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Human Engineering Data and Concepts for Handling Advanced Nuclear Systems in Space

Research and Technology Implications Report

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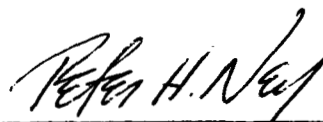
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HUMAN ENGINEERING DATA AND CONCEPTS FOR
HANDLING ADVANCED NUCLEAR SYSTEMS IN SPACE
RESEARCH AND TECHNOLOGY IMPLICATIONS REPORT

July 1965

Approved



P. H. Ney, Program Manager

MARTIN COMPANY
Denver, Colorado
Aerospace Division of Martin-Marietta Corporation

FOREWORD

This document is submitted under Contract NAS8-11425, in accordance with Contractual Statement of Work, Section VIIA2.

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I. INTRODUCTION

This study, "Human Engineering Criteria and Concepts for Handling Advanced Nuclear Systems in Space," investigated the problems associated with handling advanced nuclear systems that are to be serviced, maintained, operated, and launched in orbit. One type of nuclear propulsion (3256 MW NERVA II) and two types of auxiliary power (reactor and isotopic) systems were investigated. These nuclear devices were used as typical representatives of hardware that will be used in the systems for study. The space systems that were studied were:

- 1) Nuclear lunar ferry;
- 2) Nuclear interplanetary vehicle;
- 3) Large orbital research laboratory (LORL);
- 4) Manned orbital research laboratory (MORL).

II. OBJECTIVES OF THE STUDY

The objectives of this investigation were to:

- 1) Determine the feasibility of men handling nuclear vehicles in space;
- 2) Develop the human engineering design criteria and handling concepts needed by designers to produce nuclear systems that are easy to maintain;
- 3) Identify technological problems and their possible solutions.

This study was conducted so that resulting data can be presented as dimensionless parameters not oriented to specific space systems.

III. SUMMARY OF STUDY

The study developed probable system and equipment descriptions of the LORL, MORL, interplanetary, and lunar ferry vehicles. Using the system descriptions, tasks that probably will be allocated to man were identified.

A detailed time-line and task equipment analysis of the manned activities was performed. This analysis was prepared in logic diagram format. This methodology is described in the detailed technical report.

Isodose plots of each of the radiation sources were prepared using the task analyses computations of man's exposure per task. These exposures per task were presented in graphic form.

IV. IDENTIFICATION OF PROBLEM AREAS

The problem areas uncovered during this study are described in this chapter and are the basis for the advanced program plan (Chap. V). Although many collateral problem areas were touched on during this study, MSFC requested that only those problem areas directly relevant to the scope of this study be reported. The reported problem areas are:

- 1) Requirement for more definitive engineering design data of nuclear space systems;
- 2) Realistic radiation tolerance criteria for extended space operations;
- 3) Maintenance and repair concepts;
- 4) Development of remote maneuvering units;
- 5) Direct-remote and indirect-remote handling operations development;
- 6) Nuclear propulsion vehicle abort;
- 7) Development of criteria for removal and packaging of used reactors;

- 8) Man rating of reactor type SNAP system;
- 9) Spacesuit development.

A. DESIGN DATA FOR NUCLEAR SPACE SYSTEMS

To assure reality of this study, the study was based on the following four conceptual nuclear systems:

- 1) The interplanetary vehicle, which is powered by nuclear propulsion and has two SNAP-8 nuclear auxiliary power systems;
- 2) Lunar ferry, which is powered by a NERVA II nuclear rocket engine. Electric power is provided by a SNAP-8 reactor;
- 3) Large orbital research laboratory (LORL), which has a modified SNAP-8 mercury-Rankine cycle nuclear reactor electrical power supply;
- 4) Manned orbital research laboratory (MORL), which uses isotope-fueled Brayton cycle electrical power supply.

Although some conceptual design data exist on these systems, assumptions based on imagination were used to fill in the areas where design data were required by this study but lacking in the literature. Since this study was intended to develop general concepts applicable to a variety of future systems the incompleteness of the design data was not too limiting, however, for future studies in this area where hardware concepts are desired it is essential that complete engineering design data of nuclear space systems be available.

