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FINAL REPORT

STUDY OF THE
AUTOMATED BIOLOGICAL LABORATORY
PROJECT DEFINITION

VOLUME III OF VI
SYSTEM ENGINEERING STUDIES

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Prepared by:	Temple W. Neumann Temple W. Neumann, Program Engineer
Approved:	William Hostetler William Hostetler, Program Manager

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AERONUTRONIC
DIVISION OF PHILCO CORPORATION
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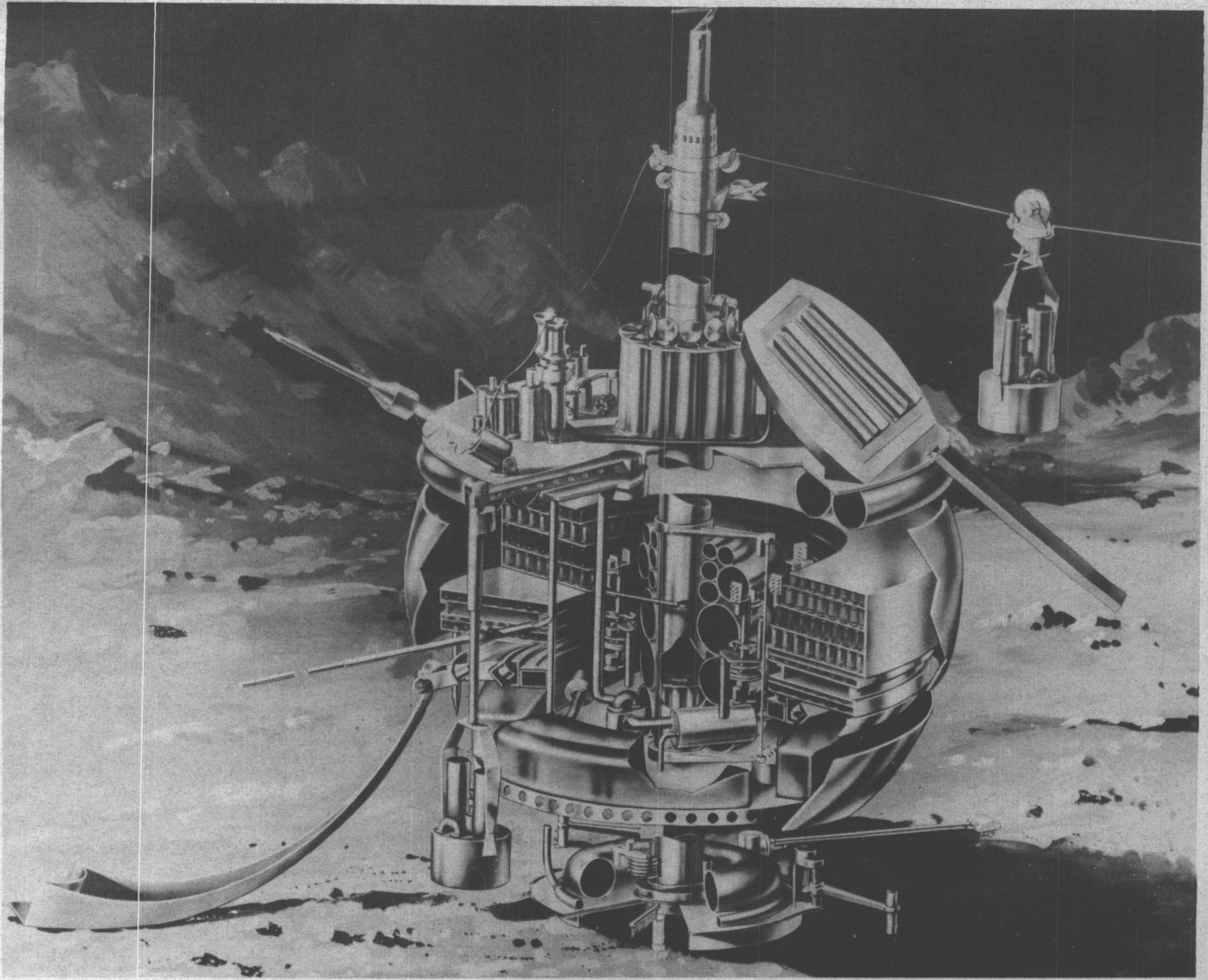

