 5-67, September 1967.

4-36. J. R. Wamsley, E. W. Youngling, and W. F. Behm. High Fidelity Simulations in the Evaluation of Environmental Stress: Acute CO_2 Exposure. Aerospace Med., Vol. 40 (12), pages 1336-1340, December 1969.

4-37. L. V. Gibbons, T. D. Franklin, P. W. Jones, and J. R. Wamsley. Physiopsychologic Responses to Acute Carbon Dioxide Exposure. Presented at the 40th Annual Scientific Meeting, Aerospace Medical Association, 5 May 1969.

4-38. K. E. Schaefer. Respiratory Pattern and Respiratory Response to CO_2. J. Appl. Physiol., Vol. 13 (1), pages 1-14, 1958.

4-39. A. Bouhuys, J. Pool, R. A. Binkhorst, and P. VanLeeuwen. Metabolic Acidosis of Exercise in Healthy Males. J. Appl. Physiol., Vol. 21 (3), pages 1040-1046, 1966.

4-40. W. A. Kachodorian, and R. E. Johnson. Renal Responses to Various Rates of Exercise. J. Physiol., Vol. 28 (6), pages 748-752, 1970.

4-41. K. E. Schaefer, G. Nichols, Jr., and C. R. Carey. Calcium Phosphorus Metabolism in Man During Acclimatization to Carbon Dioxide. J. Appl. Physiol., Vol. 18 (6), pages 1079-1084, 1963.

4-42. K. E. Schaefer. A concept of Triple Tolerance Limits Based on Chronic Carbon Dioxide Toxicity Studies. USN Medical Research Laboratory, Submarine Base, New London, Connecticut. Report 357, 16 May 1961.

4-43. F. L. Rodkey, H. A. Collison, and J. D. O'Neal. The Influence of Oxygen and Carbon Monoxide Concentrations on Blood Carboxyhemoglobin Saturation. Presented at the Joint Committee on Aviation Pathology Colloquium, Oklahoma City, Oklahoma, October 12-14, 1970.

4-44. Blood Carboxyhemoglobin Saturation of Personnel During 90-Day Test. Langley Symposium, op. cit., 1970.

4-45. R. F. Coburn, W. S. Blakemore, and R. E. Forster. Endogenous Carbon Monoxide Production in Man. J. Clin. Invest., Vol. 42, page 1172, 1963.

4-46. P. V. Harper, and C. Lipscomb. Assay and Dosimetry of Iodine-125. J. Nucl. Med., Vol. 5, pages 308-309, 1964.

4-47. W. S. Oleniacz, M. A. Pisano, M. H. Rosenfeld, and R. L. Elgart. Chemiluminescent Method for Detecting Microorganisms in Water. Envir. Sci. Technol., Vol. 2 (11), pages 1030-1033, 1968.

4-48. Water Quality Standards for Long Duration Manned Space Missions. Report of the ad hoc committee of the Space Sciences Board, National Academy of Sciences, September 1967.

4-49. J. R. Puleo, N. D. Fields, B. Moore, and R. C. Graves. Microbial Contamination Associated with the Apollo 6 Spacecraft During Final Assembly and Testing. Space Life Sciences, Vol. 2, pages 48-56, 1970.

4-50. A. J. Vargosko, F. B. Gordon, and J. R. Wilkins. Microbiologic Studies on Man in Closed Environmental Systems: Summary and Interpretation of Reported Observations. Dept. of the Navy Research Task MR005.09.0067 (1970)

4-51. W. Harriott. Experiment M-1 Aerosol Analysis NASA/McDonnell Douglas Operational 90-Day Manned Test. Monthly Progress Report, July 1970. U. S. Dept. of Transportation, Transport Systems Center, Cambridge, Mass.

4-52. Ibid, Monthly Progress Report, August 1970.

Appendix A
PARTICIPANTS

Experiment	Principal Investigators
Flight Weight Two Gas Controller	D. Popma - LRC
Atmospheric Trace Contaminant Analysis	D. Popma - LRC
Electrolysis Unit	R. Martin - LRC
Microbial Monitor (Water Subsystem)	J. Wilkins - LRC
Crew Mission Activities Analysis	K. Brender - LRC
Non-Interference Performance Assessment	R. Chambers - LRC
Humidity Control Phase Separator	C. Saunders - LRC
CO_2 Concentrator (Solid Amine)	R. Martin - LRC
Sabatier Water Separator	F. Booth - LRC
Crew Selection	R. Saucer - LRC
Microwave Oven	D. Grana - LRC
Psychomotor Tester	R. Saucer/R. Chambers - LRC
Zero-g Metering Pump	L. Clark - LRC
Respiratory Measurements	T. Wilson/O. Trout - LRC
Sleep Evaluation	R. Chambers - LRC
Psychoacoustics	R. Chambers - LRC
Frozen Food Evaluation	D. Grana - LRC
Silver Ion Generator	R. Tanner - MSC
Material Selections	M. Radnofski - MSC
Urine Receptacle	R. Tanner - MSC
Glycerol	J. Shapira - ARC

Human Transfer Function	W. Larson - ARC
Response Analysis Tester	R. Patton - ARC
Visual Field Tester	R. Haines - ARC
Atmosphere Particle Counter	W. Harriott - ERC
Physiological Stress (Serum Lipids)	R. Danziger/D. Uddin/ E. Neptuno, Jr. - NMRI
Water Recovery Unit (VD-VF)	C. Metzger - AMRL
Waste Management	C. Metzger - AMRL
Habitability	G. Hopson - MSFC
Atmosphere and Water Quality Standards	Ad Hoc Committee - NAS
Pharyngeal Samplings	J. McQueen - MSC
Viral Sampling (H_2O)	H. Dalton - MCV
Blood Analysis (CO_2 Effects)	K. Schaefer - NMRL
Metabolic Rates	H. Kelly - MDAC
Carboxyhemoglobin	F. Rodkey - NMRI
CO_2 Effects Study	J. Wamsley/D. Myers - MDAC

Appendix B

CREW TRAINING – FINAL EXAMINATION

Section I – Water Management Subsystems

1. Fill out the provided water tank data sheets for the following situation of events; which is based on a two-day tank rotation schedule:

   June 13, Day 10, 0800

   Tank 1 is full and holding for future use, tank 6 is being used, tank 4 is the most recently filled, and tank 3 is ready to use. Tanks 1 and 2 are the only heated tanks and tank 5 is being filled with water processed from the VD-VF unit using silver ion generator for bacteria control.

   June 14, Day 11, 0800

   Switched 'use' tanks from 6 to 3 and 'fill' tanks from 5 to 6. Tank 4 has been found contaminated, so at 0930 the heater was turned on and the water pumped over to tank 2 for reprocessing. The transfer was complete at 1130 and timer set to hold at temperature for 6 hours. The multifiltering process back to tank 4 was started at the end of the hold time.

   June 15, Day 12, 0800

   The filtering to tank 4 was completed at 0400 and a sample was taken for bacteria. Tank 5 was certified potable. Remaining tank status remains the same.

   June 16, Day 13, 0830

   Switched use tanks from 3 to 5 and fill tanks from 6 to 3. Tank 4 now found to be potable.

2. Fill in the missing columns on the provided water sample data sheet.

3. When a water sample is taken for chemical and physical properties and bacterial cultures, which test is performed first?

   a. Chemical b. Physical c. Bacterial

4. The 6-hour timer and buzzer alarm on the water system panel are primarily for:

   a. timing the dryer cycle

   b. reminder to change water tank

   c. check the VD-VF transfer pump

   d. timing holding tank waiting period before filtration

   e. none of the above.

5. If an indicated rotometer flow rate of 100 cc/min on either the water system panel or wash water system cannot be obtained with the flow control valve wide open, the problem is:

   a. clogged filters

   b. empty process water tank

   c. water pressure too high

   d. inlet water tank valve closed.

6. Water samples taken from the 50-gallon backup tank would be included in the water mass balance data.

   True False

7. Reclaimed water determined, by analysis, to not be potable will be dumped overboard.

   True False

Section II – Radiation

1. Describe the function of the following radiation dosimeters as used in the 90-day test of the SSS.

   a. Film Badge

   b. Pocket Dosimeter

   c. Survey Instrument

   d. Air Monitor

   e. Isotope Analysis Unit

2. Assume that the alarm on the air monitor sounds while the ratemeter is set on the 0-100 cpm scale. What is the first and simplest procedure and result with the air monitor that would prove the presence of airborne radioactivity and require the immediate evacuation of the Space Station Simulator?

3. a. Define the rad and the rem and briefly describe the relationship of these terms to the personnel dosimetry and the radiation fields onboard the SSS.

   b. What are the legal yearly and quarterly dose limits (whole body) in rem for the SSS crewmen?

   c. What approximate whole body dose in rem to a crewman would you expect as a result of the 90-day test of the SSS?

Section III – General LSS

1. The flow tube AP gage (PdI-D2) normally reads 6.4 psi; give possible causes for lower readings.

2. The coil AP gage (PdI-H14) should be steady and read ~6 psi; a drop below 6 psi indicates what type of problem?

3. List the necessary parameters that go into a mass balance as utilized in this program.

4. What is to be done when the mass spectrometer ion pump current goes up?

5. When is it necessary to read O_2 and N_2 orifice supply pressures in the 2-gas control system?

6. Where is the emergency shutoff for the O_2 and N_2 lines to the 2-gas control system?

7. What are the three types of air samples?

8. What are the major sources of bacterial contamination in the cabin atmosphere, potable water system, and cabin surfaces?

9. Which biomedical checks are performed during the biomed check each morning?

10. What types of materials produced during food preparation must be treated and how, to prevent bacterial growth?

11. What should be done for spills of biodegradable material?

12. Why are blood samples taken with the subject in a fasting state?

13. What tests are performed on blood samples and urine samples?

    a. Onboard the SSS b. Outside the SSS

14. Why is it important to perform the step by step exercise procedures the same way each time?

15. Why is O_2 consumption data taken for each exercise period?

16. What systems have valving to outboard vacuum systems, and what procedural mistakes could cause cabin pressure loss?

17. What system malfunctions could cause cabin pressure loss?

18. What are the major functions to monitor in the electrolysis systems?

19. Why is the 2-phase separator necessary to the electrolysis system?

20. At what O_2 pressure will the current controllers begin to function?

21. What is the purpose of silica gel beds?

22. When is it necessary to go to space vacuum for desorption of molecular sieve beds?

23. What precautions are taken to insure pure CO_2 in the adsorption and desorption cycles?

24. What percent of CO_2 is adsorbed by the molecular sieve?

25. What is the purpose of the exercise program and what instrumentation is directly associated with the exercise program?

26. List steps to clear urine from the phase-separator.

27. Where is the hot coolanol shutoff valve?

28. What is the purpose of the nose and throat swabs?

29. What is the purpose of the bacteriological monitoring of the water reclamation subsystem?

30. Assume everyone outside goes home.

    a. How can you get out quickly?

    b. How can you get out, leaving the cabin atmosphere almost as is?

Appendix C

HABITABILITY INVENTORY QUESTIONNAIRE

The following questions are meant to direct your attention to various factors involved in the overall habitability of the SSS. For example, there is a question concerning light levels in the general area of crew quarters, however, there are three possible sources of light in this area: (1) the fluorescent lamps, (2) the personal reading lights, and (3) the flashlight. The question does not identify specific features in the environment but is only meant to start you thinking about the area of lighting in general. For each question that evokes a non-neutral response, write the question number and your comments on the answer sheets supplied. If you truly feel that your response to the question is neutral or deserves no comment, make no marks on the answer sheet. Make sure to place your name and the test day at the top of the page.

HABITABILITY INVENTORY QUESTIONNAIRE

I. CREW QUARTERS

1. Noise level

serious disturbance	moderate disturbance	slight disturbance	no disturbance

Comment:

2. Vibration level

serious disturbance	moderate disturbance	slight disturbance	no disturbance

Comment:

3. Light level

excessive	about right	inadequate	very inadequate

Comment:

4. Overall volume

*too large about right too small much too small

Comment:

5. Storage volume – general

more than enough about right too little much too little

Comment:

6. Storage volume – debris

more than enough about right too little much too little

Comment:

7. Storage volume – personal

more than enough about right too little much too little

Comments:

8. Food Preparation Area

excessive about right inadequate very inadequate

Comments:

9. Food Storage Area

excessive about right inadequate very inadequate

Comments:

10. Recreation and Dining Table (consider aspects of size, comfort, height, area)

excessive about right inadequate very inadequate

Comments:

---

*Any space listed as "too large", "more than enough", etc., means that this space could have been better used for some other purpose.

11. Recreation and Dining Chairs (consider aspects of size, comfort, height, area)

excessive | about right | inadequate | very inadequate

Comments:

12. Bunks (consider aspects of size, comfort, height, ventilation)

excellent | good | fair | poor

Comments:

13. Bunk Area Privacy Curtain

very useful | useful | annoying | very annoying

Comments:

14. Privacy in General

more than enough | about right | too little | much too little

Comments:

15. Work/Rest Schedule

excellent | good | fair | poor

Comments: (Identify split or common):

16. Temperature, Humidity and Air Circulation

excellent | good | fair | poor

Comments: (Identify Temperature, Humidity or AC if problem):

II. EQUIPMENT AREA

1. Noise level

serious disturbance | moderate disturbance | slight disturbance | no disturbance

Comments:

2. Vibration level

serious disturbance	moderate disturbance	slight disturbance	no disturbance

Comments:

3. Light level

excessive	about right	inadequate	very inadequate

Comments:

4. Overall volume

too large	about right	too small	much too small

Comments:

5. Storage volume – general

more than enough	about right	too little	much too little

Comments:

6. Work space

more than enough	about right	too little	much too little

Comments:

7. Temperature, Humidity and Air Circulation

excellent	good	fair	poor

Comments: (Identify Temperature, Humidity or AC if problem):

8. Work Space Layout

excellent	good	fair	poor

Comments:

III. GENERAL HYGIENE AREA

1. Noise level

serious disturbance	moderate disturbance	slight disturbance	no disturbance

Comments:

2. Fecal Collection Facility

excellent	good	fair	poor

Comments:

3. Urine Collection Facility

excellent	good	fair	poor

Comments:

4. Body Hygiene Facilities: Consider water temperature, size of towels and washcloths, adequacy of cleansing agents.

excellent	good	fair	poor

Comments:

5. Dryer

excellent	good	fair	poor

Comments:

6. Washer

excellent	good	fair	poor

Comments:

IV. MISCELLANEOUS AREAS AND FACILITIES

1. Internal P. A.

excellent	good	fair	poor

Comments:

2. Intercom to Outside

excellent good fair poor

Comments:

3. Intercom to Internal

Excellent good fair poor

Comments:

4. Entertainment speaker

excellent good fair poor

Comments:

5. Entertainment headsets

excellent good fair poor

Comments:

6. Step-ladder

excellent good fair poor

Comments:

7. Bicycle Ergometer

excellent good fair poor

Comments:

8. Recreational Provisions

excellent good fair poor

Comments:

9. Skylab Clothing Ensemble Warmth (Fill in garmet number.)

Jacket No. ____	Excellent	Good	Fair	Poor
Trousers No. ____	Excellent	Good	Fair	Poor
Shirt No. ____	Excellent	Good	Fair	Poor
Drawers No. ____	Excellent	Good	Fair	Poor
Socks No. ____	Excellent	Good	Fair	Poor

Comments:

10. Skylab Clothing Ensemble Comfort (Fill in garment number)

Jacket No. ____	Excellent	Good	Fair	Poor
Trousers No. ____	Excellent	Good	Fair	Poor
Shirt No. ____	Excellent	Good	Fair	Poor
Drawers No. ____	Excellent	Good	Fair	Poor
Socks No. ____	Excellent	Good	Fair	Poor

Comments:

11. Skylab Clothing Ensemble Wear (Fill in garment number)

Jacket No. ____	Excellent	Good	Fair	Poor
Trousers No. ____	Excellent	Good	Fair	Poor
Shirt No. ____	Excellent	Good	Fair	Poor
Drawers No. ____	Excellent	Good	Fair	Poor
Socks No. ____	Excellent	Good	Fair	Poor

Comments:

12. Dupont 4484 bed sheet

excellent good fair poor

Comments:

13. Durette bedding

Excellent good fair poor

Comments:

14. PBI toweling

excellent good fair poor

Comments:

15. Terry cloth towels

excellent good fair poor

Comments:

16. PBI thermal weave blankets

excellent good fair poor

Comments:

17. Durette Clothing Ensemble

excellent good fair poor

Comments:

18. Durette Pajamas

excellent good fair poor

Comments:

19. Floor covering

excellent good fair poor

Comments:

20. Personal lights

excellent good fair poor

Comments:

21. Individual picoprojectors

excellent good fair poor

Comments:

22. Group picoprojectors

excellent good fair poor

Comments:

23. Microwave oven

excellent good fair poor

Comments:

24. Electric oven

excellent good fair poor

Comments:

25. Refrigerator

excellent good fair poor

Comments:

26. Eating utensils

excellent good fair poor

Comments:

27. Tool kit

excellent good fair poor

Comments:

28. Freezer

excellent good fair poor

Comments:

29. Body hygiene provisions (haircutting, shaving, etc.)

excellent good fair poor

Comments: (Identify as necessary):

30. Langley Complex Coordinator

excellent good fair poor

Comments:

31. RATER

excellent good fair poor

Comments:

32. Human Describing Function Experiment

excellent good fair poor

Comments:

33. Onboard laboratory work-space layout

excellent good fair poor

Comments:

34. From an aesthetic viewpoint which compartment do you prefer?

Crew compartment Equipment compartment

Sleep quarters Waste Management area

Comments:

35. If you could modify the interior color scheme of the SSS how would you do so?

36. If you could change one color which one would it be and how would you change it?

37. Comments on areas and facilities not covered in questionnaire:

38. Aside from the technical problems encountered, would you recommend this general configuration as a desirable living and working area for long term space missions? Please explain.