B. RADIATION CRITERIA FOR SPACE OPERATIONS

The most apparent problem area uncovered by this study is that no radiation criteria for manned space operations presently exist.

C. MAINTENANCE AND REPAIR CONCEPTS

It is apparent from the conclusions drawn from this study that time required to perform tasks is the most sensitive variable determining man's ability to perform required tasks. Hardware solutions that permit man to remove, repair, and replace components rapidly are required.

The reactor type (as opposed to isotope type) of advanced nuclear systems will involve negligible radiation hazards before nuclear source activation. Therefore, checkout, maintenance, and repair functions can be accomplished without regarding the radiation hazard. Once the nuclear sources have been activated the radiation hazard becomes the prime consideration in scheduling the orbital launch and maintenance crew activities.

The radiation dosage to man is directly related to the amount of time that the man is exposed to the radiation environment. Therefore, consideration must be given to ways of increasing task efficiency and reducing overall task times.

Many of the manned tasks related to the four space systems under study in this program have been determined to be generally feasible; however, it is necessary to take into consideration that present engineering design concepts and fabrication methods are such that tasks involving assembly, disassembly, installation, and removal procedures for nuclear and nuclear accessory components are both difficult and time consuming.

At the present time, engineering design concepts and practices as related to equipment fabrication and installation are based primarily upon mechanical and structural requirements such as torsion, tension, shear strength, fatigue factors, etc. In general, design considerations have not taken into account the necessity of developing quick-disconnect and breakaway connections except in the area of electrical, pneumatic, and fluid connections.

In order to appreciably shorten the task accomplishment times, it will be necessary for equipment designers to devise new techniques and methods for equipment mounting and assemblies. These techniques and methods should include the following:

- 1) Design of nuclear engines so that quick-disconnect separation planes between the reactor vessel, exhaust nozzle, and reactor mounting structures will permit rapid and simple methods of equipment removal or replacement of hot components. Consideration in new designs should be given to such methods as explosive bolts, magnetic locking devices, over center cam locking devices, quarter- or half-turn quick disconnect couplings, etc;

- 2) Design of component mounting devices so that individual components can be disconnected electrically and mechanically by a minimal amount of effort in a minimal time period. Again, considerations should be given to over center cam locking devices, quick-disconnect couplings, etc;
- 3) It is also imperative that every effort be made to improve and refine existing quick-disconnect equipment and concepts as well as development of new concepts and methods.

The use of accessory shielding reduces the radiation dosage to man, however to provide shielding sufficient to appreciably increase the time a man may safely spend in a task area in proximity to nuclear sources, we are faced with a matter of practicality. The major problem is twofold. First, the use of accessory shielding involves remote manipulation of the task, and second, the economic practicality of placing large mass portable shields in orbit.

The use of remote manipulating devices, while adequate and desirable in some instances, is undesirable in other instances because such devices are bulky, unmaneuverable, and operationally complex. While it is expected that refinements in operation and design of remote manipulators will occur within the next few years, it is unlikely that they will become sophisticated enough that it will be possible to use them to the exclusion of direct manipulation by man.

D. DEVELOPMENT OF REMOTE MANEUVERING UNITS AND SPACE LOGISTICS VEHICLES

An analysis of the nuclear environment behind the shadow shield of the lunar ferry and interplanetary vehicle reveals that manual activities are precluded. The shielding required to safeguard man in this area is prohibitive. Several contractors are presently developing concepts of space logistics vehicles that may fill the required need. These concepts are not sufficiently developed at this time to permit detailed task analysis. However, it is strongly recommended that further investigation in this area be undertaken. Design criteria for these vehicles should include:

- 1) An independent maneuvering system with reasonable reserves for unexpected problems;
- 2) A self contained power source;
- 3) A stabilized reaction control system;
- 4) Radar target acquisition system for intelligence input to the guidance system;
- 5) Stereoscopic (probably) television system to provide intelligence to the man controlling the unit;
- 6) Manipulator arms to provide some capability for remote repair;
- 7) Appropriate tools and test equipment built into the unit to facilitate inspection or maintenance and repair jobs;
- 8) Communications equipment for transmission of data, television signals, guidance control, and manipulator control signals.