ABL DESIGN POINT CONFIGURATION

ABSTRACT

This report, in six volumes, contains the results of a twelve-month study conducted for the Bioscience Programs Division, Office of Space Science and Applications, of NASA Headquarters by the Aeronutronic Division of the Philco Corporation. The feasibility of an automated biological laboratory (ABL) for use in the exploration of Mars was investigated. The objectives of the study included definition of the scientific objectives for such a mission, selection of a representative complement of experiments, definition of the required instrument complement, performance of a preliminary design feasibility study for a representative design point payload, and the execution of a program definition and development plan. The first objectives were attained in the study through interviews, discussions, and reviews with scientists in government, academic institutions, and industrial concerns. Desirable objectives and approaches to the biological exploration of Mars were defined. A great many possible experiments, both biological and physical, were evaluated and ranked numerically. A complement of 35 such experiments were selected for purposes of establishing a representative instrumentation payload for a Voyager-class landing mission to Mars in 1975. This payload was used as a basis for conducting a preliminary design feasibility evaluation of an automated biological laboratory.

The concept for an ABL investigated in this study was a departure from current concepts in scientific payload organization. In the ABL concept the experimental program is conducted, not with individually mechanized experiments, but by an integrated complement of basic instruments operated in a sequential fashion, in the same way biological experimentation is performed in terrestrial laboratories. The laboratory is controlled by an on-board computer, with command override capability provided for Earth-based scientists to select alternative experimental programs, or even to initiate completely new programs, in response to the results obtained from preceding experiments. The study results indicate several advantages accruing to the ABL concept. The most important of these is that far more

meaningful scientific results are possible from a given instrument complement operated in this manner than for the same instrument complement operated as fixed predesigned experiments. In addition, weight and reliability advantages are also demonstrated for the concept.

The design point landed payload was designed for two year (Earth) life on the surface of Mars and resulted in an approximately spherical configuration, 68 inches in diameter weighing approximately 1200 pounds.

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SECTION 1

INTRODUCTION

The preceding volume dealt with the problems of defining the scientific payload for an ABL-class planetary landing mission. The broad and complex long-range objectives for the biological exploration of the planets have been identified. The scientific implications of the method of payload conceptual organization were reviewed and it was shown that very important advantages, from the standpoint of the return of meaningful scientific results, accrue to certain methods of payload organization. Specifically, payloads organized in such a way that sequential experimentation can be performed and so that each succeeding experiment can profit from the results of the preceding ones, were shown to yield far more meaningful results than equivalent instrument capability operated as preprogrammed experiments. This concept, as it relates to the biological exploration of Mars, has been identified as the fundamental principal which characterizes the ABL.

While the concepts set forth in Volume II were seen to exhibit clear advantages from the viewpoint of the quality of the science which could be achieved, important questions remained to be answered concerning the engineering feasibility of the concept and the nature of the problems associated with its execution. Also of interest were the possible systems engineering advantages or disadvantages that might affect the relative attractiveness of the concept in relationship to other possible approaches. The engineering analyses undertaken to obtain answers to these questions are the subject of this volume of the report.

The evaluation of a design point payload was undertaken, based upon the instrumentation complement defined in Volume II. The results of this analysis are reported in Section 5 and reveal that the engineering problems presented by the execution of a payload based on the ABL concept are no greater than for other payloads of similar total experimental capability, and gross weight. While complex by comparison to today's space payloads, this is an unrealistic comparison. Payloads in the mid-1970's will make use of Saturn-class booster capability, and instrumented payloads of this size will be complex regardless of how they are organized. Complexity in itself is not a deterrent to successful accomplishment of the mission objectives. Our technology abounds with successful, complex systems. Requirements for unattainable technologies in even a simple payload would be a far greater deterrent. No such technologies have been identified as required for the success of the ABL. There are no quantum jumps in technology required or postulated for any of the concepts resulting from these analyses. The required capability can be attained with only reasonable and moderate extrapolations of today's art.