PRECEDING PAGE BLANK NOT FILMED

Appendix D

CREW OPERATING GROUND RULES

1. The program philosophy is to allow the inside crew as much flexibility as possible in the scheduling and performance of events to be accomplished during any given day of the simulation. The crew activity schedule, with a recommended sequence of events, will be available to both the inside crew and the outside support staff. All mandatory and recommended events will be clearly marked on the schedule presented. The Crew Commander will be responsible for implementation of the daily crew assignments with authority to change the schedule as required to accomplish all mandatory events. Assistance in crew activity rescheduling required as a result of a contingency or prolonged unscheduled maintenance will be provided by the outside staff personnel upon request of the Crew Commander. Concurrence for deletion of mandatory events must be obtained from the Program Manager through the Communications Monitor to preclude loss of daily crew incentive pay.

2. Voice communications from inside the SSS through the Communications Monitor will be unlimited. Outside staff personnel will endeavor to limit voice communications to the inside crew and in all instances will conduct these communications in a business-like manner. During contingency operations, outside staff personnel will direct the inside crew as required in accordance with procedures contained in Section 3 of NASA CR-111882.

3. The Communications Monitor will assure audio privacy between the physician and crew member during medical interviews and between phychologist and crew member during interviews of a behavioral nature.

4. To insure compatibility between manual scheduling and computer scheduling, the following work/rest cycle and fixed times will be used for two crewmen up/two crewmen down:

   a. Crewman 1 and Crewman 2: Sleep 2300 to 0700 hours.

   b. Crewman 3 and Crewman 4: Sleep 1300 to 2100 hours.

   c. Crewman 1 and Crewman 2: Breakfast: 0800 hours to 0900 hours, except Tuesday - 0810 to 0910.
      Lunch: 1250 to 1400 hours.
      Dinner: 1830 to 1950 hours.

d. Crewman 3 and Crewman 4: Breakfast: 2200 to 2300 hours.
Lunch: 0150 to 0300 hours
Dinner: 0700 to 0820 hours, except Tuesday — 0830 to 0950.

e. Tuesday Sample Passout: 0810 hours, plus or minus 15.

5. The crew activity schedule will contain details on all crew duty events. The remainder of the time during the 24-hour period will be for either free time or sleep. No attempt will be made to schedule events during free-time periods. Data on crew activities during free time will be derived from review of the time-lapse video tapes and Mission Analysis monitor logs. It is imperative that all constraints in the Crew Event Matrix be programmed to insure compliance with restrictions as imposed by principal investigators, engineers, and program management.

6. The nominal free-time period will be three hours daily, scheduled to allow the crew as much consecutive free time as possible for individual activities, such as research projects. Mandatory tasks take priority over free time and, when necessary, free time will be reduced for any specific day to insure their accomplishment. To facilitate the Non-Interference Performance Assessment experiment (see Section 3.9), the 3-hour consecutive free-time period should be scheduled during the period of the day when all four crewmen are up and have an opportunity for interaction.

7. The operation of the audio/video monitoring system is the responsibility of the outside Communications Monitor. The crew will not intentionally mask a TV camera lens or turn off a TV camera without permission of the Communications Monitor unless scheduled as a duty event in the Crew Activity Schedule. When necessary, the crew will delay performing this event to ensure that it takes place during times of low activity to preclude loss of significant data.

8. Each crew member will be permitted to make one telephone call per week. Complete audio privacy will be assured by the Communications Monitor.

9. All events scheduled to occur during the 90-day test are categorized into "mandatory" and "recommended" events. Mandatory events are those which the onboard crew must perform on the day scheduled or obtain a release from the outside staff in order to earn their daily incentive pay. The recommended events are scheduled, but compliance with the schedule is not incentivized and performance of the event is (1) at the individual crewman's discretion and (2) on a non-interference basis with the mandatory events.

10. The Communications monitor will insure the uninterrupted use of scheduled free-time periods by the crew by: (1) assuring that requests from the outside staff for unscheduled maintenance or instrument monitoring are evaluated by the test conductor prior to transmitting instructions to the crew and (2) delaying all other requests until the end of the scheduled free-time period.

11. It is recognized that usually no two people interpret the written or spoken word in exactly the same manner. It is, therefore, essential that computer programmers, operations, and management personnel maintain a close working relationship to insure that a common understanding exists for all entries contained in the Crew Events Matrix. This is especially true as pertains to all stated constraints. The correct interpretation and use is doubly important in that the resolution of conflicts usually requires participation of personnel from numerous discipline areas.

12. The following listing of mandatory and recommended events (see paragrpah 9 above) is made to assist in the computer programming of crew activity schedules and to provide a listing which may be used by the outside staff in the event of a requirement for deviation from normal operating procedures. The ordering of events within the mandatory category assumes normal operating conditions and generally reflects the ordering of (1) crew safety, (2) crew health, (3) equipment operation and maintenance, and (4) baseline experiments. Within the recommended category, the ordering is generally on the basis of (1) personal activities and (2) add-on experiments.

MANDATORY EVENTS

1. Safety inspection
2. Pencil dosimeter, read and charge
3. Film badge change
4. Biomedical checks
5. Blood samples
6. Blood tests
7. Urine samples
8. Urinalysis
9. Bacteria sample count
10. Water samples/tests
11. Nose and throat swabs
12. Throat wash sample
13. Food consumption data

14. Station atmosphere samples
15. Station surface swabs
16. Sample pass-through
17. Medical interview
18. Mass balance data collection
19. Electrolysis maintenance
20. Switch water tanks
21. VD-VF Isotope relocation
22. VD-VF Startup
23. VD-VF Liquid transfer
24. TV Camera maintenance
25. Wash water filter change
26. Commode linen change
27. Ion exchange element recharge
28. Alpha particle filter change (higher priority)
29. Aerosol particle analysis
30. Descriptive sentence test
31. Exercise
32. Group Confinement inventory
33. Habitability inventory
34. Hostility scale
35. Isolation symptomatology
36. LRC psychomotor test
37. Personal space measure
38. Primary affect scale
39. Sleep log
40. Sociometric questionnaire

41. Sleep
42. Psychologist interview

RECOMMENDED EVENTS

1. Waste management – defecate
2. Waste management – urinate
3. Breakfast
4. Lunch
5. Dinner
6. Diary
7. Data management (general)
8. Glycerol-based drink
9. Visual acuity tester
10. Human describing function
11. RATER
12. Lighting
13. Psychoacoustics
14. Body hygiene – wash
15. Bacterial sensor equipment
16. Photography
17. Body hygiene – shave
18. Laundry
19. Cabin cleaning
20. Bed linen change
21. Snack
22. Picoprojector
23. Free time

PRECEDING PAGE BLANK NOT FILMED

Appendix E
NOISE QUESTIONNAIRE

The questionnaire shown in this appendix was given to the crew members 2 days after their exit from the chamber. Responses are tabulated directly on the multiple-choice questions, and open-ended responses are summarized.

BEHAVIORAL ACOUSTICS QUESTIONNAIRE*

The background noise in the living quarters was:

1. A. Very quiet

(1) B. Quiet

(3) C. About as loud as tolerable

D. Too loud

2. What is your suggestion for a maximum living quarters level permissible in future simulation or actual missions.

A. Much quieter than current living quarters

(2) B. Slightly quieter than current living quarters

(2) C. The level of the living quarters in this test

D. Somewhere between the two cabins

E. About as loud as the equipment room

F. Slightly louder than the equipment room

G. Much louder than the equipment room

3. The background noise in the equipment room was:

A. Very quiet

B. Quiet

*Numbers in parentheses indicate number of crew members responding to the particular choice.

(2) C. About as loud as tolerable

(2) D. Too loud

4. While trying to sleep, what items of equipment or actions of the crew created noises which bothered you. Please rank order in terms of annoyance from most to least disturbing. (Place answer on separate sheet).

5. For future similar (90-day) tests, do you think the acoustics battery given was:

(3) A. Too long

(1) B. About right in length

C. Short enough so that it could be lengthened

6. I found the last few replications of the test:

(2) A. Very boring

(2) B. Slightly boring

C. Neither boring nor motivating to any great extent

D. Interesting

E. Very interesting

7. The test I liked best was:

(3) A. Audiogram

B. Acceptability matching

(1) C. Speech comprehension

8. The test I liked least was:

A. Audiogram

(4) B. Acceptability matching

C. Speech comprehension

9. Are there any factors you feel lowered the accuracy of the tests? (Answer on separate sheet).

10. If the noise level in the living quarters had been as loud as the noise in the equipment room, it would have been:

    A. Very quiet

    B. Quiet

(1) C. About as loud as tolerable

(3) D. Too loud

11. Would you feel that the audio testing conducted here would be acceptable for future simulations or actual missions? Please explain your answer on separate sheet.

12. How often should acoustic tests be given in future cabin activities? (Answer on separate sheet).

13. Do you have any other suggestions for improving acoustic testing? (Answer on separate sheet).

RESPONSES TO OPEN-ENDED QUESTIONS

Question	Number of Crew Members So Responding
4. (Noise which affected sleeping)	
Intermittent pump noise	3
Crew members talking	3
Food preparation/microwave oven	2
Sliding doors on shelves	1
Equipment room door	1
Calisthenics	1
Laundry	1
9. (Factors reducing accuracy of acoustic tests)	
Intermittent background noise	3
Repetition of same word lists weekly	1

Question	Number of Crew Members So Responding
11. (Acceptability of acoustic tests on future simulations)	
Eliminate acceptability test	2
Make tests shorter	1
Make tests less frequent	1
12. (Suggested time between acoustic tests)	
10-14 days	2
Weekly	1
13. (Suggested improvement in acoustic testing)	
Better headset	3
Reduction of extraneous noise	2

(Major concern with headset quality was to increase the attenuation of the circumaural pads, thus reducing background noise)

Appendix F
NIPA DATA COLLECTION EXHIBITS

This appendix shows a printout of a typical raw data tape and a condensed presentation of the entries made by the observer. The data in Figure F-1 was collected between 1300 hours and 1700 hours on the 35th day of the 90-day manned test (July 17, 1970). The observer for this tape was a local graduate student hired and trained to be an observer.

The printout will be clearer if some of the characters are explained. The slash (/) characters in this raw data printout are time marks put onto the tape every 30 seconds by an automatic triggered solenoid pressing the slash-marked key of the teletypewriter. The English language comment on the printout, it can be seen, is preceded by an "I". This letter indicated to the data reduction programs that an English language comment was to follow and that the comment should not be interrogated as a coded entry.

Each observer followed a rigid sign-on procedure. The observer's name came first, then the date followed by the time of day using the 24-hour clock. The observer was encouraged to indicate the actual time at half-hour intervals throughout the run. This was to enable the "clock" in the data reduction program to be updated by the actual time, thus providing a check of the slash time mark count. In signing off, four periods were to be followed by the observer's name, the day of the year, and the sign-off time.

Each of the three- and four-letter coded entries can be visually decoded by referring to the teletypewriter keyboard, Figure F-2. A "Q" for example, stands for crewman 1. The letter "Z" stands for neutral affect, giving information, "W" is crewman 2. Any entry that contains an "A", "Z", "S", or "X" is a verbal interaction entry. In a similar manner, an entry starting with the name of a crewman followed by three numbers is a space mobility and activity entry. Thus, the entry Q701 means that crewman 1 was in location 70 doing activity number 1. Other entries, for example the bulkhead door, represented by the letter "P", can be seen in the printout. The letter "D", if it is not contained in a comment, is a delete symbol. A single D requests the data reduction program to delete the entry immediately preceding the letter D. DD meant the deletion of the entire word preceding the DD.

Knowing these simple rules and using the keyboard chart, it is possible to decode all of the data collected by the NIPA observers during the entire manned test. The string manipulation programs discussed in Appendix G did essentially this, in addition to providing tallies and frequencies for the development of indices of interest.

```
/IWSEMPLE I071770 /ITIME1307 ///ITIME1309 Q701 W641 E932 R932
///// 0641 W641 E932 R932 ///// 0825 W825 E932 R932 ///// Q825
W825 E932 R932 /////.0825 W825 E932 R932 ///// 0825 W825 E932 R932
////WZ0 0ZW WZ0 WZ0 / 0825 W641 E932 R932 ///// Q825 W825 E932
R932 /ITERRY&STEVEEATING /ILITTLEC0NVERSATI0N /// 825 W825 E932
R932 //WZQ WZQ /WZQ WZQ WZ0 /QZW / 0825 W825 E932 R932 //QZW
WZQ /WZQ WZ0 //ITIME1334 0601 W601 E932 R932 //WZQ WZQ /// 601
W401 E932 R932 ///// QZW WZQ / Q401 W601 E932 R92D32 //// Q301
W501 E932 R932 //////WP1 WP2 Q701 W121 E932 R932 //// Q701 W121
E932 R932 ///// Q701 W107 E932 R932 ///// 0701 W107 E932 R932
/WZ0 /WP1 WP2 /ITERRYTALKINGT0STAFF // Q707 W823 E932 R932 /
///ISM0KEALARM / Q809 W101 W932 R932 WP/1 //// 0823 W107 E932
R932 ///WP2 // Q823 W707 E932 R932 /ISTEVETALKINGT0STAFF ///
QZW WZQ WZ0 /ITIME1404 Q823 W821 E932 R932 / Q06 W06 E07 R07
/ITERRYREADING /// Q823 W821 E932 R932 ///// Q823 W821 E932 R932
///// Q823 W823 E932 R932 /ITERRY&STEVEATTABLE /ILITTLEC0NVERSATI0N
/Q/P1 / Q201 W501 E932 R932 ///ISTEVEPEELEDUPS0ME /IM0REFL00R
IC0VERING / Q201 W501 E932 R932 ///// Q201 W501 E932 R932 //
/// Q201 W501 E932 R932 QZW WA/Q QZW QAW WZQ WAQ//QZW WZQ WAQ QZW
/// Q201 W301 E932 R932 ///// Q401 W301 E932 R932 ///// 0401
W823 E932 R932 ///// Q207 W821 E932 R932 ///// 0P2 Q501 W821
E932 R932 //ITERRYTALKINGT0STAFF ///ITIME1436 Q121 W821 E932 R932
///// 0121 W821 E932 R932 //QP1 QP2 /// Q823 W827 E932 R932
///// Q823 W823 E932 R932 //WXW /ISTEVEB0THEREDBY /IM0NIT0R'S
IC0NSTANT /ICALLING Q823 W823 E932 R932 ///// Q823 W823 E932 9D
R932 ///// Q823 W823 E932 R932 ///// Q823 W823 E932 R932 ///
// Q823 W823 E932 R932 ///// Q823 W823 E932 R932 /ITERRY&STEVE
IATTABLE /IN0C0NVERSATI0N ///ITIME1501 Q823 W823 E932 R932 /
Q06 W06 E07 R07 //// 0823 W823 E932 R932 I0FF ////I0N /ITIME1506
Q823 W823 E932 R932 ///// Q823 W823 E932 R932 ///// Q823 W823
E932 R932 ////WP1 W02 DD W/P2 Q823 W989 E932 R932 ///// Q823
W823 E932 R932 ///// Q823 W823 E932 R932 ///// Q823 W823 E932
R932 ///// Q823 W823 E932 R932 /QP/1 QP2 /QP1 QP2 // Q404 W823
E932 R932 ////WP1 / Q823 W20/1 E932 R932 WP2 ////ITIME1531 Q823
W989 E932 R932 ///// Q823 W989 E932 R932 ///// Q823 W989 E932 R932
///// Q823 W989 E932 R932 //WP1 WP2 ISTEVEINAREA40LAST/ TD ITEN
IMIN/// Q823 W501 E932 R932 WZ0 /WZQ //// Q823 W823 E932 R932
///ITERRYREADING /ISTEVEJUSTSITTING / Q823 W823 E932 R932 //
/// Q823 W823 E932 R932 QZW WZQ /WZQ WZQ QAW WZQ //// Q823 W823
E932 R932 ///// Q821 W823 E932 R932 ///// Q821 W823 E932 R932
//QP1 /// Q401 W823 E932 R932 /////ITIME1601 Q261 W823 E932 R932
/Q07 W07 E07 R07 //// Q261 W823 E932 R932 ///// Q261 W823 E932
R932 ///// Q261 W823 E932 R932 ///// Q261 W823 E932 R932 ///
// Q261 W823 E932 R932 ///// Q261 W823 E932 R932 ///// Q261
W823 E932 R932 ///// Q261 W823 E932 R932 ///// Q261 W823 E932
R932 ///// Q261 W823 E932 R932 ////// Q261 W823 E932 R932 //
//ITIME1631 Q261 W823 E932 R932 ///QP1 QP2 WP1 WP2 // WP1 WP2
Q261 DD Q401 /W261 E932 R932 //// Q401 W261 E932 R932 /////
Q401 W261 E932 R932 ///// Q401 W261 E932 R932 ///// Q401 W261
E932 R932 ///// Q401 W261 E932 R932 ///// Q401 W261 E932 R932
//QP1/ // Q401 W261 E932 R932 /QP2 //// Q605 W261 E932 R932
///// Q823 W261 E932 R932 / Q03 W03 E07 R07 / TB1 TN1 TM1 T.1 T.1
///ITIME1659 Q825 W261 E932 R932 /I.... IWSEMPLE /I071770 ITIME1700
```

Figure F-1. Raw Data Tape Printout

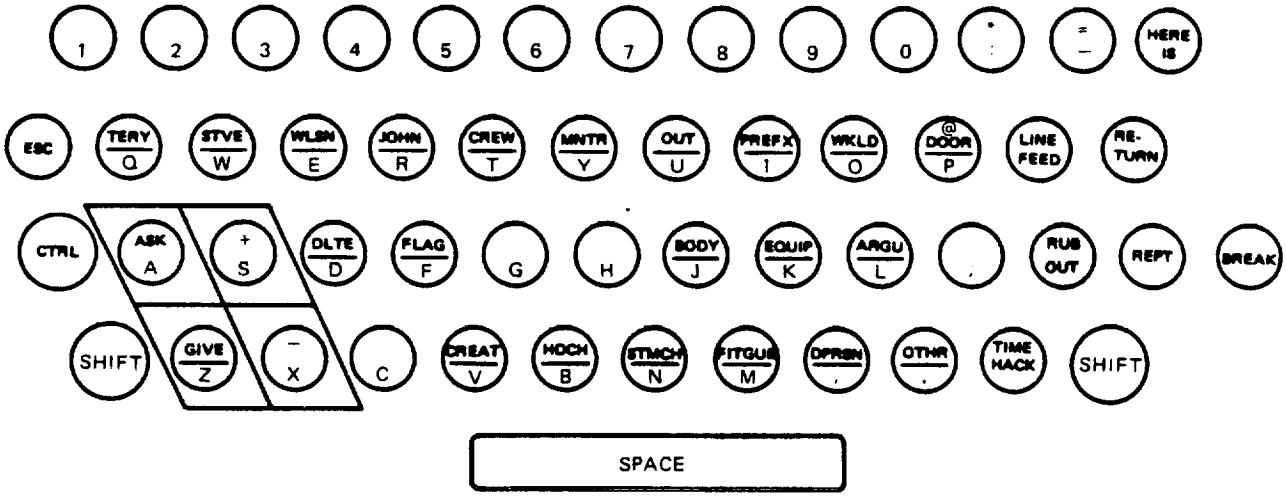


Figure F-2. Teletypewriter Keyboard Labeled for NIPA

The Figure F-3 shows a condensed version of the rules followed by the observer in making entries on the teletypewriter. For each type of entry, the possibilities for the entry are given in the right of each boxed-in area. Thus for the verbal interaction the speaker could be Q (crewman 1) then an A followed by a W. Or the entry could read QSW, QZW, or QXW. It is not possible to list all the alternatives for each of the types of observer entry. Some examples are given to the right in each of the areas. Thus, for verbal interaction, QAW is a valid entry. Likewise, RXWQ, WZY, EAUIJIM, are all valid entries.