E. DIRECT-REMOTE AND INDIRECT-REMOTE HANDLING OPERATION DEVELOPMENT

Applications of remote handling in space can be classified in two categories: (1) direct remote, where the operator is positioned behind a shield operating manipulators directly; and (2) indirect-remote, where the operator is positioned at a control module physically distant from the manipulative device that must be operated remotely.

A survey of published data on manipulator systems has indicated that much of the data developed on terrestrial systems have questionable application to space systems. Detailed studies of the following problems must be conducted to determine the design criteria for manipulators and their limitations for in-space maintenance:

- 1) Manipulator reach;
- 2) Force and torque requirements;
- 3) Number of degrees of freedom;
- 4) Articulation points to provide access;
- 5) Joint rotational capability required;
- 6) Number of manipulators and grapples required;
- 7) Mode of control and actuation systems;
- 8) Man-machine interface;
- 9) Feedback requirements and mode of presentation;
- 10) Environmental protection problems;
- 11) Volume and weight considerations.

From the human-factors point of view, the best configuration for remote-handling devices will be the one allowing the best operator performance. This entails both display fidelity and control effectiveness. Performance decrements could conceivably be functionally related to quantitative measures of each relevant parameter of the display and control systems. Before this task is undertaken, additional research should be directed toward performance measures themselves, the dependent variables against which control and display configuration will be evaluated. Usually, only time scores have been extensively used, but error scores have also been mentioned (e.g., control reversals, dropping objects, overshoot undershoot, etc). Time data, i.e., time to complete a given task, are usually contaminated, in an undetermined or at least unspecified manner, with (or biased by) errors. Either the data for a trial on which an error occurred are ignored or the data, if included, reflect not only the task time but both the time to commit and correct the error. The information content of the data is not fully used in either case, and no one seems concerned about this confounding of performance metrics. Actually, this may represent not only a confounding of dependent variables but of the corresponding independent variables as well.

Other performance metrics could also conceivably be used; for example, rate of travel, acceleration, and collision-impact force. The unanswered question is how these interact.

This study has indicated that the nuclear environment outside the protection of the shadow shield precludes direct remote manipulation. Therefore, there exists the strong requirement for development of practical indirect-remote systems.

F. NUCLEAR PROPULSION VEHICLE ABORT

At the present time there exists no definition of OLF control of a nuclear vehicle after an orbital launch attempt has been initiated. Such a definition must be generated since all tasks associated with abort procedures are dependent on this definition.

It is obvious that the radiation environment in which repair after abort must be performed is dependent on the length of burn time of the nuclear engines. Also, the length of burn time determines the relative positions of the OLF and nuclear powered vehicle at the time of abort. Retrieval concepts must be generated for these eventualities. Concepts of maintenance and repair performed by the vehicle crew were not within the scope of this study, but it is apparent that the requirement for future studies to resolve the interface of activities between the OLF maintenance crew and the onboard vehicle crew exists.

G. DEVELOPMENT OF CRITERIA FOR REMOVAL AND PACKAGING USED REACTORS

It is presently conceived by MSFC that activated reactors will be returned to earth for either disposal or refurbishment. Hardware and procedural techniques for the removal of hot reactors from the nuclear systems in space must be developed. Design of the reentry package must be developed with particular emphasis on the development of poison insertion techniques. This is a major problem area identified by this study since the nuclear environment associated with removal and packaging of hot reactors precludes man's direct involvement.

H. SPACESUIT DEVELOPMENT

Man's capabilities while contained by an advanced spacesuit are not known at this time. The study assumed that man would not be limited by a space suit that would be developed for the 1975 to 1985 time period. However, this assumption points up the requirement for radical improvements in spacesuit design, providing to the space worker greater mobility, dexterity, speed, accuracy, stay time, and comfort than is provided by present spacesuits.