Of considerable interest were effects of the ABL payload on other systems with which it must interface. The results of investigations in these areas are reported in Section 6. Results in Paragraph 6.6 summarize the integration of the ABL payload with its entry delivery vehicle. No difficulty is anticipated in this area, particularly if a separable ABL payload is employed as described.

The results of preliminary weight and reliability analyses (reported in Paragraphs 4.4 and 5.4, respectively) for the representative design point ABL studied disclose some rather remarkable system advantages for the ABL concept in these two areas. These advantages of the ABL concept, in addition to those of a scientific nature discussed in Volume II, make the concept one worthy of further serious consideration by both NASA and the scientific community.

SECTION 2

SYSTEM ENGINEERING OBJECTIVES AND CONSTRAINTS

2.1 SYSTEM DEFINITION

It was necessary, early in the system engineering studies, to define as precisely as possible, the ABL system under study. Broad guidelines for the study were laid down by NASA in the work statement. For example:

- "The purpose of the study is to define the biological experiments and associated support equipment that will comprise the integrated experimental package known as the Automated Biological Laboratory."

Clearly the experiments and the instrument and processing capability required for their performance are an essential element of the ABL. Also essential are certain support systems required for the proper functioning of the experimental payload. In order to define what these support systems are the functional block diagram shown in Figure 2-1 was prepared. This diagram was based on achieving the desirable features of the integrated laboratory concept discussed in Volume II. This concept assumes that the basic laboratory analytical capability is organized in a way that permits any experiment to utilize the full capability of the laboratory. It is also assumed that the operations are controlled by a central onboard computer in such a way that changes in the preprogrammed complement of experiments can be accomplished by means of internal feedback from previous experiments, from the results of other laboratory functions such as failure detection, or by Earth command.