It will be noted that a legend of the various individual entry items is given on the right of the first page of Figure F-3. All of these definitions were made prior to the data collection effort. It was found that some of the definitions were not needed as the data collection got under way. For example, entry type 10, the flag, was rarely used. This was originally intended to provide a means for the observer to indicate to those doing the analysis at a later time that something had happened and that the time lapse recording being made concurrent with the observations should be examined in more detail.

Both entry types 9 and 11 were heavily used by all the observers. Type 9, comments and time, were typically used about every 100 entries. The delete option, No. 11, was used whenever the observer made a mistake and wished to correct it. The actual deletion of the mispunched data took place during the data reduction phase, that is during computer program run.

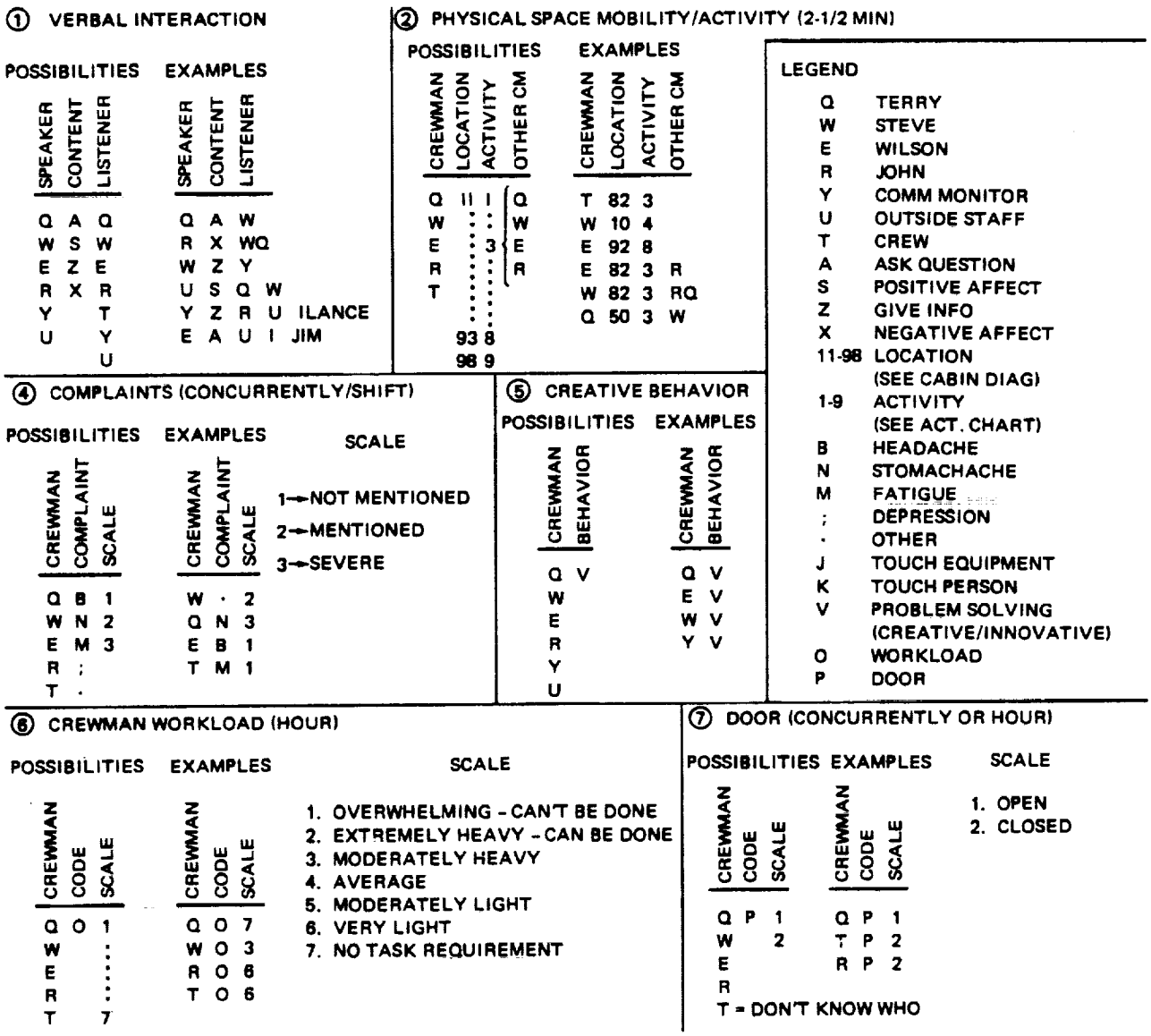


Figure F-3. NIPA Observer Function (Page 1 of 2)

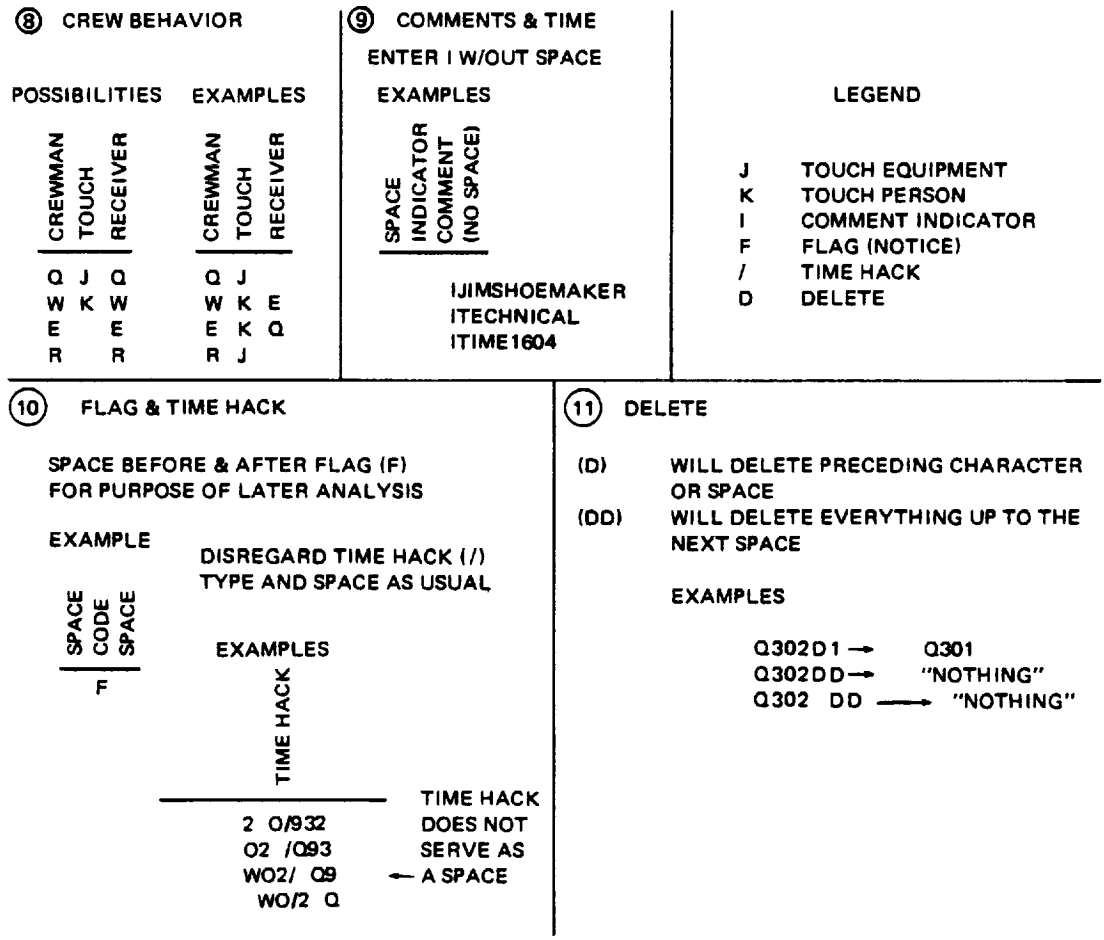


Figure F-3. NIPA Observer Function (Page 2 of 2)

PRECEDING PAGE BLANK NOT FILMED

Appendix G
NIPA DATA REDUCTION EXHIBITS

This appendix consists of matrices and flow charts which pertain directly to the data reduction effort. It would not be practical to include all the detailed flow charts and systems design documents necessary to fully explain the data reduction effort. The intent here is to provide the higher level documentation along with an example flow chart giving the general idea of how the data reduction was accomplished.

Figure G-1 shows the distance matrix which indicates the distances used in the calculation of average distances moved and dispersion distances, in two triangular matrices. For psychological distance the data reduction program chose the area in which the crewman started, or the area in which he finished equal to i, depending on which was the larger area. Psychological distance is based on subjective opinions of the NIPA investigators as to how far one crewman would feel from another crewman if they were in different areas. If actual distances were required, j was assigned the larger of the two SSS areas.

R292-III

j → SSS AREAS

← i SSS AREAS	10	20	30	40	50	60	70	80	90
10	0	5	10	15	15	20	20	20	25
20	2	0	5	10	10	15	15	15	20
30	12	10	0	5	5	10	10	10	15
40	10	10	10	0	5	10	10	10	15
50	13	13	1	10	0	5	5	5	10
60	13	13	4	10	1	0	5	5	10
70	13	13	3	10	2	2	0	5	5
80	13	13	5	10	4	1	2	0	5
90	13	13	15	10	9	9	5	5	0

MATRIX OF DISTANCES USED IN DISPERSION AND DISTANCE N.I.P.A. INDICES. IF i > j, THE MATRIX WILL PROVIDE "PSYCHOLOGICAL" DISTANCE BETWEEN AREAS IN THE SSS. IF i < j, ACTUAL DISTANCES WILL BE PROVIDED.

Figure G-1. Distance Matrices

The figures shown under the heading of frequency matrices (Figure G-2) are the detailed design of the matrices in which the tally counts were inserted. Thus if crewman 1 was positive toward crewman 2 the "sender" dimension would be the first subscript, the "type" dimension would be the second subscript, and the "receiver" dimension would be the third subscript. That is, the tally count for crewman 1 being positive toward crewman 2 would be updated by one in element position (1, 2, 5).

Matrix A$ is a summation matrix of Matrix A and is needed for certain calculations in the data reduction program. Matrix B is the space mobility and activity matrix. It also has a summary matrix, Matrix B$. The other matrices that are used to record the NIPA variables are of small enough size so as not to require summary matrices.

It will be noticed that all of the frequency matrices come directly from the NIPA measures talked about in the variable definition and data collection sections. The entries punched onto the paper tape by the teletypewriter become tallies in the frequency matrices by those same type categories.

Figure G-3 shows a simplified flow chart of the data reduction process dealing only with verbal interaction and space mobility and activity. The data reduction program essentially accomplishes the examination of each character for its validity. When the character is found to be valid, it is assigned a value on a particular dimension. Thus when the first character of a particular entry is found to be a Q, it is assigned a 1. If A is found to be the next character of that entry, it is assigned a 1 on the next dimension. If the third character is a W, it is assigned a 2 on the third dimension. In Figure G-3 the checking of its character is shown, but the assignment of the value to the different dimensions is assumed. Once an entry is found to be valid and all of the appropriate values on the different dimensions of the matrix have been arrived at, the appropriate tallies are entered in the correct matrix. Thus, the first page of the flow chart shows a box entitled "Enter Appropriate Tallies in Verbal Interaction Matrices." Since there are two verbal interaction matrices, the large detailed matrix and the small summary matrix, both tallies are entered by the same subroutine of the data reduction program. The second, third and fourth pages of the flow chart deal with the space mobility and activity data reduction in a manner similar to the verbal interaction portion of the data reduction program.

In general if any invalid character was found, the entire entry was discarded. The data reduction program allows the option of printing out these notices or ignoring the entry without notification of any sort.

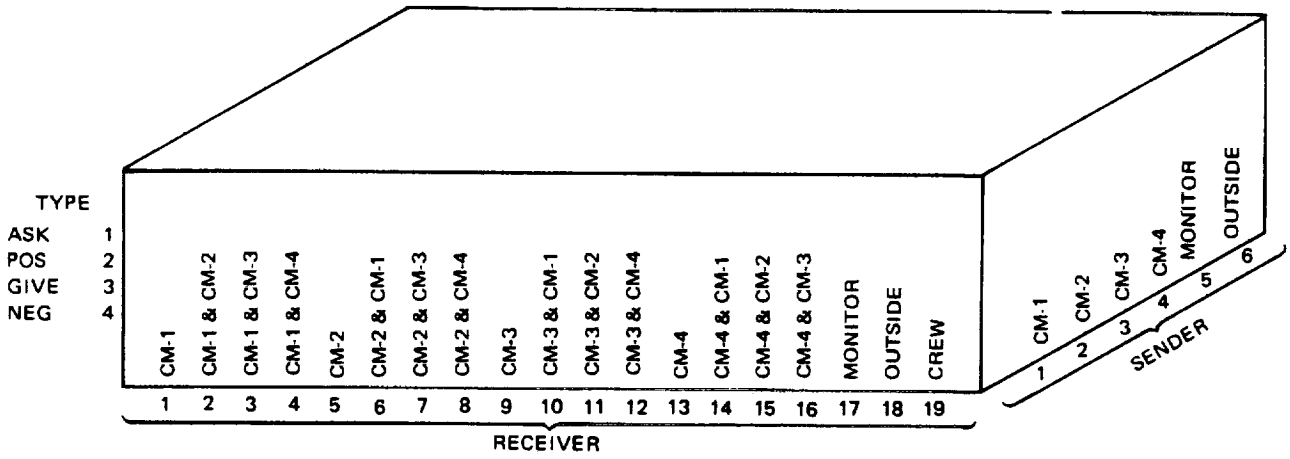
In summary, the purpose of the data reduction program was to take the raw data produced by the observer, which lists individual variables of interest to the NIPA investigators, and from them produce the indices which may be descriptive of crew behavior. These indices are listed in Appendix H, along with the detailed definition of each index.

"A" (VERBAL INTERACTION) MATRIX: A (I, J, K)

I DENOTES "SENSOR"; J DENOTES "TYPE"; K DENOTES "RECEIVER"

MATRIX ELEMENT = FREQUENCY OF OCCURRENCE (TALLIES/TIME PERIOD).