Concurrent with the development of advanced spacesuit investigation, an investigation of man's capabilities in the suits must, of course, be carried on.

The results of these investigations must be used to update the task-time requirements presented by this study.

I. MAN RATING OF REACTOR-TYPE SNAP SYSTEM

The SNAP-8 power supply, which was studied as part of the LORL, lunar ferry and interplanetary vehicles, must be designed to permit man to maintain, repair, and operate the system.

In an unrestricted environment it is assumed that a significant amount of repair, adjustment, and replacement can be accomplished in the power conversion loops, coolant-lube loops, startup mercury injection system, primary instrument sensors, the controls, and protective systems included in the power plant compartment. The degree of diagnosis, repair, and replacement possible on these components would be limited only by the skills and capabilities of the maintenance crew. The degree of repair and maintenance that can be applied in correcting faults in major system components that are connected into the loops is more questionable. Consideration will have to be given to such problems as:

- 1) Breaking and making of fluid connections;
- 2) Methods of assuring joint integrity;
- 3) Handling toxic liquid metals;
- 4) Draining and refilling fluid systems;
- 5) Methods of maintaining loop cleanliness.

With proper shielding between the primary reactor loop and the enclosure of the power conversion loops, the temperature of the powerplant compartment may become a problem. The components and loops will be operating at temperatures ranging from 500 to 1250°F, and even with cooling, the ambient temperature may be higher than that in which a man can work effectively. Consequently, it may be necessary to shut down the powerplant and allow the systems to cool before the powerplant compartment can be entered.

One of the assumptions used in the present study was that a means will be provided to reduce temperatures in the powerplant compartment to a level that will allow a man to perform necessary maintenance. If this assumption proves to be unfeasible as system requirements become firm, then shutdown of the powerplant will have to be initiated before any maintenance tasks can be accomplished.

V. ADVANCED PROGRAM PLAN

The advanced program plan conceived to resolve the identified problem areas is presented in this chapter. The advanced program plan is in two parts: (1) a follow-on to this study; and (2) an overall advanced program plan relative to fiscal years, including estimated cost and manpower requirements to solve the identified problem areas as part of overall development of the four systems that have been considered throughout this study.

A. FOLLOW-ON PROGRAM

This present study may be considered a beginning to the development of human engineering criteria for handling advanced nuclear systems in space. It was intended to result in broad concepts applicable to a wide variety of advanced space vehicles. Very little development of hardware concept was undertaken because of:

- 1) The lack of detailed hardware design information available relative to future spare systems;
- 2) The intention of the contractor and MSFC to develop broad concepts that would not be tied directly to specific systems;
- 3) The direction given by MSFC to present the results in non dimensional parametric format.

It is recommended that three follow-on programs be initiated to continue the activities begun by this study:

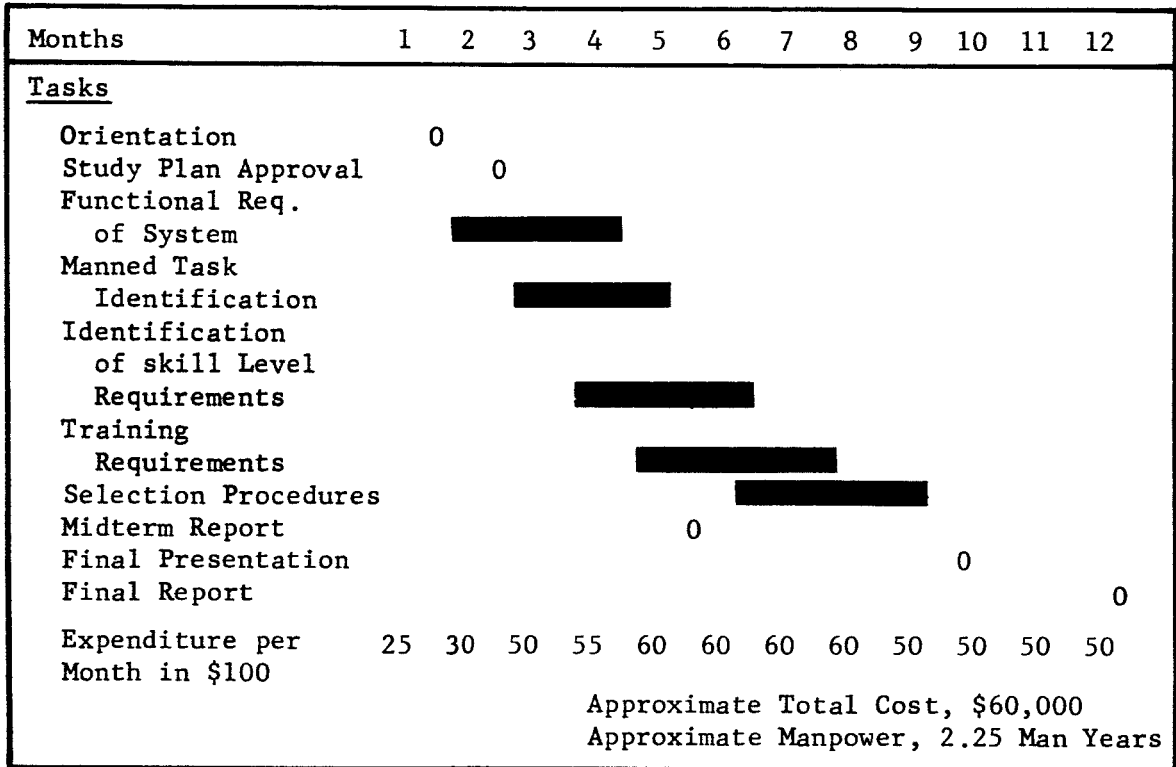
- 1) Development of hardware concepts relating to human engineering criteria for handling advanced nuclear systems in space;
- 2) Abort and retrieval concepts of nuclear powered space vehicles;
- 3) Personnel subsystem development for nuclear space systems.

At the present time various advanced nuclear systems are being developed, therefore, it is not too early, to initiate a study which would be oriented toward the development of hardware concepts. This present study has identified the need for the development of certain hardware solutions in the areas of:

- 1) Maintenance and repair concepts;
- 2) Remote maneuvering units and space logistics vehicles;
- 3) Direct-remote and indirect-remote handling equipment;
- 4) Receipt, removal, and packaging of hot reactors.

Months	1	2	3	4	5	6	7	8	9	10	11	12
<u>Tasks</u>												
Orientation	0											
Study Plan Approval			0									
Obtain and Analyse System Design data												
Identify Maintenance and Repair Requirements												
Maintenance and Repair Concepts												
Maneuvering Unit Criteria												
Remote Handling Criteria												
Receipt Removal, Packaging Criteria												
Follow-on Program Plan												
Midterm Report												
Final Presentation												
Final Report to NASA												
Expenditure per Month in \$100	30	40	60	70	90	90	100	90	80	80	80	80
Approximate Total Cost, \$89,000												
Approximate Manpower, 3.5 Man Years												

**Personnel Subsystem Development for Handling Advanced Nuclear
Systems in Space**



B. ADVANCE PROGRAM PLAN RELATIVE TO FISCAL YEARS

The advance program plan chart (Fig. 1) depicts in chart form the pertinent data relative to the development time, cost, and manpower required to perform further study on the problem areas uncovered by this study.

Included in Fig. 1 are development time, cost, and manpower estimates of the four major vehicles used in this study. These data were compiled from contractor reports on the various vehicles and composite interpolation where data were inadequate or incomplete.

This information is used as a reference baseline only to allow the user to better correlate individual problem areas against the type of vehicles upon which they will be tested or used in an operational mode.

Vehicle data are presented in a logical development process including all manpower, hardware, and development costs for the vehicle itself. Booster development costs and manpower are not included and vehicle span times are predicated upon booster availability. Operational figures include logistic support vehicles plus operational costs of logistic support requirements, refurbishment requirements, and vehicle plus launch costs.