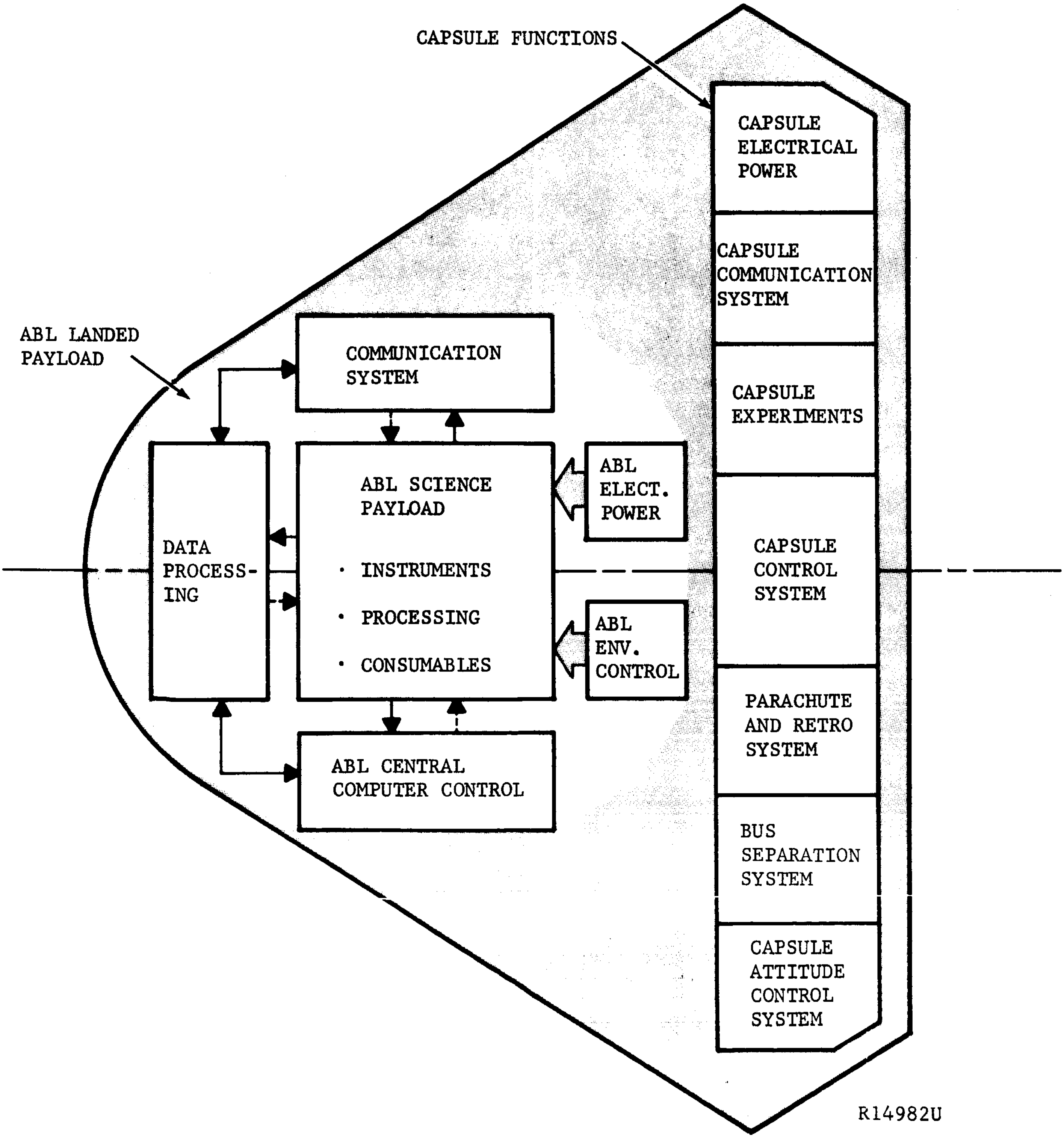

FIGURE 2-1. ABL FUNCTIONAL BLOCK DIAGRAM

It was clear at the outset of this study that certain of the subsystems shown in Figure 2-1 were so intimately related to basic ABL functions that they were inseparable from it in a system sense. Among these are the central onboard computer control and data processing subsystems. Other subsystems can be considered as either a part of ABL or as a part of the entry vehicle system, depending upon the specific mode of organization chosen for each. A further guideline established for the study by NASA directed that the interfaces between ABL and its delivery vehicle and subsystems be studied. In certain entry vehicle/payload configurational concepts that have been proposed, many of the subsystems could be considered an integral part of an ABL, and thus would have direct bearing on its operational characteristics. Since these subsystems would have to be studied in sufficient depth, in any case, to define their operating characteristics so that interfaces could be established, it appeared that the most thorough systems engineering analysis would result when all principal subsystems affecting the ABL's long-term operation were considered integrally with it. This approach was therefore adopted for this study and the term "ABL landed payload" established to designate this entity and to distinguish it from other terms in use such as the "science payload" and the "entry vehicle payload." The ABL landed payload is defined as consisting of the ABL or science payload (containing the instruments, processing equipment and consumable laboratory supplies) plus its necessary supporting subsystems for complete long-duration independent operation on the Martian surface. These subsystems are electrical power, data processing and control, communications, environmental control, and structure.

The total entry vehicle payload, then, is composed of the ABL landed payload plus the entry vehicle subsystems consisting of entry instrumentation, bus separation system, attitude control, parachute deceleration system, and terminal retro and/or deceleration systems, if employed. A separate electrical power supply to provide for these entry vehicle subsystem functions may also be required, of course, depending on the details of the system mechanization.

Consequently, the preliminary design study, reported in Section 5, considered the systems engineering problem to be the analysis of the landed payload, as defined, and an evaluation of the interfaces between that payload and the entry vehicle and its subsystems. While it is recognized that other arbitrary definitions of what constitutes the ABL system can be advanced, it is important to note, in the following analyses, that certain performance and functional advantages do accrue to the definition adopted here (see Paragraph 5.3.1) in addition to the one advanced for its use in this study that it permits a more thorough and comprehensive system analysis to be performed.