6 X 4 X 19 = 456 ELEMENTS



A$ (VERBAL INTERACTION SUM MATRIX): A$ (I, J)

7 X 4 = 28 LOCATIONS

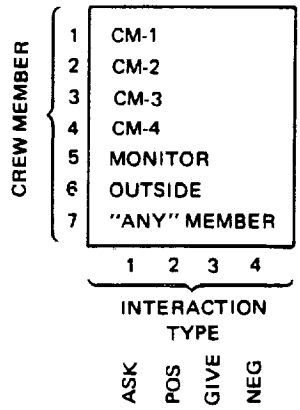


Figure G-2. Frequency Matrices (Page 1 of 5)

"B" (SPACE MOBILITY & ACTIVITY) MATRIX: B (I, J, K)

I DENOTES "CREW MEMBER"

J DENOTES "LOCATION"

K DENOTES "ACTIVITY"

MATRIX ELEMENT DENOTES
FREQUENCY OF OCCURRENCE
(TALLIES/TIME PERIOD)

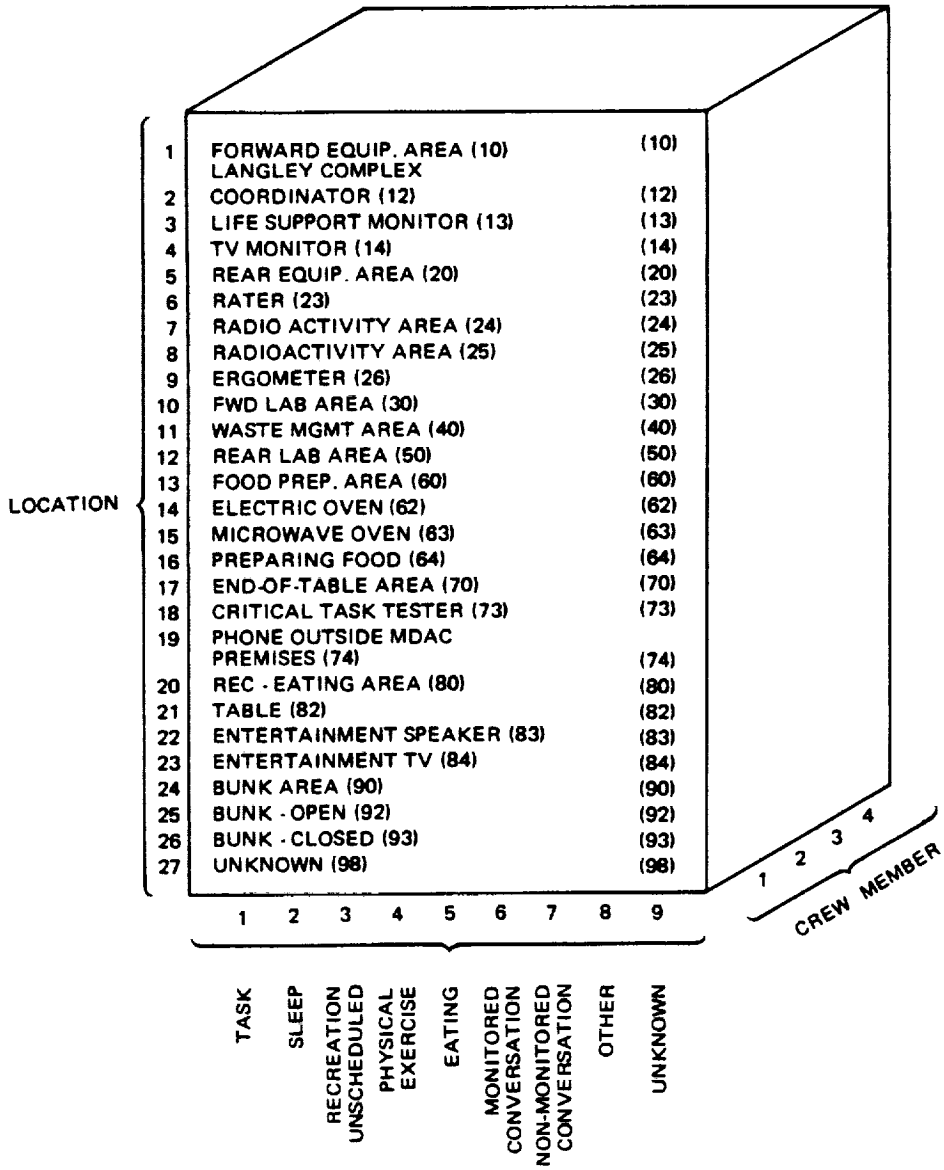


Figure G-2. Frequency Matrices (Page 2 of 5)

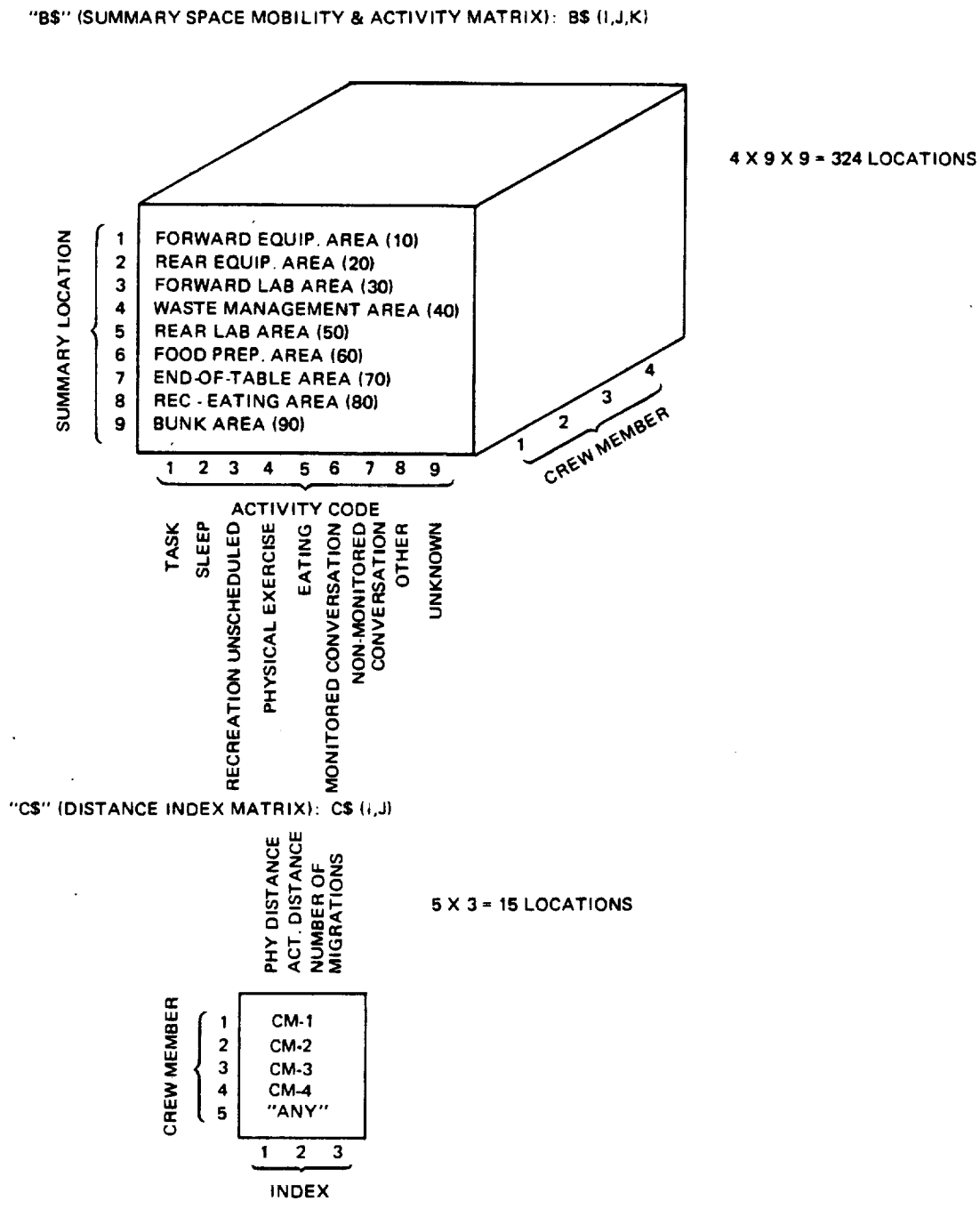
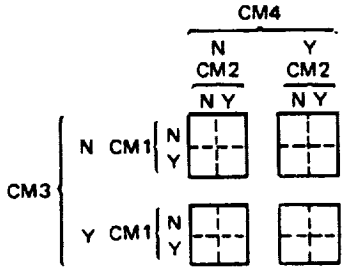


Figure G-2. Frequency Matrices (Page 3 of 5)

"C" (RECREATION) MATRIX: (I-1, I-2, I-3, I-4)

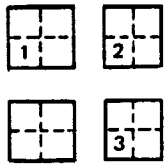


4 DIMENSIONAL MATRIX

2 X 2 X 2 X 2 = 16 ELEMENTS

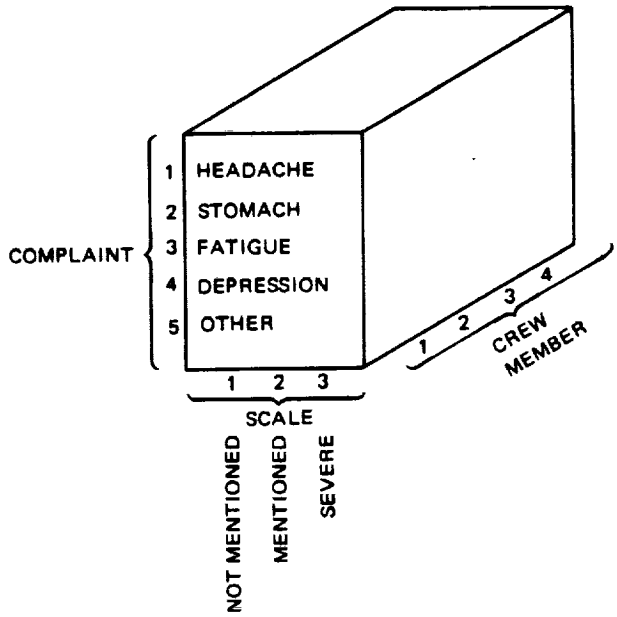
MATRIX ELEMENT DENOTES FREQUENCY OF OCCURRENCE OF WHO IS THE RECREATING WITH WHOM. Y = YES; N = NO.

EXAMPLE:



1 = CM1 RECREATING BY HIMSELF
2 = CM1 & CM4 RECREATING TOGETHER
3 = CM1, CM3, CM4 RECREATING TOGETHER

"D" (COMPLAINT) MATRIX: D(I, J, K)



I DENOTES "CREW MEMBER"

J DENOTES "COMPLAINT"

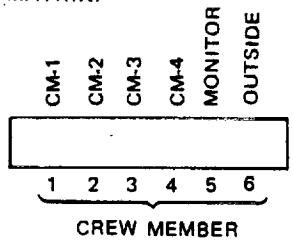
K DENOTES "SCALE"

MATRIX ELEMENT DENOTES FREQUENCY OF OCCURRENCE (TALLIES/TIME PERIOD)

4 X 5 X 3 = 60 ELEMENTS

Figure G-2. Frequency Matrices (Page 4 of 5)

"E" (CREATIVITY) MATRIX: E (I)

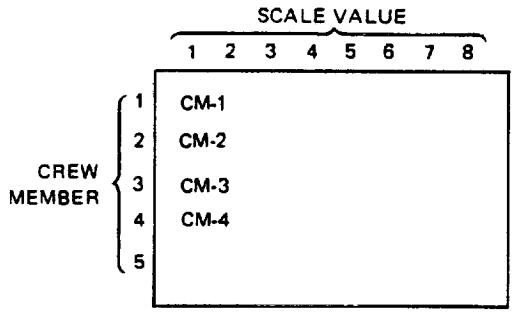


I DENOTES "CREW MEMBER"

MATRIX ELEMENT DENOTES FREQUENCY OF CREATIVITY (TALLIES/TIME PERIOD)

1 X 6 = 6 ELEMENTS

"F" (WORK LOAD) MATRIX: F (I, J)



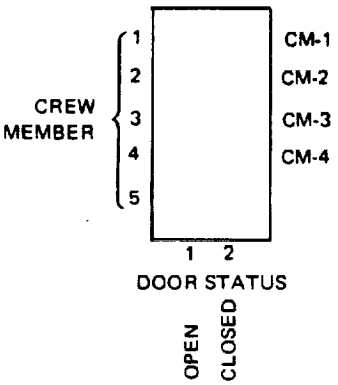
I DENOTES "CREW MEMBER"

J DENOTES "SCALE VALUE"

MATRIX ELEMENT DENOTES FREQUENCY OF OCCURRENCE (TALLIES/TIME PERIOD)

5 X 8 = 40 ELEMENTS

"G" (DOOR) MATRIX: G (I, J)



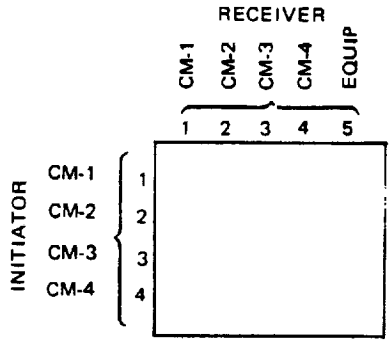
I DENOTES "CREW MEMBER"

J DENOTES "DOOR STATUS"

MATRIX ELEMENT DENOTES FREQUENCY OF OCCURRENCE (TALLIES/TIME PERIOD)

5 X 2 = 10 ELEMENTS

"H" (TOUCH) MATRIX: H (I, J)



I DENOTES "TOUCH INITIATOR"

J DENOTES "TOUCH RECEIVER"

MATRIX ELEMENT DENOTES FREQUENCY OF OCCURRENCE (TALLIES/TIME PERIOD)

4 X 5 = 20 ELEMENTS

Figure G-2. Frequency Matrices (Page 5 of 5)

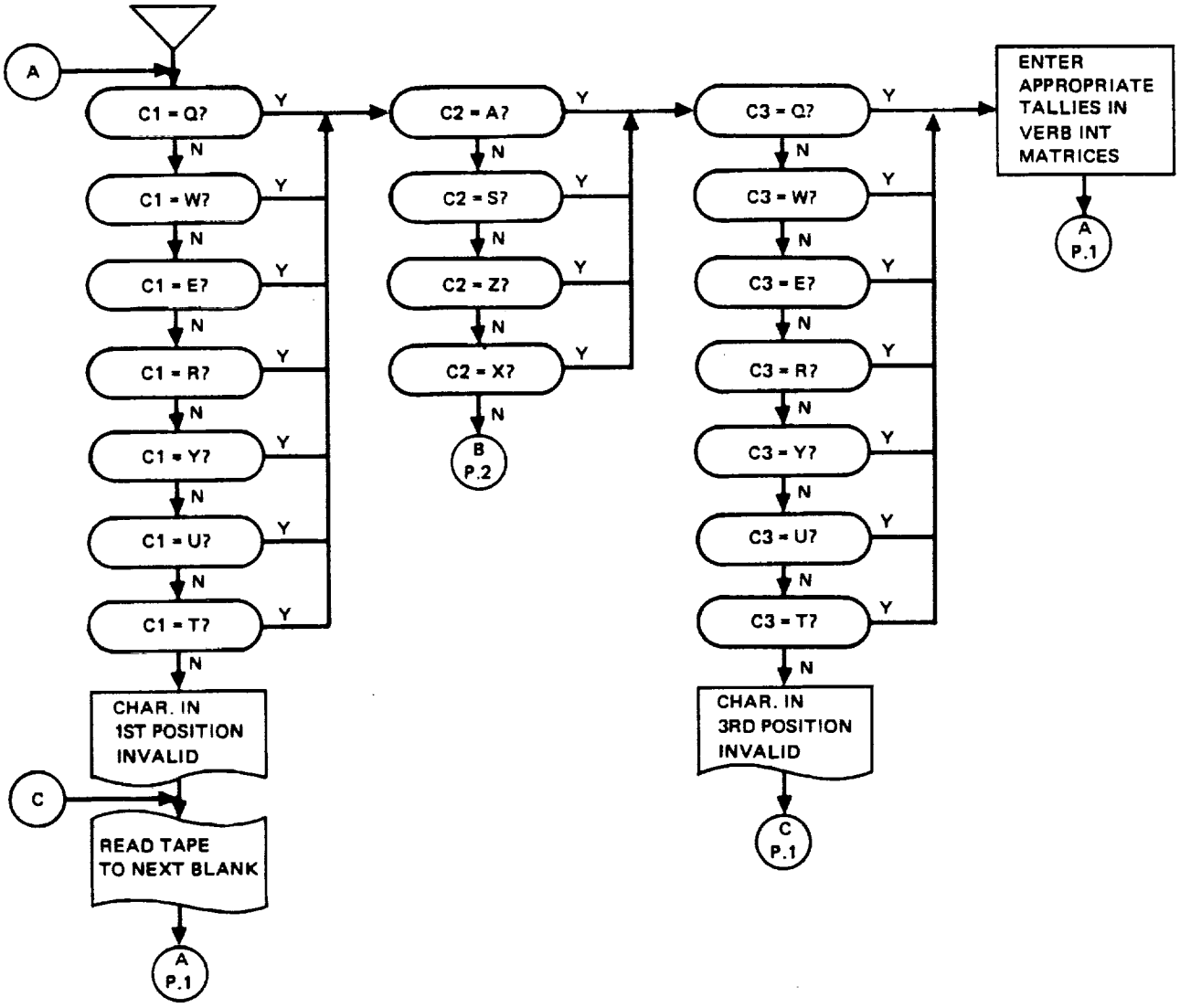


Figure G-3. Simplified Flow Chart Showing Method of Entering Tallies in Matrices (Page 1 of 4)