Development span times, costs, and manpower are predicted upon sequential program go-ahead and operational test periods as indicated.

All data in Fig. 1 are subject to change as the state-of-the-art in each area becomes more advanced.

Figure 2 includes a list of various types of vehicles upon which experiments (developed from each listed problem area) may be conducted.

Key to Figure 1

	Advance Study Effort
	Develop System Criteria/Concepts
	Design and Development of System
	Ground Test of System
	Orbital Flight Test of System
	Orbital Operational Test and Update of System
	Data Inputs from Orbital Operational Tests and Update of Concept

System/Vehicle		1	2	3	4	5	6
Manned Orbital Research Laboratory Type Vehicle	Cost x Missions/Year	41	512	702	609	322	102
	Development Span						
	M/P x Thousands/Year	1.5	13.8	12.8	11.4	3.9	1.4
	1st Launch (Unmanned)						↑
Large Orbital Research Laboratory Type Vehicle	Cost x Missions/Year				58.9	525.9	487.3
	Development Span						
	M/P x Thousands/Year				2.1	14.9	13.2
	1st Launch (Unmanned)						
Lunar Ferry Type Vehicle	Cost x Missions/Year						
	Development Span						
	M/P x Thousands/Year						
	1st Launch (Unmanned)						
Interplanetary Type Vehicle	Cost x Missions/Year						
	Development Span						
	M/P x Thousands/Year						
	1st Launch (Unmanned)						
		1	2	3	4	5	6
Nuclear Powered Systems/Space Vehicle Design Criteria Available			▼ MORL			▼ LORL	
Space Tug	Cost x Millions/Year	0.24	0.48	3.6	22.5	36.3	35.2
	Development Span						
	M/P x Thousands/Year	0.01	0.02	0.15	0.50	0.75	0.70
Remote Maneuvering Unit	Cost x Millions/Year	0.48	0.48	0.96	0.96	0.96	2.4
	Development Span						
	M/P x Thousands/Year	0.02	0.02	0.04	0.04	0.04	0.1
Direct-Remote Handling Unit	Cost x Millions/Year	6.9	6.5	32.6	19.5	11.9	11.6
	Development Span						
	M/P x Thousands/Year	0.10	0.10	0.50	0.30	0.20	0.20
Indirect-Remote Handling Unit	Cost x Millions/Year	1.2	1.68	2.16	2.4	2.4	2.4
	Development Span						
	M/P x Thousands/Year	0.05	0.07	0.90	0.10	0.10	0.10
Spacesuit	Cost x Millions/Year	36.0	36.0	54.0	70.0	70.0	90.0
	Development Span						
	M/P x Thousands/Year	0.50	0.50	0.75	0.10	0.10	1.5
Radiation Tolerance Criteria	Cost x Millions/Year	0.24	0.36	0.60	0.96	1.68	3.6
	Development Span			Ground Study Efforts			
	M/P x Thousands/Year	0.01	0.015	0.025	0.04	0.07	0.15
Maintenance and Repair Concepts	Cost x Millions/Year	1.2	2.4	3.6	3.6	3.6	3.6
	Development Span						
	M/P x Thousands/Year	0.05	0.10	0.15	0.15	0.15	0.15
Man-Rating Reactor Type SNAP Systems	Cost x Millions/Year	0.048	0.072	0.072	0.24	0.24	0.24
	Development Span						
	M/P x Thousands/Year	0.002	0.003	0.003	0.010	0.010	0.010
Orbital Receipt of Nuclear Powered Vehicles/Subsystems	Cost x Millions/Year	0.24	0.72	0.96	1.44	2.40	2.40
	Development Span						
	M/P x Thousands/Year	0.01	0.03	0.04	0.06	0.1	0.1
Orbital Disposition of Activated Nuclear Reactors/Isotopes	Cost x Millions/Year	0.24	0.48	0.96	1.44	2.40	4.80
	Development Span						
	M/P x Thousands/Year	0.01	0.02	0.04	0.06	0.10	0.20
Orbital Abort of Nuclear Powered Vehicles	Cost x Millions/Year	0.48	0.48	0.48	0.48	0.48	0.48
	Development Span						
	M/P x Thousands/Year	0.02	0.02	0.02	0.02	0.02	0.02