2.2 OBJECTIVES OF THE SYSTEMS ENGINEERING STUDIES

It was also important early in the study to identify the specific objectives to be accomplished by the systems engineering evaluations. In general, two broad categories of study approaches can be taken, and the objectives are considerably different in the two cases. It is possible to pursue broad parametric studies in which the objectives are principally gross system optimization and comparisons with alternative approaches. Alternatively, it is possible to select what is felt to be a representative design point case and to examine that case in considerable depth by means of preliminary design studies so that engineering and development problems residing at the level of principal components and subsystems can be identified and evaluated. Obviously some of both of these objectives are desirable in a study of this kind, and were so indicated by NASA in the study work statement. However, what is gained in breadth must, of necessity, be sacrificed in depth. The ABL presented certain inordinately complex problems in the system engineering evaluation because of the broad scope of the mission (and the study) and because of the unique problems represented in combining the objectives and methods of research biology and space systems engineering. In order to achieve meaningful results in these areas, it was absolutely essential to pursue the definition of problem areas in sufficient detail so that critical aspects affecting system feasibility would be brought to light. Because the number of such potential problem areas was very large, this objective represented a significant effort. There may be those who feel that the study did not go far enough in this direction. Certainly it was not possible, within the limits of this study, to become as familiar with the potential problems associated with each instrument or technique as those specialists working exclusively with it; as important as these problems may be to the questions of ABL feasibility.

At the same time, it was not possible to ignore the gross system performance and its relationship to other approaches. In fact, in the study work statement a specific task effort was identified by NASA for this purpose. Early in the study, however, it was mutually agreed that these studies would have a specific content, narrower in scope than the entire ABL system evaluation and requiring completion at a point in the program before the preliminary design data were available for comparison. The question of overall system performance and optimization was curtailed thereby, although by no means eliminated from the study. Analyses reported in Paragraphs 4.4, 5.4, and 6.6 cover variations from the design point case for a number of significant alternative approaches for achieving the system objectives, and a considerable amount of ground has been covered toward the goal of achieving system optimization. However, because of the considerations stated above, and the fact that the evaluation of system feasibility should be the principal study objective at this early stage, the major emphasis was placed on the design point analysis.

NASA concurred in this decision and established the criteria defined in the next paragraph, and in Paragraph 5.2, for the selection of the design point case to be examined. The effect of these decisions on the study results can be summarized as shown in Figure 2-2. It can be concluded that subsequent systems studies of the ABL concept, which should now follow the evaluation of the design point case, can be established on a much firmer basis as a result of the detail attained in this study.

2.3 STUDY CONSTRAINTS

The decision to proceed with considerable study emphasis placed on a preliminary design point analysis presented the requirement for defining what that case should be. Such a design point case, of course, represents a single set of parameters out of the entire matrix of possible parameters that could be selected. One overriding consideration in making this selection was the one referred to in Section 5 of Volume II, that is, it is desirable that the selected parameters define a payload which will exhibit all of the principal problems that can be reasonably expected for similar payloads in the time period of interest. The selection of the design point instrument complement in Paragraph 5.3 of Volume II was accomplished with this objective in mind. The instrument complement defines, to a large extent, the other functions of the laboratory, and therefore resulted in a very comprehensive laboratory capability. From this point of view, it became far more important to include extensive capability, so that its effects on the laboratory could be studies, than to determine if the capability were the optimum one to choose. Examples of this were the core hole drill and the large numbers of chemical processing chambers. The cost of including these was later evaluated in the weight studies.

The remaining question regarding definition of the design point system parameters had to do with payload size and mission constraints. These were defined for the study by NASA and are described, along with many of the detailed implications which they created in terms of design criteria, in Paragraph 5.2. The most important are listed in Table 2-I. Although the design point mission was 1975, those analyses which were time sensitive, such as communications, were evaluated over a range, usually from 1970-1980.

TABLE 2-I

PRINCIPAL STUDY CONSTRAINTS

MISSION TIME	1975
MISSION DURATION	Two Earth years on Mars
PAYLOAD SIZE	500 - 1000 pounds
MISSION PHILOSOPHY	The mission is to be a comprehensive biological and related environmental surface exploration, probably following orbital and possibly simple entry or landing mission in 1969, 1971, and 1973.