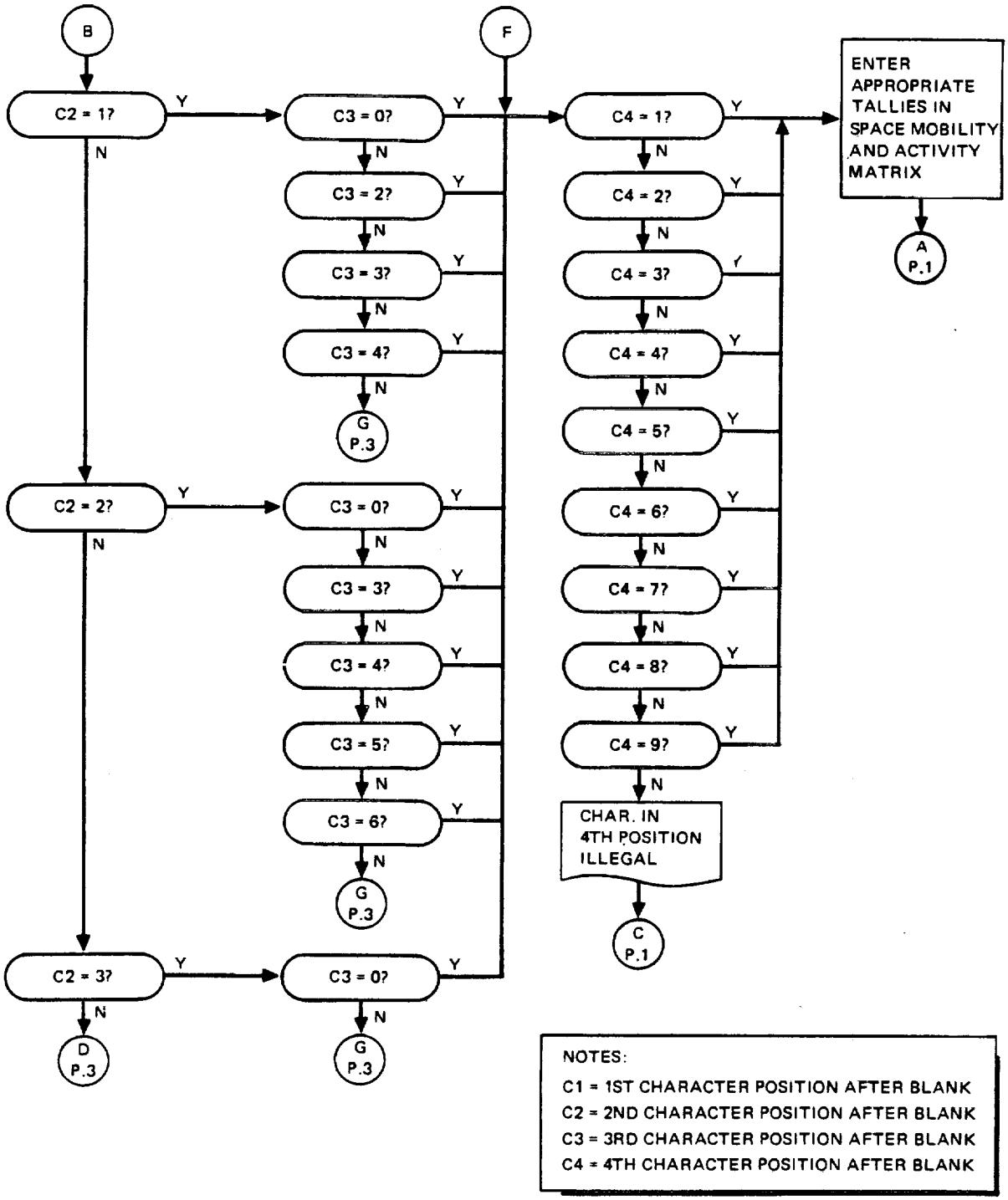


Figure G-3. Simplified Flow Chart Showing Method of Entering Tallies in Matrices (Page 2 of 4)

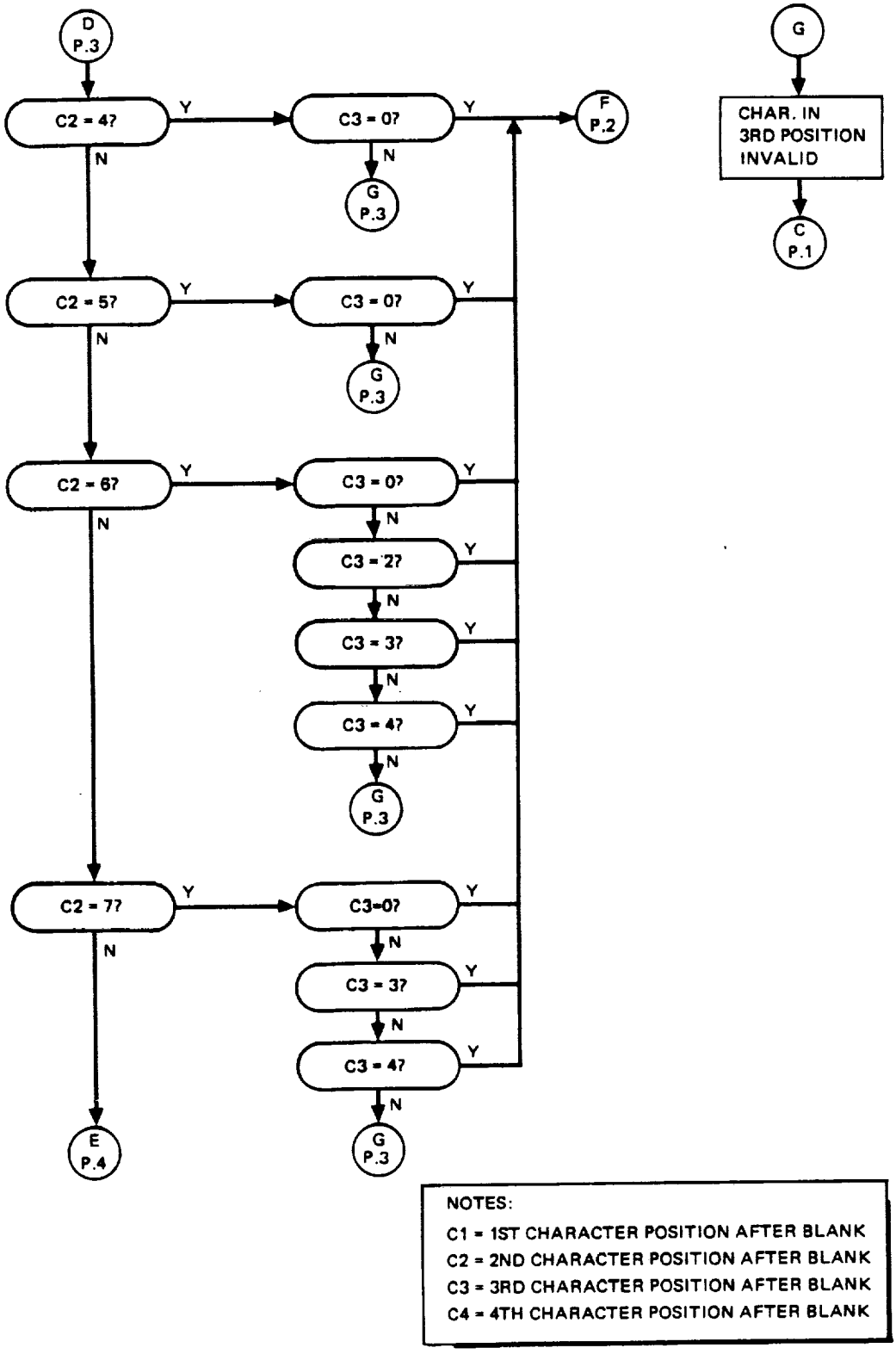
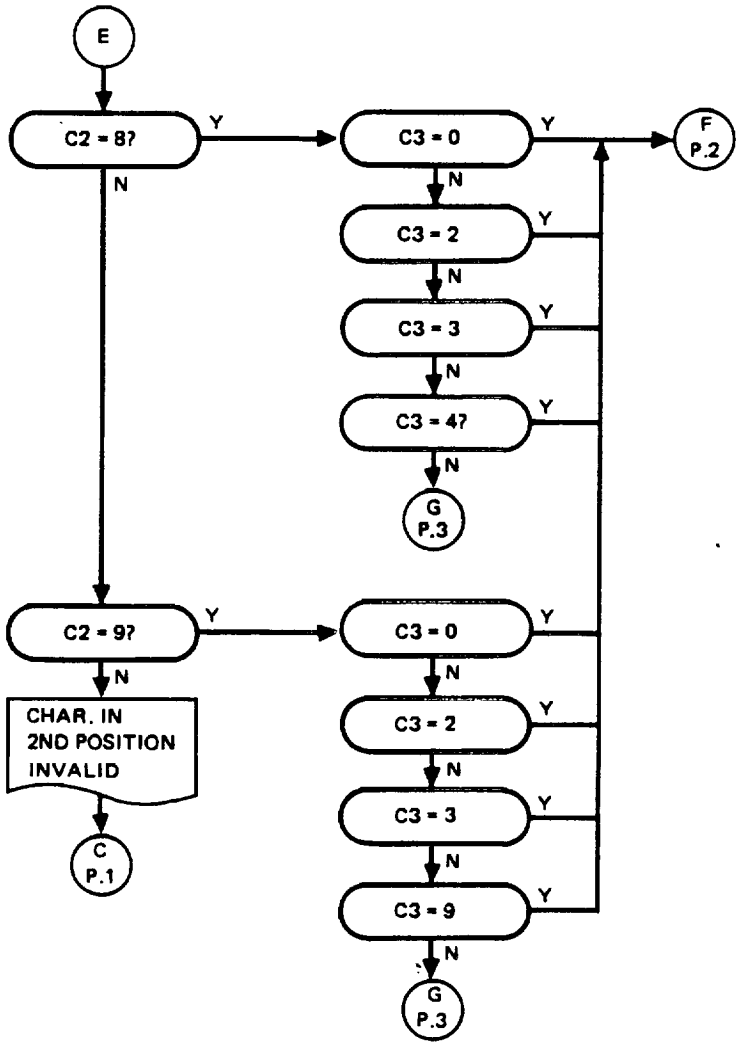


Figure G-3. Simplified Flow Chart Showing Method of Entering Tallies in Matrices (Page 3 of 4)



NOTES:
C1 = 1ST CHARACTER POSITION AFTER BLANK
C2 = 2ND CHARACTER POSITION AFTER BLANK
C3 = 3RD CHARACTER POSITION AFTER BLANK
C4 = 4TH CHARACTER POSITION AFTER BLANK

Figure G-3. Simplified Flow Chart Showing Method of Entering Tallies in Matrices (Page 4 of 4)

PRECEDING PAGE BLANK NOT FILMED

Appendix H

GLOSSARY OF NIPA INDICES

The 66 indices used for NIPA were developed from NIPA observations, psychological and other questionnaires, physiological measures, and life support and environmental control measures. The indices are given below with the associated abbreviation for each index used in the correlational analysis. The three-digit number at the beginning of each section is the card number on which the index values were entered.

Six of the indices in paragraph 1 and all of the indices in paragraph 2 incorporate distance measures. Actual computations were made using distances between the chamber areas (identified for the NIPA study) in which crewmen were located. Psychological distances are defined in Figure G-1 shown in Appendix G. Physical distances of 5 feet between adjacent areas were assumed.

1. On-line NIPA Indices (101) individual crewman
(151) crew means

Privacy Seeking (PVCY): A ratio composed of the number of times a crewman is alone in a numbered chamber area divided by the number of observations made on the crewman.

Psychological Dispersion (PDSPN): A ratio composed of the sum distances of an individual crewman, in psychological units, (based on NIPA investigators' subjective opinion as to how far one crewman would feel from another crewman if they were in the two areas), from the other three crewmen divided by the number of observations.

Physical Dispersion (DSPN): A ratio composed of the sum distances of individual crewmen, in actual feet, from the other three crewmen divided by the number of observations.

Motility, distance/move, Psychological (PD/MVE): A mean distance that an individual crewman moved, in psychological units, for every move the crewman made.

Motility, distance/move, actual (D/MVE): The mean distance moved by an individual crewman, in actual feet, for each move made by the crewman.

Motility, distance/time period, psychological (PD/TME): The mean distance moved by an individual crewman, in psychological units, per time period.

Motility, distance/time period, actual (D/TME): The mean distance moved by an individual crewman, in actual feet, per time period.

Non-Affect Ratio (O AFF): The ratio of asking information, plus giving information, divided by positive affect plus negative affect plus asking information plus giving information.

Receive-Initiate Ratio (RC-INT): A ratio of the number of communications an individual crewman received over the number of communications the crewman initiated plus the number of communications he received.

Positive Affect Ratio (+ AFF): A ratio composed of the frequency of positive statements divided by the sum of the frequency of negative statements plus the frequency of positive statements. This ratio is the inverse of the negative affect ratio.

Negative Affect Ratio (-AFF): A ratio consisting of the frequency of negative statements divided by the sum of the positive statements plus the negative statements. This ratio is the inverse of the positive affect ratio.

Task Press (TASK PR): This is a number on a scale from 1 to 7 which typified the pressure of engineering oriented tasks that the crew was experiencing in any 4-hour period. Number 1 on the scale represented the task press to be overwhelming and could not be done. Number 7 was extremely light task load or no engineering tasks at all.

Time on Tasks (TASK T1): The ratio of the number of observation periods spent working on tasks divided by the total number of observation periods. This is the percentage of the time that individual crewmen spent working on task-oriented activities.

2. On-line NIPA Indices (152) crew means only

Psychological dispersion between crewmen

1-2 (DSP1-2): The mean psychological distance of Crewman 1 from Crewman 2 per observation period.

1-3 (DSP1-3): The mean psychological distance of Crewman 1 from Crewman 3 per observation period.

1-4 (DSP1-4): The mean psychological distance of Crewman 1 from Crewman 4 per observation period.

2-3 (DSP2-3): The mean psychological distance of Crewman 2 from Crewman 3 per observation period.

2-4 (DSP2-4): The mean psychological distance of Crewman 2 from Crewman 4 per observation period.

3-4 (DSP3-4): The mean psychological distance of Crewman 3 from Crewman 4 per observation period.

Actual dispersion between crewmen

1-2 (DSA1-2): The mean actual distance, in feet, of Crewman 1 from Crewman 2 per observation period.

1-3 (DSA1-3): The mean actual distance, in feet, of Crewman 1 from Crewman 3 per observation period.

1-4 (DSA1-4): The mean actual distance, in feet, of Crewman 1 from Crewman 4 per observation period.

2-3 (DSA2-3): The mean actual distance, in feet, of Crewman 2 from Crewman 3 per observation period.

2-4 (DSA2-4): The mean actual distance, in feet, of Crewman 2 from Crewman 4 per observation period.

3. Outside Indices (201) individual crewman
(252) crew means

Effective Temperature (TEMP): A temperature in degrees celsius based on dry bulb temperature, wet bulb temperature, humidity, and air flow.

Comfort Zone Tally (X TEMP): The effective temperature incorporates measures of relative humidity, dry bulb temperature, wet bulb temperature, and air flow. The comfort zone tally is the number of times the effective SSS temperature appeared in the range called the comfort zone.

CO_2 Partial Pressure (CO_2): The partial pressure of CO_2 measured in Newtons/Sq. cm of mercury.

Complex Coordinator, Morning (PCM1): The score on the Langley Complex Coordinator measured in seconds for the total time the crewmen took to complete 100 trials; morning coordinator test.

Complex Coordinator, Noon (MCM2): The score on the Langley Complex Coordinator measured in seconds for the total time the crewmen took to complete 100 trials; noon coordinator tests.

Complex Coordinator, Evening (PCM3): The score on the Langley Complex Coordinator measured in seconds for the total time the crewmen took to complete 100 trials; evening coordinator test.

Work Load (U TASK): The total time a crewman spent on unscheduled tasks in minutes.

Number of Impositions (IMPOS): The number of calls received from the outside by a crewman requesting that he carry out some task related to the life support equipment.

Diary entries (DIARY): A binary measure for the presence or absence of a diary entry for any given day by any crewman. A score of 1 indicates the presence of an entry, zero indicates the absence of an entry.

Number of Outside Calls (OSCALL): The number of calls to persons outside the MDAC complex initiated by a crewman.

4. Questionnaire Indices, Sleep (205) individual crewman
(255) crew means

Retiring Time (RETIRE): The time of day, based on the 24-hour clock, that a crewman retired.

Duration of Sleep (DUR): The number of hours that an individual crewman reported that he was asleep.

Time to Fall Asleep (TM2ZZ): The time in hours and fractional hours a crewman reported that it took to fall asleep.

Numbers of Times Awoke (AWOKE): The total number of times a crewman reported that he awoke in the night.

How Feel in the Morning (ZFEEL): A subjective comment on how each crewman felt each morning was translated into a 4-point scale from zero to 3. The zero score meant that the crewman slept poorly, the 3 score meant that he slept very well.

5. Outside Indices, Physiological (209) individual crewman
(259) crew means

Free Fatty Acids (FRFAT): Metabolic products in the blood which have been observed to rise in concentration in response to exercise and possibly emotional stress. Numerical values represent concentration.

Sphingomyelin (SPHMYL): One type of free fatty acid, thought to be a major contributor to the general group of free fatty acids.

6. Outside Indices, Physiological (210) Individual crewman
(260) crew means

Urine electrolytes Na^+/K^+ (URINEL): A clinical measurement of physical condition included in the analyses to evaluate it as an indicator of emotional stress.

7. Questionnaire Indices (211) individual crewman
(261) crew means

Hostility Scale: A measure of mood on a continuum from pleasure to hostility. This scale was developed by the Naval Medical Research Institute, Bethesda, Maryland.

Hostility Scale, Toward Outside Crew (HSOCRW): The raw score range is from 00 to 97 with 15 choices of how the subject feels scored within this range.

Hostility Scale, Toward Inside Crew (HSICRW): The raw score range is from 00 to 97 with 15 choices of how the subject feels scored within this range.

Hostility Scale, Noise Equipment Compartment (HSEQCP): The raw score range is from 00 to 97 with 15 choices of how the subject feels scored within this range.

Hostility Scale, Noise Crew Compartment (HSCRWC): The raw score range is from 00 to 97 with 15 choices of how the subject feels scored within this range.