Years from Program Go-Ahead

7	8	9	10	11	12	13	14	15	16	17	18	19	20
2498	540	460	375	325									
10.1	6.9	6.1	5.2	4.6									
485.8	536.9	590.8	136.6	120.0									
12.6	12.3	10.6	1.9	1.6									
31.0	80.0	264.5	330.6	332.9	329.4	336.0	398.0	133.2	90.2	73.8			
1.2	2.6	7.5	9.1	8.9	8.5	7.7	7.1	1.8	1.3	0.9			
		46.4	98.4	119.0	258.1	266.2	274.9	462.9	529.5	384.1	202.8	111.2	
		1.8	3.2	3.4	7.1	7.1	7.1	10.8	10.8	6.9	2.7	1.5	
7	8	9	10	11	12	13	14	15	16	17	18	19	20
14.7	25.3	20.7	18.6	13.6	6.7	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2
0.20	0.40	0.35	0.30	0.20	0.10	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
6.0	27.3	39.7	37.3	36.8	12.7	12.9	11.73	11.73	7.37	7.26	2.96	2.96	2.94
0.25	1.00	1.55	1.35	1.30	0.35	0.40	0.35	0.35	0.25	0.20	0.07	0.07	0.07
11.1	9.8	9.5	9.0	6.6	6.4	6.0	5.8	5.5	5.5	5.5	5.5	5.5	5.5
0.20	0.15	0.15	0.15	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
3.6	3.6	3.6	3.6	10.6	38.8	63.0	69.0	64.8	32.8	28.8	16.4	14.4	14.4
0.15	0.15	0.15	0.15	0.35	1.20	1.75	1.15	0.90	0.50	0.40	0.25	0.20	0.20
70.0	36.0	54.0	70.0	90.0	70.0	36.0	36.0	36.0	70.0	90.0	90.0	90.0	90.0
0.10	0.50	0.75	0.10	1.5	0.10	0.50	0.50	0.50	0.10	1.5	0.15	1.5	0.15
3.6	2.4	1.2	2.4	3.6	2.4	1.2	1.2	1.2	2.4	3.6	3.6	3.6	3.6
0.15	0.10	0.05	0.10	0.15	0.10	0.05	0.05	0.05	0.10	0.15	0.15	0.15	0.15
2.4	1.2	1.2	3.6	3.6	2.4	1.2	2.4	3.6	3.6	3.6	3.6	3.6	3.6
0.10	0.05	0.05	0.15	0.15	0.10	0.05	0.10	0.15	0.15	0.15	0.15	0.15	0.15
0.24	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
0.010	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
1.92	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44
0.08	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
3.60	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40
0.15	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
0.48	0.48	0.48	0.72	0.96	0.96	1.44	2.4	4.8	4.8	2.40	2.40	2.40	2.40
0.02	0.02	0.02	0.03	0.04	0.04	0.06	0.10	0.20	0.20	0.10	0.10	0.10	0.10

Fig. 1 Advanced Program Plan

Test/Experiment	Gemini	Apollo (AES)	MOL	MORL	LORL	OLF	Lunar Ferry	Interplanetary Vehicle
Spacesuits	X	X	X	X	X	X	X	X
Direct-Remote Handling Unit			X	X				
Space Tug				X	X	X		
Remote Maneuvering Unit					X	X		
Indirect Remote Handling Unit						X	X	
Radiation Tolerance			X	X	X	X	X	X
Maintenance and Repair			X	X	X	X	X	X
Man-Rating Reactor, SNAP					X	X		
Orbital Receipt, Nuclear System				X	X	X	X	
Orbital Disposition, Nuclear System				X	X	X	X	
Orbital Abort Nuclear Vehicles						X	X	

Fig. 2 Orbital Experimentation

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