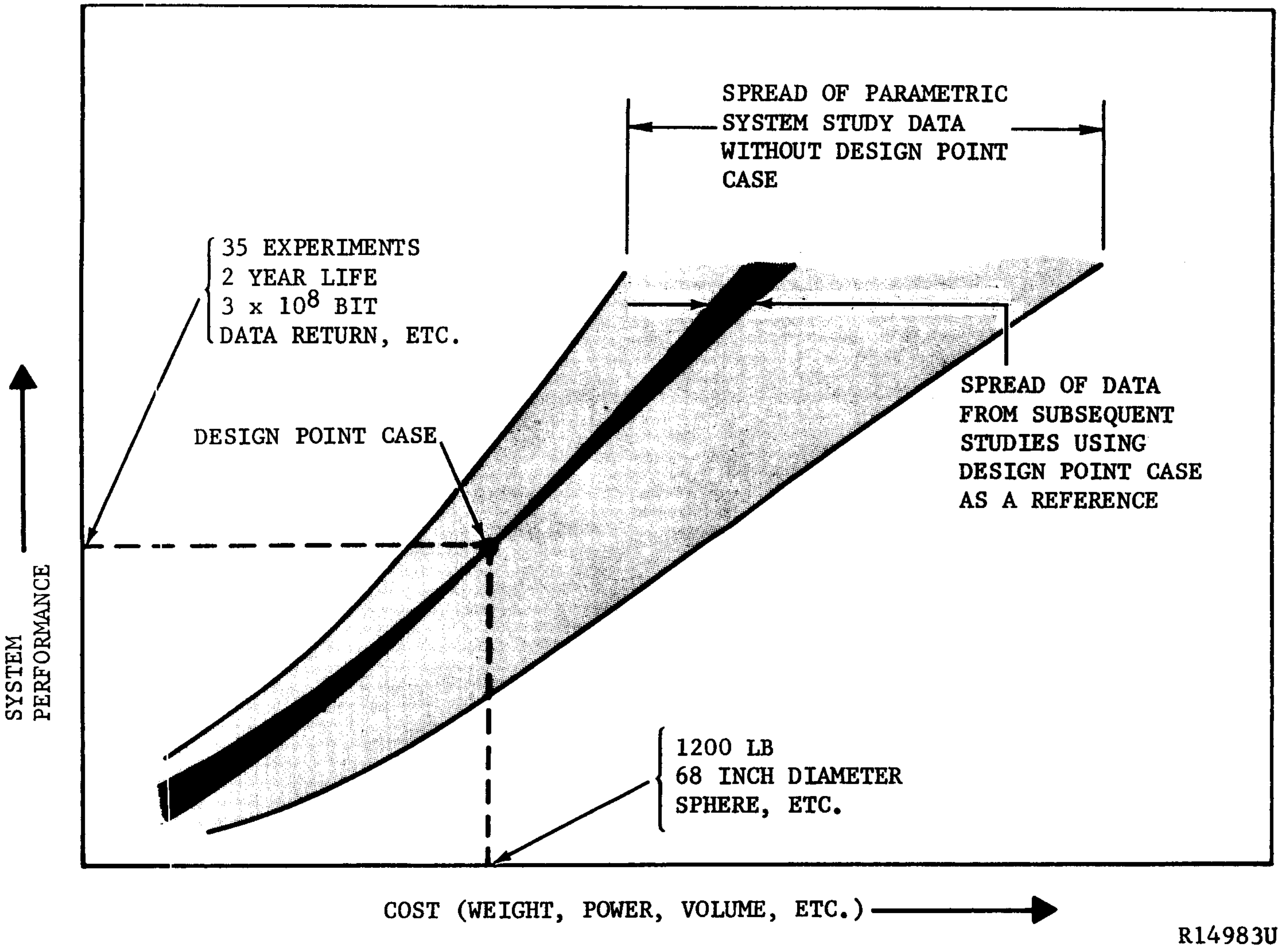

FIGURE 2-2. COVERAGE OF ABL SYSTEMS STUDIES

SECTION 3

SPECIAL PAYLOAD STUDIES

3.1 INTRODUCTION

Early in the study program, before the preliminary design point analysis was initiated, it was of interest to obtain a comparative evaluation of various suggested scientific experimental payloads so that first order estimates of representative combinations which appeared feasible for early Voyager missions could be obtained, and the gross effect of payload size and complexity on overall weight be determined. The fundamental parameter of comparison was weight. The comparison was concerned with two primary system weights; the scientific payload weight and the total entry weight of the scientific payload, its supporting subsystems and entry body.