Primary Affect: Primary Affect Scale: Assesses the reaction of an individual to his environment on the feeling level. This scale was developed by the Naval Medical Research Institute, Bethesda, Maryland.

Primary Affect Scale, Happy (PAHAPY): The range of raw scores is from 00 to 38 with 15 choices available to the subject.

Primary Affect Scale, Angry (PAANGY): The range of raw scores is from 00 to 38 with 15 choices available to the subject.

Primary Affect scale, Depressed (PADPRS): The range of raw scores is from 00 to 30.

8. Questionnair Indices, Group Confinement Inventory (212) Individual crewman
(262) crew means

Group Confinement Inventory:* Assesses the effects of confinement on an individual in his relations to the group.

Number of Positives (GPCON+)

Number of Negatives (GPCON-)

Sum of Positives and Negatives (GPCONS)

*The original subgroupings for the Group Confinement Inventory and the Isolation Symptomatology Questionnaire were not used. For purposes of comparison with NIPA measures, all items were examined and data were used only for those items judged to contain positive or negative affect.

9. Questionnaire Indices, Isolation Symptomatology (213) individual crewman
(263) crew means

Isolation Symptomatology:* Assess an individual's mood reaction to isolation.

Number of Positives (ISOL+)

Number of Negatives (ISOL-)

Sum of Positives and Negatives (ISOL S)

10. Questionnaire Indices, Subjective Stress (214) individual crewman
(264) crew means

Subjective Stress (SUBJSS): measures the perceived stress from no stress to incapacitance. The raw score range is from 0 to 94 with 15 choices. This scale was developed by the Naval Medical Research Institute, Bethesda, Maryland.

11. Questionnaire Indices, Sociometry (215) individual crewman
(265) crew means

Sociometry:** A measure of integrity or cohesion of a small group, the on-board crew, modified from the Tektite program. The raw score range is from 0 to 6, the high score representing high cohesion.

Score A.A. (SOCIOA)

Score Q.B. (SOCIOB)

12. Questionnaire Indices, Descriptive Sentence (216) individual crewman
(266) crew means

Descriptive Sentence (DESCRS): Measures cognitive functioning and critical reasoning. This test is comparatively well correlated with I.Q. The raw score range is from 0 to 60. This test was developed by Baddeley and was called the three-minute reasoning test.

*The original subgroupings from the Group Confinement Inventory and the Isolation Symptomatology Questionnaire were not used. For purposes of comparison with NIPA measures, all items were examined and data were used only for those items judged to contain positive or negative affect.

**A score of 6 was assigned to the designee ranked at the top and a score of 1 to the designee ranked at the bottom. SOCIOA and SOCIOB scores were obtained by adding the weights (ranks) assigned to inside crewmen only (Outside crewmen who were performing support functions were included as possible sociometric choices).

13. Questionnaire of items on different Habitability features of the Space Station Simulator. The scores are a hedonic rating with a range from 1 to 4, 1 being the best rating, 4 being the worst.

Crew Quarters (HABCQU)

Equipment Quarters (HABEQU)

General Hygiene Area (HABHYG)

Miscellaneous Areas Facilities (HABMSC)

Mean (HABAVE)

Appendix I

BLOOD CHEMISTRY RESULTS

Table I-1. Blood Chemistry Results, Raw Data

Date		K^+ mEq/L	Na^+ mEq/L	Cl mg %	Ca^{++} mg %	Inorg. P mg %	Glucose mg %	BUN mg %	Uric Acid mg %	Cholesterol mg %	Tot. Protein gm %	Alb. gm %	Tot. Bilirub. Mg %	Alk. Phos. mU/ml	LDH mU/ml	SGOT mU/ml	Hgb gm	Hct. Vol %	RBC $\times 10^6/mm^3$	WBC $\times 10^3/mm^3$	MCV μ^3	MCH $\mu\mu g$	MCHC %	Eos. %	Segs. %	Lymphs. %	Monos %
5 26 70	1	4.4	139	104	9.9	3.51	85	17.2	4.4	158	7.93	5.18	0.81	40	98	28	15.1	46.1	4.82	9.7	93	30.9	33.1	0	74	25	1
18	2	4.1	138	105	9.2	3.74	85	18.0	5.4	200	7.31	4.33	0.46	23	182	29	14.8	43.7	4.90	4.4	88	29.7	33.3	1	68	28	3
Days	3	4.8	139	105	9.9	3.84	90	18.4	6.3	238	7.25	4.79	0.61	17	141	28	15.4	48.6	5.43	6.8	89	28.0	31.3	2	60	35	3
	4	4.2	138	108	9.9	3.82	83	16.1	6.3	183	6.46	4.67	2.20	31	124	31	15.9	45.7	5.15	5.8	89	30.3	34.2	0	74	24	2
6 2 70	1	4.6	138	100	9.7	3.98	86	19.4	4.1	136	7.76	4.89	0.85	56	107	32	15.1	44.2	4.82	6.9	89	31.2	33.9	2	56	41	1
11	2	4.4	138	100	9.2	3.79	87	11.4	4.9	192	7.28	4.36	0.52	22	140	28	15.4	43.0	4.73	5.2	91	32.5	35.9	1	53	42	5
Days	3	4.2	140	100	9.7	4.01	93	15.9	6.1	236	7.28	4.79	0.44	21	142	23	16.2	48.1	5.41	6.2	83	29.7	34.1	4	56	39	1
	4	4.2	138	106	9.2	3.90	87	13.0	6.8	202	6.41	4.48	2.76	39	116	32	16.7	47.7	5.39	5.9	83	30.9	35.6	0	50	48	1
6 9 70	1	4.3	136	101	9.9	3.13	89	12.4	3.8	144	7.85	4.91	0.52	49	114	31	15.3	44.9	4.83	6.3	92	32.2	33.7	0	68	28	4
4	2	4.4	139	106	9.9	4.14	87	14.3	6.0	234	7.62	4.72	0.76	18	152	28	15.1	46.3	5.07	4.1	90	31.6	33.8	1	53	42	4
Days	3	4.2	142	108	10.0	4.08	92	17.4	7.0	208	6.94	4.57	0.48	18	130	17	15.0	45.4	5.28	6.0	85	29.6	35.0	2	68	28	2
	4	4.0	138	101	9.8	4.16	96	11.2	6.3	184	6.75	4.84	1.77	46	156	31	16.5	46.9	5.44	6.2	87	31.4	34.7	0	65	30	5
6 12 70	1	4.4	139	108	9.4	3.50	—	—	—	—	—	—	—	—	—	—	16.3	46.4	4.92	6.0	93	30.8	32.9	3	63	31	2
1	2	4.6	138	110	9.8	2.90	—	—	—	—	—	—	—	—	—	—	14.9	43.9	4.87	4.8	89	30.2	34.0	0	60	38	2
Days	3	3.9	138.5	103	9.4	3.70	—	—	—	—	—	—	—	—	—	—	16.6	47.8	5.35	5.7	88	28.7	32.6	1	64	31	4
	4	4.1	141	107	9.2	3.20	—	—	—	—	—	—	—	—	—	—	17.0	48.8	5.60	7.0	89	30.4	34.2	1	61	34	4
6 23 70	1	4.2	138	103	9.4	3.84	88	15.7	4.0	137	7.38	4.81	0.54	37	110	32	15.6	46.1	5.18	5.6	91	30.3	33.3	1	60	36	3
Test	2	4.4	137	102	9.4	4.36	88	16.3	5.0	203	7.45	4.83	0.35	18	200	74	15.0	44.1	5.06	4.9	87	29.6	33.9	2	65	30	3
Day	3	4.3	139	105	9.5	4.22	92	25.6	7.4	205	6.98	4.74	0.43	17	140	33	15.1	46.3	5.24	7.8	86	28.9	32.6	2	63	30	5
11	4	4.3	138	101	9.4	4.34	121	20.5	6.2	205	6.83	5.07	2.35	32	130	38	16.4	47.0	5.40	5.1	83	28.8	33.0	1	59	38	2
7 7 70	1	4.2	137.5	100	9.9	4.12	118	14.2	4.2	130	7.75	4.94	0.75	40	108	27	15.6	46.6	4.87	5.9	93	31.2	34.2	0	62	34	4
Test	2	3.8	138	101	9.5	4.60	90	16.7	5.7	240	7.80	4.83	0.53	20	148	30	15.8	47.1	5.03	6.0	92	30.4	33.9	0	66	43	2
Day	3	4.0	141	103	9.6	5.22	90	26.0	7.2	207	6.68	4.52	0.38	18	151	30	13.7	41.4	4.59	8.9	88	29.3	34.0	0	70	28	2
26	4	4.2	140	103	9.7	4.36	88	16.8	6.7	187	6.52	4.58	2.14	37	128	37	15.0	44.6	4.95	6.6	88	29.8	34.3	1	70	27	2
7 21 70	1	4.1	140	104	10.4	3.30	87	14.6	4.4	160	8.10	4.60	0.90	36	115	31	15.7	45.7	5.15	6.0	89	30.7	35.1	2	66	29	3
Test	2	4.0	141	105	10.0	4.30	87	14.0	6.1	240	7.50	3.95	0.70	14	140	32	15.8	46.5	5.17	4.7	89	30.8	35.0	1	59	36	4
Day	3	4.0	142	103	10.0	4.65	95	22.0	6.2	247	7.30	4.10	0.40	17	130	26	14.7	46.3	5.28	7.9	90	28.1	32.0	1	62	36	1
39	4	4.4	141	104	9.8	3.40	90	16.0	6.0	198	6.60	4.10	2.35	32	136	27	16.0	46.9	5.15	4.7	91	31.0	34.2	1	70	26	3
8 4 70	1	4.1	140	103	9.7	4.31	79	15.2	4.1	143	7.77	5.08	0.75	35	120	38	15.5	47.0	4.83	5.4	98	32.5	32.9	1	56	43	1
Test	2	3.8	140	103	9.8	4.64	76	17.1	5.9	242	7.94	4.89	0.93	20	148	38	15.3	46.4	4.81	4.9	97	32.3	33.0	1	50	46	3
Day	3	4.3	141	103	9.8	4.80	86	20.0	5.4	205	7.02	4.73	0.38	20	156	40	14.4	46.2	4.85	7.2	93	30.3	32.0	1	64	34	1
53	4	4.0	140	103	9.7	4.37	82	19.6	5.7	184	6.89	4.93	2.26	25	126	32	15.1	43.7	4.73	7.1	93	32.4	34.5	1	65	33	1
8 18 70	1	4.0	135	106	9.8	4.48	82	17.2	4.1	127	7.28	4.91	0.43	33	98	38	14.3	44.5	4.86	4.9	96	31.4	32.7	0	57	43	0
Test	2	3.5	138	100	9.2	4.38	83	19.1	6.8	216	7.31	4.67	0.57	17	120	38	15.2	45.6	4.89	5.0	94	31.8	33.8	0	52	46	3
Day	3	4.2	137	102	9.8	3.88	88	19.5	8.2	218	7.00	4.86	0.36	11	132	48	14.2	44.1	4.92	8.1	91	28.6	32.7	1	68	30	1
87	4	4.2	137	106	9.8	4.37	89	20.2	6.5	184	6.77	5.18	1.89	24	124	57	15.4	46.5	5.10	6.8	90	30.8	34.4	0	74	26	1
9 1 70	1	3.8	140	103	9.2	4.50	91	14.7	4.2	143	7.87	5.14	0.48	41	108	39	16.0	46.5	5.28	6.1	92	31.7	34.3	0	62	32	6
Test	2	3.7	141.5	104	9.9	4.70	92	16.5	5.7	225	7.68	4.78	0.56	20	131	35	15.8	45.6	5.20	5.6	92	31.8	34.7	0	52	46	2
Day	3	3.8	141	105	8.8	4.40	97	23.3	6.5	222	7.11	4.77	0.35	20	129	39	15.1	42.9	5.12	10.5	88	30.7	35.0	2	60	33	5
81	4	4.4	141.5	106	9.3	4.00	88	23.7	5.9	191	6.88	5.07	2.01	21	129	44	15.6	46.9	5.42	6.4	89	30.1	34.1	0	65	32	3
9 8 70	1	3.9	139	101	9.2	4.10	76	14.0	4.1	134	7.58	4.96	0.59	40	98	35	14.8	44.8	4.80	5.1	93	30.9	33.1	3	58	36	3
Test	2	3.6	138	97	9.2	4.61	79	15.8	6.0	229	8.00	4.99	0.56	21	118	30	16.0	46.2	5.05	5.1	92	31.1	34.3	3	53	42	2
Day	3	3.7	137.5	103	9.2	4.42	92	19.5	6.2	232	7.26	4.93	0.27	24	149	36	14.6	42.8	4.83	9.7	88	29.7	34.0	1	62	33	4
88	4	3.9	138.5	105	9.5	3.88	74	16.3	5.9	181	6.76	5.10	1.92	31	121	44	14.9	42.9	4.83	6.4	89	30.3	34.6	1	63	32	4
9 15 70	1	4.2	139	104	10.1	3.73	84	19.9	4.2	147	7.61	5.00	0.71	49	120	44	14.3	42.9	4.73	4.9	90	30.2	33.9	1	68	29	1
+4	2	4.0	136	95	9.7	3.48	86	14.5	6.3	218	7.85	4.92	0.65	21	126	35	16.5	46.0	5.00	5.0	87	30.0	33.1	1	71	24	4
Days	3	3.9	140	104	10.2	4.25	86	20.1	6.6	241	7.22	4.87	0.44	20	123	31	14.5	43.2	5.02	5.2	86	28.7	33.9	1	63	34	2
(Fasting)	4	4.1	137	100	10.0	3.91	86	15.4	5.2	184	6.68	5.08	1.18	33	100	35	15.7	44.7	5.23	5.0	85	30.1	35.8	2	60	35	3
+4	1	—	—	—	9.8	3.56	81	18.6	4.1	138	7.31	4.90	0.64	35	107	30	—	—	—	—	—	—	—	—	—	—	—
Days	2	—	—	—	9.6	3.39	80	13.8	6.1	190	7.85	4.87	0.63	16	123	34	—	—	—	—	—	—	—	—	—	—	—
(2 Hr Post	3	—	—	—	9.8	3.81	93	19.5	6.2	226	6.64	4.61	0.36	16	110	31	—	—	—	—	—	—	—	—	—	—	—
Prandial)	4	—	—	—	9.5	3.89	86	14.2	5.1	186	6.41	4.91	1.33	30	95	31	—	—	—	—	—	—	—	—	—	—	—
Normal Range (Fasting)		3.6 – 5.5	132 – 152	98 – 108	8.5 – 10.5	2.5 – 4.5	65 – 110	10 – 20	2.5 – 8.0	130 – 300	6.0 – 8.0	3.5 – 5.0	0.15 – 1.00	30 – 85	90 – 200	10 – 50	14 – 18	42 – 52	4.6 – 6.2	4.8 – 10.8	80 – 94	27 – 31	32 – 36	1 – 4	51 – 67	20 – 30	5 – 10

NOTES: ADDITIONAL PRETEST SAMPLES WERE OBTAINED BETWEEN 1-29-70 AND 5-26-70; THESE DATA POINTS WERE INCLUDED IN CALCULATING PRETEST CONTROL MEAN VALUES (SEE SUBSECTION 4.1.2) FOR EACH CREW MEMBER

Appendix J

URINE CHEMISTRY RESULTS

Table J-1. Urine Chemistry (Page 1 of 3)

DATE	TEST DAY	C M	P_{CO_2} (mmHg) (1) SAMPLE	WEEK	RANGE	TO DATE	pH	T.A. (mEq/ 24 hrs)	H^+ (mEq/ 24 hrs)	Na^+ (mEq/ 24 hrs)	K^+ (mEq/ 24 hrs)	Cl^- (mEq/ 24 hrs)	Ca^{++} (mEq/ 24 hrs)	$PO_4^{=}$ (mg/ 24 hrs)	SP. GRAV.	VOL. (ml/24h)	REMARKS/NOTES
6-16 1970	4	1	4.84	4.50	3.79- 5.24	4.50	6.3	43.7	73.7	242	50	222	107	950	1.022	1,215	(1) P_{CO_2} DURING SAMPLE PERIOD
		2	4.84				6.2	42.4	72.4	263	61	238	119	930	1.025	1,212	
		3	4.80				6.6	52.4	92.4	312	69	252	139	1,380	1.025	1,415	
		4	4.80				6.7	36.4	75.4	244	67	207	101	900	1.024	1,363	
		$\bar{x}$	4.82				6.45	43.47	78.57	265.2	61.75	229.75	116.50	1,040	1.0237	1,301.2	
6-23 1970	11	1	4.84	4.91	4.28- 5.50	4.81	6.6	46.5	76.5	295	79	215	202	1,580	1.020	1,500	
		2	4.84				6.4	43.8	73.8	175	54	147	120	1,660	1.025	1,301	
		3	5.05				6.1	56.0	96.0	167	62	142	121	1,220	1.024	1,175	
		4	5.05				6.5	60.0	100.0	285	94	212	145	1,800	1.020	1,426	
		$\bar{x}$	4.94				6.40	51.57	86.57	230.5	72.25	179.00	147.00	1,565	1.0222	1,350.5	
6-30 1970	18	1	4.40	5.41	3.66- 9.00	5.07	5.6	49.9	76.9	145	43	137	108	660	1.026	875	
		2	4.40				5.8	45.7	83.7	130	39	116	126	920	1.020	1,085	
		3	4.00				5.8	52.8	92.8	170	65	148	122	1,100	1.025	1,100	
		4	4.00				6.2	45.1	90.1	218	55	188	174	1,080	1.017	1,620	
		$\bar{x}$	4.20				5.85	48.37	85.87	165.7	50.50	147.25	132.50	940	1.0220	1,170.0	
7-7 1970	25	1	5.06	5.52	4.25- 9.90	5.21	6.0	30.9	62.9	135	29	123	77	750	1.020	965	
		2	5.06				6.2	39.0	83.0	231	58	206	112	1,060	1.018	1,399	
		3	4.93				5.6	64.4	97.2	222	88	222	107	1,370	1.027	1,192	
		4	4.93				5.7	73.5	116.5	290	72	288	164	1,480	1.027	1,792	
		$\bar{x}$	5.00				5.87	51.95	89.90	219.5	61.75	209.75	115.00	1,165.0	1.0230	1,337	
7-14 1970	32	1	4.64	4.97	3.90- 7.18	5.15	6.1	37.5	66.5	220	51	188	102	1,300	1.022	1,250	
		2	4.64				5.9	52.2	101.2	213	45	252	96.7	1,400	1.025	1,274	
		3	4.40				6.2	53.5	97.5	378	107	336	146	2,100	1.025	1,844	
		4	4.40				5.8	75.9	121.9	376	79	337	139	2,100	1.027	1,651	
		$\bar{x}$	4.52				6.00	54.77	96.77	296.7	70.50	278.00	120.75	1,725	1.0247	1,504.7	
7-21 1970	39	1	3.84	4.74	3.26- 7.70	5.07	6.1	32.2	80.2	140	45	137	135	830	1.015	1,400	
		2	3.84				6.1	29.3	64.3	183	44	167	142	810	1.016	1,467	
		3	3.48				6.2	53.3	108.3	298	89	250	200	1,600	1.023	1,805	
		4	3.48				6.3	41.1	95.1	319	106	282	134	1,700	1.027	1,417	
		$\bar{x}$	3.66				6.17	38.47	86.97	235.0	70.75	209.00	152.75	1,237.5	1.0202	1,522.2	
7-28 1970	46	1	6.30	4.48	3.53- 8.20	4.98	6.0	41.6	86.6	179	57	160	163	1,200	1.016	1,489	
		2	6.30				6.2	29.4	72.4	236	54	216	173	900	1.016	1,470	
		3	4.60				5.8	53.2	94.2	163	51	126	109	1,400	1.027	986	
		4	4.60				5.9	54.8	91.8	237	76	236	134	1,300	1.026	1,246	
		$\bar{x}$	5.46				5.97	44.75	86.25	203.7	59.50	184.25	144.75	1,200	1.0212	1,297.8	

Table J-1. Urine Chemistry (Page 2 of 3)

DATE	TEST DAY	C M	P_{CO_2} (mmHg) (1) SAMPLE	WEEK	RANGE	$\bar{X}$ TO DATE	pH	T.A. (mEq/ 24 hrs)	H^+ (mEq/ 24 hrs)	Na^+ (mEq/ 24 hrs)	K^+ (mEq/ 24 hrs)	Cl^- (mEq/ 24 hrs)	Ca^{++} (mEq/ 24 hrs)	$PO_4^{\equiv}$ (mg/ 24 hrs)	SP GRAV	VOL (ml/ 24 hrs)	REMARKS/NOTES
8-4-1970	53	1	5.97	6.70	5.48-9.20	5.21	5.9	43.3	108.3	222	81	208	104	1,240	1.025	1,084	(1) P_{CO_2} DURING SAMPLE PERIOD
		2	5.97				5.8	34.8	82.8	206	41	186	96	980	1.019	1,023	
		3	5.92				6.4	49.0	99.0	331	96	287	85	1,840	1.026	1,440	(2) MEAN FOR PERIOD BETWEEN END OF SAMPLE PERIODS FOR THIS AND SUBSEQUENT COLLECTIONS; ALSO APPLIES TO RANGE
		4	5.92				6.4	48.0	100.0	415	99	337	89	1,700	1.028	1,598	
		$\bar{x}$	5.94				6.12	43.77	97.52	293.2	79.00	264.50	93.50	1,435	1.0245	1,286.5	
8-7-1970	56	1	5.05	4.97[2]	4.50-6.10	5.20	6.4	28.0	61.0	147	53	108	109	1,100	1.020	1,334	
		2	5.05				6.4	33.3	61.3	240	48	179	95	1,300	1.024	1,232	
		3	4.74				6.1	42.0	81.0	210	87	206	85	1,800	1.029	1,234	
		4	4.74				5.9	57.5	112.5	295	80	276	156	1,900	1.026	1,516	
		$\bar{x}$	4.90				6.20	40.20	78.95	223.0	67.00	192.25	111.25	1,525	1.0247	1,329.0	
8-11-1970	60	1	8.88	7.43	4.35-9.58	5.36	6.3	35.8	73.8	236	68	218	133	1,300	1.020	1,626	
		2	8.88				6.4	33.5	65.5	260	64	235	122	1,300	1.019	1,679	
		3	9.15				6.3	47.0	84.0	318	80	258	114	1,900	1.026	1,517	
		4	9.15				6.6	34.6	66.6	415	90	350	138	2,000	1.023	1,730	
		$\bar{x}$	9.02				6.40	37.72	72.47	307.2	75.50	265.25	126.75	1,625	1.0220	1,638.0	
8-14 1970	63	1	4.78	6.59	4.50-8.84	5.42	6.3	34.1	79.1	240	80	206	183	1,160	1.025	1,550	
		2	4.78				6.3	36.7	68.7	252	62	209	94	1,310	1.030	1,147	
		3	4.90				6.4	52.4	106.4	347	85	296	220	2,060	1.025	1,690	
		4	4.90				6.0	48.0	100.0	331	75	294	200	1,450	1.027	1,652	
		$\bar{x}$	4.84				6.25	42.80	88.55	292.5	70.50	251.25	174.25	1,495	1.0267	1,509.7	
8-18 1970	67	1	6.30	5.47	4.50-6.70	5.43	6.4	36.5	75.5	195	69	145	181	1,330	1.023	1,257	
		2	6.30				6.2	36.2	69.2	204	64	176	113	1,610	1.030	1,133	
		3	5.96				6.2	51.0	95.0	208	70	179	175	1,640	1.025	1,341	
		4	5.96				6.1	58.5	107.5	286	91	252	186	2,140	1.027	1,428	
		$\bar{x}$	6.13				6.22	46.55	86.80	223.2	73.50	188.00	163.75	1,680	1.0262	1,269.7	
8-21 1970	70	1	6.04	5.70	4.80-6.86	5.44	6.0	39.4	86.4	178	50	182	166	1,000	1.011	2,074	
		2	6.04				6.2	36.0	66.0	245	62	214	93	1,160	1.016	1,711	
		3	5.83				6.1	37.8	71.8	195	59	168	83	1,400	1.022	1,095	
		4	5.83				5.3	69.0	124.0	201	78	219	88	1,430	1.026	1,259	
		$\bar{x}$	5.94				5.90	46.55	87.05	204.7	62.25	196.75	107.50	1,248	1.0187	1,534.7	
8-25 1970	74	1	6.38	6.16	5.50-7.25	5.47	6.3	20.3	63.3	262	42	236	114	1,260	1.015	1,757	
		2	6.38				6.5	17.2	52.2	312	49	274	124	1,370	1.015	1,901	
		3	6.11				6.4	24.5	72.5	416	82	380	131	1,880	1.021	1,877	
		4	6.11				5.9	36.8	89.8	383	70	336	116	1,900	1.023	1,665	
		$\bar{x}$	6.24				6.27	24.70	69.45	243.2	60.75	301.50	121.25	1,802	1.0185	1,764.0	

Table J-1. Urine Chemistry (Page 3 of 3)

DATE	TEST DAY	C M	P_{CO_2} (mmHg) (1) SAMPLE	WEEK	RANGE	TO DATE	pH	T.A. (mEq/ 24 hrs)	H^+ (mEq/ 24 hrs)	Na^+ (mEq/ 24 hrs)	K^+ (mEq/ 24 hrs)	Cl^- (mEq/ 24 hrs)	Ca^{++} (mEq/ 24 hrs)	$PO_4^{\equiv}$ (mg/ 24 hrs)	SP GRAV	VOL (ml/ 24 hrs)	REMARKS/NOTES
8-28 1970	77	1	6.78	7.13	6.04-8.35	5.56	6.3	39.2	88.2	232	62	218	153	1,160	1.014	2,068	(1) P_{CO_2} DURING SAMPLE PERIOD
		2	6.78				6.0	42.6	76.6	204	56	199	110	1,050	1.022	1,252	
		3	7.52				6.6	53.1	107.1	323	88	299	121	1,620	1.022	1,835	
		4	7.52				6.1	62.6	115.6	405	93	358	116	1,960	1.024	1,845	
		$\bar{x}$	7.15				6.25	49.37	96.87	291.0	74.75	268.5	125.00	1,447.5	1.0205	1,750.0	
9-1 1970	81	1	7.71	7.43	6.90-8.50	5.63	6.5	22.0	44.0	152	42	131	90	660	1.017	1,100	
		2	7.71				6.0	38.0	65.0	163	49	144	89	1,110	1.015	1,584	
		3	7.49				6.2	59.2	112.2	227	90	196	186	1,700	1.023	1,600	
		4	7.49				6.2	56.1	102.1	362	119	321	214	1,750	1.025	1,754	
		$\bar{x}$	7.60				6.22	43.82	80.82	226.0	75.00	198.0	144.75	1,305	1.020	1,509.5	
9-4 1970	84	1	4.60	5.90	4.20-11.30	5.65	5.8	44.4	88.4	161	42	274	114	1,310	1.017	1,305	
		2	4.60				5.9	52.4	94.4	204	43	166	115	1,590	1.015	1,804	
		3	4.54				6.0	48.7	97.7	246	46	220	161	1,650	1.024	1,215	
		4	4.54				5.3	52.8	107.8	181	50	195	119	1,240	1.027	999	
		$\bar{x}$	4.57				5.75	49.57	97.07	198.0	45.25	213.75	127.25	1,447.5	1.0207	1,330.7	
9-8 1970	88	1	4.78	4.58	4.18-5.10	5.61	5.9	36.3	78.3	134	27	127	96	1,150	1.021	1,010	
		2	4.78				6.1	32.1	61.1	144	33	111	81	1,130	1.019	1,105	
		3	4.47				5.8	54.8	114.8	246	58	234	178	1,850	1.025	1,306	
		4	4.47				6.0	51.2	93.2	242	84	222	144	2,140	1.027	1,190	
		$\bar{x}$	4.62				5.95	43.6	86.85	191.5	50.50	173.5	124.75	1,567.5	1.0230	1,152.7	
9-10 1970	90	1	5.38	5.35	5.00-5.80	5.60	6.3	23.4	54.4	139	32	118	94	850	1.019	902	
		2	5.38				6.0	36.0	61.0	190	37	152	106	1,180	1.015	1,472	
		3	5.39				6.1	51.5	101.5	219	59	188	160	1,720	1.024	1,228	
		4	5.39				6.2	36.0	73.0	294	71	257	162	1,260	1.023	1,284	
		$\bar{x}$	5.38				6.15	36.72	72.47	210.5	49.75	178.75	130.50	1,252.5	1.0202	1,221.5	
9-17 1970	+7	1					5.8	38.2	80.2	119	55	121	104	800	1.024	931	
		2					5.6	29.2	59.2	110	41	117	93	610	1.012	1,458	
		3					6.8	38.1	75.1	305	212	330	232	1,740	1.025	1,811	
		4					6.7	22.5	58.5	322	99	308	207	900	1.015	2,250	
		$\bar{x}$					6.22	32.00	68.25	214.0	101.75	219.00	159.00	1,012.5	1.0190	1,612.5	

Appendix K
USNSMC VENOUS BLOOD GAS AND ELECTROLYTE DATA

Table K-1. USNSMC Venous Blood Gas and Electrolyte Data (1 of 4)

R292

S = DATE SAMPLED A = DATE ANALYZED TEST DAY	CREWMAN	PLASMA							RED CELLS					
		pH	P_{CO_2} mm Hg	HCO_3^- mEq/L	Na^+ mEq/L	K^+ mEq/L	Cl^- mEq/L	H_2O %	pH	HCO_3^- mEq/L	Na^+ mEq/L	K^+ mEq/L	Cl^- mEq/L	H_2O %
S-6-9-70	1.	7.323	52.3	26.2	135.5	4.3	102.2	90.7	7.179	16.0	23.5	77.7	63.8	66.5
A-6-11-70	2.	7.334	53.8	27.5	153.0	4.1	111.8	88.1	7.177	16.3	21.5	76.5	64.8	69.7
	3.	7.386	49.6	28.6	140.5	3.8	104.3	91.0	7.254	18.0	25.5	77.0	64.9	71.7
-1	4.	7.289	56.6	25.8	128.5	4.1	98.4	91.3	7.143	15.9	21.0	85.8	67.2	76.6
	$\bar{x}$	(7.333)	(53.0)	(27.0)	(139.38)	(4.08)	(104.18)	(90.52	(7.188)	(16.6)	(22.98)	(79.00)	(65.12)	(71.12)
	CONTROL I	7.400	44.4	26.5	126.5	3.9	98.4	91.2	7.272	16.8	22.2	76.5	63.3	69.0
	CONTROL II	7.346	51.4	25.2	129.5	3.8	97.9	91.0	7.165	15.2	21.1	73.3	65.1	76.7
	$\bar{x}$	(7.388)	(47.9)	(25.8)	(128.0)	(3.85)	(98.65)	(91.10)	(7.218)	(16.0)	(21.65)	(74.90)	(64.20)	(72.85)
S-6-16-70	1.	7.360	52.0	28.4	128.0	3.7	103.2	91.5	7.218	17.4	20.8	56.3	50.0	63.9
A-6-19-70	2.	7.356	48.4	26.1	139.5	3.8	101.1	91.8	7.200	16.5	29.9	76.0	64.9	70.6
	3.	7.336	57.4	26.5	133.0	3.8	104.4	91.5	7.208	16.7	25.5	75.5	62.0	69.5
4	4.	7.364	53.4	28.7	136.5	4.1	99.1	91.4	7.217	17.8	26.6	69.6	64.2	62.7
	$\bar{x}$	(7.352)	(51.3)	(27.4)	(134.25)	(3.85)	(101.95)	(91.56)	(7.210)	(17.1)	(25.70)	(69.35)	(60.28)	(66.68)
	CONTROL II	7.368	55.0	29.8	133.5	4.1	100.9	91.4	7.209	18.0	28.1	71.0	65.7	63.8
S-6-23-70	1.	7.354	51.0	27.5	132.0	3.9	101.2	90.3	7.204	16.5	27.1	74.7	66.4	72.9
A-6-25-70	2.	7.338	52.0	26.9	131.5	3.4	96.1	90.3	7.182	16.0	25.3	73.9	72.6	73.1
	3.	7.364	48.8	26.2	137.5	4.0	100.7	84.8	7.210	16.0	24.8	76.2	67.5	75.4
11	4.	7.293	56.0	26.2	139.0	4.2	99.6	83.5	7.159	16.2	24.7	78.0	65.6	76.4
	$\bar{x}$	(7.335)	(52.0)	(26.7)	(135.00)	(3.88)	(99.40)	(87.22)	(7.189)	(16.4)	(25.48)	(75.70)	(68.02)	(74.45)
	CONTROL I	7.377	53.6	28.0	138.0	3.8	98.2	97.2	7.220	18.0	26.2	72.0	(65.1)	78.8
S-6-30-70	1.	7.327	60.0	30.2	139.0	3.8	108.1	91.0	7.181	18.4	20.2	82.9	71.6	60.0
A-7-2-70	2.	7.248	70.8	29.1	137.0	3.6	101.5	90.2	7.078	17.1	26.6	78.5	69.3	60.9
	3.	7.203	82.0	30.9	136.5	3.5	106.3	89.8	7.059	19.0	22.3	82.6	69.2	71.0
18	4.	7.226	78.0	30.7	138.0	3.8	102.0	91.1	7.078	18.9	21.2	80.2	67.5	71.7
	$\bar{x}$	(7.251)	(72.6)	(30.2)	(137.38)	(3.68)	(104.48)	(90.50)	(7.099)	(18.4)	(22.58)	(81.05)	(69.40)	(65.90)
	CONTROL II	7.294	73.6	34.3	135.0	4.2	101.2	91.1	7.142	20.6	23.9	79.9	69.5	63.2
S-7-7-70	1.	7.313	60.5	29.5	134.5	3.9	95.9	91.1	7.172	18.2	23.5	76.3	64.3	60.6
A-7-9-70	2.	7.362	56.4	29.7	134.0	3.6	96.9	90.6	7.215	18.4	28.1	81.5	64.3	62.2
	3.	7.315	52.6	25.6	136.0	3.6	99.2	91.9	7.131	14.4	34.2	70.8	66.0	58.2
25	4.	7.411	47.7	29.6	137.0	4.3	100.0	92.2	7.266	17.8	32.7	71.3	71.7	76.7
	$\bar{x}$	(7.348)	(54.0)	(28.6)	(135.12)	(3.85)	(98.00)	(91.5)	(7.196)	17.2	(29.62)	(74.98)	(66.58)	(64.42)
	CONTROL II	7.378	51.0	29.0	135.0	4.4	99.2	91.5	7.229	17.5	30.5	73.0	71.1	62.7
S-7-14-70	1.	7.364	49.2	27.2	134.5	3.8	99.1	91.7	7.225	16.6	33.9	73.9	69.3	61.4
A-7-16-70	2.	7.362	54.8	29.3	134.5	3.5	103.7	90.9	7.208	17.9	34.9	72.6	73.3	64.8
	3.	7.373	50.0	28.3	140.0	4.1	100.1	91.2	7.220	16.8	24.6	75.4	68.0	62.5
32	4.	7.378	52.5	29.8	137.0	3.8	104.9	91.7	7.234	18.2	33.4	69.5	68.7	66.1
	$\bar{x}$	(7.367)	(51.6)	(28.6)	(136.50)	(3.80)	(102.0)	(91.4)	(7.222)	(17.4)	(31.70)	(72.85)	(69.82)	(63.70)
	CONTROL I (HEMOLYZED)	7.391	56.4	32.6	141.5	5.2	98.6	91.3	7.269	20.8	56.3	68.1	68.6	53.1

Table K-1. USNSMC Venous Blood Gas and Electrolyte Data (2 of 4)

R292

DATE TEST DAY	CREWMAN	PLASMA							RED CELLS					
		pH	P_{CO_2}	HCO_3^-	Na^+	K^+	Cl^-	H_2O	pH	HCO_3^-	Na^+	K^+	Cl^-	H_2O
S-7-21-70	1.	7.374	56.2	31.8	134.8	4.0	101.3	90.6	7.234	19.5	30.4	79.6	61.4	64.4
A-7-23-70	2.	7.408	49.8	30.4	139.5	4.1	108.0	90.6	7.266	18.6	29.7	74.3	66.0	71.2
39	3.	7.396	48.5	29.4	140.3	3.9	108.7	90.3	7.255	18.0	34.8	70.3	63.5	63.9
	4.	7.424	43.8	27.7	139.5	4.2	108.0	91.7	7.288	17.2	30.2	71.2	61.3	75.7
	$\bar{x}$	(7.400)	(49.8)	(29.8)	(138.52)	(4.05)	(106.5)	(90.8)	(7.261)	(18.3)	(31.28)	(74.00)	(63.06)	(68.80)
	Control I	7.396	52.2	31.0	130.5	3.9	101.8	90.2	7.273	19.8	31.3	71.6	61.5	67.6
S-7-28-70	1.	7.355	52.2	28.2	132.5	4.0	97.3	90.8	7.212	17.2	35.7	66.0	67.7	70.2
A-7-30-70	2.	7.348	58.5	30.7	138.0	4.5	101.1	90.9	7.201	18.8	44.2	67.0	71.8	58.8
	3.	7.391	48.2	28.5	134.5	4.0	102.4	91.7	7.239	18.9	39.4	66.0	62.5	59.5
	4.	7.390	46.6	27.2	133.5	3.9	103.9	92.2	7.246	16.6	36.7	64.8	63.9	61.7
46	$\bar{x}$	(7.371)	(51.4)	(28.6)	(134.62)	(4.1)	(101.18)	(91.4)	(7.224)	(17.4)	(39.00)	(65.95)	(66.42)	(62.56)
	CONTROL I	7.390	50.6	29.5	134.0	4.1	101.4	90.7	7.252	18.3	40.9	62.5	73.1	59.3
	CONTROL II	7.397	43.0	25.6	134.5	3.9	101.4	91.2	7.262	15.9	35.3	62.2	65.2	63.6
	CONTROL III	7.381	47.5	27.2	133.0	4.0	100.6	91.4	7.243	16.8	42.8	67.0	68.9	57.6
	$\bar{x}$	(7.389)	(47.0)	(27.4)	(133.8)	(4.0)	(101.13)	(91.1)	(7.262)	(17.0)	(39.7)	(63.90)	(69.07)	(60.17)
S-8-4-70	1.	7.356	49.5	26.7	133.0	4.1	100.0	90.9	7.219	16.6	36.6	79.2	80.4	66.0
A-8-12-70	2.	7.354	48.0	25.9	130.5	3.8	102.3	-	7.212	15.8	43.1	71.1	79.3	58.1
	3.	7.405	42.0	25.5	142.0	4.3	108.1	90.8	7.258	15.4	31.7	66.7	74.1	72.2
53	4.	7.396	40.4	23.9	139.0	4.1	105.6	91.4	7.246	14.4	24.0	78.7	78.8	76.6
	$\bar{x}$	(7.377)	(45.0)	(25.5)	(136.12)	(4.02)	(103.50)	(91.01)	(7.234)	(15.6)	(33.85)	(73.92)	(78.15)	(68.22)
	CONTROL I	7.407	40.0	24.4	141.0	4.5	99.5	90.3	7.274	15.2	29.3	68.9	77.9	56.9
	CONTROL II	7.401	47.2	28.5	134.5	3.4	100.2	90.6	7.268	17.7	43.9	67.9	75.9	62.1
	CONTROL III	7.378	50.0	28.4	132.5	3.8	98.0	90.3	7.241	17.6	27.7	71.7	78.1	69.1
	$\bar{x}$	(7.386)	(45.7)	(27.1)	(136.00)	(3.90)	(99.23)	(90.4)	(7.261)	(16.8)	(33.63)	(66.17)	(77.30)	(62.70)
S-8-11-70	1.	7.219	78.2	30.4	136.5	4.0	102.4	91.4	7.190	18.5	15.2	67.2	75.9	71.7
A-8-13-70	2.	7.352	53.2	28.6	143.5	4.2	103.4	90.6	7.209	17.4	17.9	46.6	81.9	68.6
	3.	7.395	46.0	27.3	141.5	4.4	108.7	90.4	7.264	16.7	28.2	80.0	74.0	69.6
60	4.	7.374	53.2	30.0	137.5	4.0	99.8	92.1	7.233	18.4	28.2	67.7	78.6	83.4
	$\bar{x}$	(7.335)	(57.6)	(29.0)	(139.8)	(4.2)	(103.6)	(91.10)	(7.222)	(17.8)	(21.9)	(60.4)	(77.57)	(73.3)
	CONTROL I	7.324	58.2	29.7	143.5	4.4	101.9	90.7	7.186	18.4	26.5	66.5	76.9	76.3
	CONTROL II	7.290	60.0	27.6	134.0	4.2	103.7	90.4	7.146	17.0	36.1	69.9	75.7	67.8
	CONTROL II	7.323	60.6	30.3	143.0	4.3	108.6	91.3	7.183	18.7	26.5	69.7	74.2	73.1
	$\bar{x}$	(7.311)	(59.9)	(29.2)	(140.2)	(4.3)	(104.10)	(90.8)	(7.172)	(18.0)	(29.7)	(68.7)	(75.80)	(72.1)

Table K-1. USNSMC Venous Blood Gas and Electrolyte Data (3 of 4)

R292

DATE TEST DAY	CREWMAN	PLASMA							RED CELLS					
		pH	P_{CO_2}	HCO_3^-	Na^+	K^+	Cl^-	H_2O	pH	HCO_3^-	Na^+	K^+	Cl^-	H_2O
S-8-18-70	1.	7.376	46.8	26.5	142.5	4.4	104.5	90.5	7.220	15.7	39.5	78.0	80.6	63.0
A-8-21-70	2.	7.377	53.2	30.3	138.0	3.8	97.3	91.0	7.235	18.5	41.5	67.1	80.2	68.0
	3.	7.422	42.5	27.0	141.0	4.6	102.5	90.6	7.272	16.1	43.1	73.4	77.5	65.2
67	4.	7.432	37.8	24.6	146.0	4.6	105.0	90.8	7.296	15.1	44.9	68.3	76.4	62.7
	$\bar{x}$	(7.402)	(46.1)	(27.1)	(141.38)	(4.35)	(102.58)	(90.8)	(7.256)	(16.4)	(42.25)	(71.70)	(78.65)	(64.72)
	CONTROL I	7.418	40.6	25.3	146.0	4.7	112.5	89.2	7.281	15.7	44.2	68.9	79.1	65.6
	CONTROL II	7.406	40.3	24.5	147.0	4.4	110.4	89.7	7.271	15.2	52.1	65.0	81.9	58.3
	$\bar{x}$	(7.412)	(40.5)	(24.9)	(146.50)	(4.55)	(111.45)	(89.42)	(7.276)	(15.5)	(48.15)	(66.95)	(80.50)	(61.90)
S-8-25-70	1.	7.342	49.2	25.7	139.0	4.0	101.0	90.9	7.198	16.7	28.0	79.0	78.7	64.3
A-8-27-70	2.	7.343	52.4	27.6	138.5	4.3	97.7	90.2	7.200	16.8	39.0	68.3	77.2	59.0
	3.	7.338	52.8	27.3	138.0	3.8	98.4	91.4	7.181	16.2	47.5	70.2	71.4	57.5
74	4.	7.367	48.0	26.0	143.0	4.5	104.3	91.1	7.206	15.6	28.2	78.9	73.5	74.0
	$\bar{x}$	(7.345)	(50.6)	(26.6)	(139.62)	(4.15)	(100.35)	(90.9)	(7.196)	(16.1)	(35.68)	(74.10)	(75.20)	(63.70)
	CONTROL I	7.349	53.0	28.0	148.0	4.5	107.9	90.6	7.208	17.3	31.4	77.8	75.2	76.6
	CONTROL II	7.369	47.6	26.5	145.0	4.4	100.9	90.0	7.231	16.4	34.4	76.5	71.1	56.7
	CONTROL III	7.313	54.8	26.6	140.5	4.5	109.4	90.3	7.215	16.4	24.1	84.8	84.2	60.1
	$\bar{x}$	(7.344)	(51.8)	(27.0)	(144.50)	(4.47)	(108.07)	(90.45)	(7.218)	(16.7)	(29.97)	(79.20)	(76.83)	(64.47)
S-9-1-70	1.	7.308	58.4	28.1	136.0	4.0	99.7	—	7.163	17.2	36.4	71.3	76.5	—
A-8-8-70	2.	7.371	48.6	27.2	135.0	3.8	100.1	—	7.230	16.7	41.0	66.0	77.4	—
	3	7.368	44.4	24.5	137.8	4.1	97.1	—	7.208	14.5	38.7	51.3	63.5	—
81	4.	7.269	57.6	25.0	146.5	4.7	107.6	—	7.111	15.0	41.6	68.7	74.7	—
	$\bar{x}$	(7.329)	(52.2)	(26.2)	(138.58)	(4.18)	(101.1)	—	(7.178)	(15.8)	(39.42)	(71.72)	(73.02)	—
	CONTROL I	7.391	48.2	28.4	132.5	4.0	101.1	—	7.257	17.6	33.6	70.4	70.6	—
	CONTROL II	7.385	43.0	25.0	143.5	4.5	99.2	—	7.257	15.5	43.1	67.3	79.2	—
	CONTROL III	7.348	47.6	25.0	140.0	4.8	100.1	—	7.207	16.5	37.7	72.7	74.5	—
	$\bar{x}$	(7.375)	(46.3)	(28.1)	(138.67)	(4.43)	(100.1)	—	(7.238)	(16.2)	(38.13)	(70.13)	(74.77)	—
S-9-11-70	1.	7.338	56.4	29.0	134.0	3.6	98.7	90.6	7.191	17.7	41.0	75.0	85.4	60.7
A-9-17-70	2.	7.302	56.0	24.6	143.5	3.8	106.2	89.6	7.161	16.1	40.2	73.3	77.9	58.4
	3.	7.332	48.0	26.4	132.0	3.4	102.5	90.5	7.174	14.5	37.7	76.0	70.3	66.3
90	4.	7.363	50.0	26.9	132.5	3.4	99.0	91.3	7.206	16.2	47.7	65.9	73.7	64.9
	$\bar{x}$	(7.331)	(53.1)	(26.7)	(135.5)	(3.6)	(101.6)	(90.5)	(7.183)	(16.0)	(41.7)	(72.3)	(76.8)	(62.6)
	CONTROL I	7.337	60.0	30.9	138.5	3.9	98.7	90.9	7.197	19.1	38.7	70.1	74.5	66.5
	CONTROL II	7.314	56.3	27.5	139.5	3.7	100.3	91.2	7.174	17.0	39.5	69.1	75.6	67.4
	CONTROL III	7.317	57.8	28.2	135.0	4.7	99.8	91.4	7.172	17.4	26.6	75.3	75.2	—
	$\bar{x}$	(7.323)	(58.0)	(28.9)	(137.7)	(4.1)	(99.6)	(91.2)	(7.181)	(17.8)	(34.9)	(71.5)	(75.1)	67.0

Table K-1. USNSMC Venous Blood Gas and Electrolyte Data (4 of 4)

R292

DATE TEST DAY	CREWMAN	PLASMA							RED CELLS					
		pH	P_{CO_2}	HCO_3^-	Na^+	K^+	Cl^-	H_2O	pH	HCO_3^-	Na^+	K^+	Cl^-	H_2O
S-9-15-70	1.	7.422	48.6	30.8	140.0	4.2	98.7	90.9	7.274	18.9	26.2	79.9	75.6	65.5
A-9-17-70	2.	7.430	45.5	29.5	134.0	4.7	102.1	90.6	7.294	18.1	30.4	75.1	75.7	72.2
+4	3.	7.419	49.8	31.2	137.0	4.6	99.0	91.2	7.266	18.6	30.0	80.4	74.7	79.4
	4.	7.401	52.0	31.5	135.5	4.2	99.7	91.8	7.257	19.0	32.7	74.4	72.9	66.0
	$\bar{x}$	(7.418)	(49.0)	(30.8)	(136.6)	(4.4)	(99.9)	(91.1)	(7.273)	(18.6)	(29.9)	(77.5)	(74.7)	(70.8)
	CONTROL II	7.385	52.8	30.5	137.5	4.5	99.3	91.3	7.248	18.9	34.5	72.1	71.8	67.8
	CONTROL III	7.389	49.2	28.7	135.5	4.1	99.0	90.6	7.252	17.8	32.7	67.9	73.9	68.6
	$\bar{x}$	(7.387)	(51.0)	29.6	(136.5)	(4.3)	(99.2)	(91.0)	(7.250)	(18.4)	(33.6)	(70.0)	(72.9)	(68.7)
S-9-29-70	1.	7.392	46.5	27.5	139.0	4.0	100.6	90.9	7.239	16.3	26.3	84.6	78.7	77.6
A-10-1-70	2.	7.374	51.2	28.9	145.0	6.0	103.1	90.8	7.230	17.6	32.5	78.5	81.1	68.6
	3.	7.400	52.0	31.2	147.0	4.6	99.0	89.9	7.241	18.3	29.1	75.7	77.0	60.6
+18	4.	7.355	52.3	28.3	140.5	4.2	98.5	92.0	7.201	16.8	27.5	75.4	75.0	77.9
	$\bar{x}$	(7.380)	(50.5)	(29.0)	(142.9)	(4.7)	(100.6)	(90.9)	(7.228)	(17.2)	(28.9)	(78.6)	(78.0)	(71.1)
	CONTROL I	7.366	53.6	29.5	137.5	3.8	101.6	90.3	7.237	18.7	31.2	76.4	78.4	64.5
	CONTROL II	7.396	57.0	30.3	141.5	4.0	102.4	91.2	7.249	18.3	30.7	76.4	76.1	67.0
	CONTROL III	7.365	47.6	26.3	140.0	5.5	101.8	91.7	7.229	16.3	27.1	80.3	73.9	66.0
	$\bar{x}$	(7.376)	(50.7)	(28.7)	(139.7)	(4.4)	(101.9)	(91.1)	(7.238)	(17.8)	(29.7)	(77.0)	(76.1)	(65.8)
S-10-6-70	1.	7.407	44.7	27.2	144.0	4.1	104.1	90.5	7.256	16.1	27.7	84.5	74.2	74.0
11-10-9-70	2.	7.404	51.8	31.4	139.5	4.5	102.8	90.6	7.266	19.2	42.6	67.8	80.4	68.8
	3.	7.392	53.0	31.3	143.0	4.4	101.5	90.9	7.249	19.2	31.5	75.9	63.7	68.2
+25	4.	7.385	53.5	29.5	143.0	4.0	103.4	91.7	7.223	18.5	38.7	67.2	66.9	54.4
	$\bar{x}$	(7.392)	(50.8)	(29.8)	(142.4)	(4.3)	(103.0)	(90.9)	(7.248)	(18.2)	(35.4)	(73.9)	(71.3)	(66.4)
	CONTROL I	7.356	59.5	32.0	140.5	3.9	97.4	90.4	7.227	20.3	33.4	89.2	68.7	63.0
	CONTROL II	7.409	57.6	31.6	139.5	4.2	98.6	90.6	7.242	18.2	30.0	71.9	73.2	65.8
	$\bar{x}$	(7.382)	(55.5)	(31.8)	(140.0)	(4.1)	(97.0)	(90.5)	(7.234)	(19.2)	(31.7)	(70.6)	(71.0)	(64.4)
S-12-8-70	1.	7.270	61.0	26.7	140.0	4.3	101.7	90.9	7.110	15.9	27.4	89.8	70.9	61.9
A-12-11-70	2.	7.373	61.9	35.0	144.0	4.0	104.6	90.5	7.237	21.6	39.2	80.5	73.9	58.1
	3.	7.348	67.6	29.9	141.0	3.9	99.6	90.9	7.209	18.8	35.3	89.3	66.7	64.9
+88	4.	7.282	56.8	30.6	137.5	3.9	99.9	92.2	7.131	18.5	37.0	79.6	71.1	66.7
	$\bar{x}$	(7.318)	(61.8)	(30.6)	(140.6)	(4.0)	(101.5)	(91.1)	(7.172)	(18.6)	(34.7)	(84.8)	(70.7)	(62.9)
	CONTROL I	7.333	61.0	31.4	140.5	3.9	102.8	91.2	7.208	19.9	33.5	79.7	65.1	62.6
	CONTROL II	7.315	54.8	26.8	142.0	4.3	100.9	91.4	7.143	15.4	37.7	80.0	62.9	63.2
	$\bar{x}$	(7.324)	(57.9)	(29.1)	(141.3	(4.1)	(101.9)	(91.3)	(7.176)	(17.6)	(35.6)	(79.9)	(64.0)	(62.9)