Eight experimental combinations were established to provide a basis for estimating these weights. Payloads I, II, and III were selected from early phases of the study by Aeronutronic to define scientific objectives and their associated experimental procedures for the ABL. Payloads IV and V were based on the results of the final report of the Committee on Martian Landers of the *ad hoc* Biosciences Working Group which met in Newport Beach, California, in March of this year. This report is included in Appendix 8 of this study. Payloads VI, VII, and VIII were taken from experiments suggested by JPL as a result of studies of a minimum biological payload. These payloads from JPL are also given in Appendix 8.

3.2 SUBSYSTEM PARAMETERS

3.2.1 MISSION LIFETIME

The basic mission for this early comparison study was defined as a 1971 Type I mission with an arrival at Mars in August. The total lifetime after landing was defined to be 6 months. The 6-month lifetime was chosen to give the laboratory an opportunity to repeat experiments to attain higher statistical reliability in the data output, as well as detect changes which will occur in the ambient conditions. Longer lifetimes for early missions were not considered to be reasonable nor necessary for this study. Payload I which represents the most complex configuration was assumed to repeat the experimental sequence 40 times in the lifetime of the laboratory while the remaining payloads repeat the sequence 10 times.

3.2.2 COMMUNICATIONS

The communications system assumes the use of S-band. Two modes of communication are considered. A relay mode with an estimated data rate of 700 bits per second was used to compare transmission times with the direct Earth communications mode. Based on analyses conducted both at JPL and Philco, the direct Earth link mode will possess a higher probability of success than the relay mode, although the data transmission rate is greatly reduced. Since the operating lifetime is six months and the experimental sequences will utilize only a small percentage of this lifetime, the direct Earth communications mode was chosen for this study.

To assess the transmission requirements, the characteristics of several types of existing S-band transmitters were compared and are shown in Table 3-I. Based on the current technology, a 25-watt transmitter with about 15 percent efficiency was considered reasonable for a transmitter ruggedized to withstand high landing impacts. This size transmitter is used for all the payloads in this study except Payload VI which produces the smallest quantity of data.

The other important consideration in the telecommunication link is the gain achieved with the antenna. High gain in a conical beam antenna is achieved at the expense of the high degree of sophistication in the pointing system required. It also reduces the total transmission time available if the beam is fixed with respect to Mars since Earth is in the field of view a shorter time. Thus, a lower gain antenna with longer view time can be as efficient in terms of transmitting a total data load.

A more optimum system for these less complex types of landers was determined to be a 20 degree by 80 degree fan beam with a gain of +12 db. This beam requires only an initial orientation with the wide fan of the beam lying in the ecliptic plane for the duration of the mission. The data transmission capability for this antenna system is shown in Figure 3-1. The circles indicate the data transmission capability in terms of months after landing for the payloads considered in this study, using 25 watts of radiated power. The bit rate varies from a maximum in the first month of 16 bits per second to a minimum of 1.7 bits per second in the sixth month. The transmission power is the largest single power requirement

TABLE 3-I

SUMMARY OF S-BAND TRANSMITTER CHARACTERISTICS

	TWT	Amplitron	Triode Cavity	All Solid State Using Selected 2N3375	All Solid State Using RCA TA2675 Device
Power Output	20 w	20 w	20 w	20 w	14.6 w
Power Input	100.2	52	115	269	131.4
Efficiency Percentage	24.9	36	17.7	7.5	11.6
Weight, Pounds	6	9	9.25	12.6	9
Volume, in.^{3}	120	180	185	210	139
Degree of Impact Resistance	Poor	Poor	Fair	Good	Good
Density lb/in.^{3}	0.05	0.05	0.05	0.06	0.065

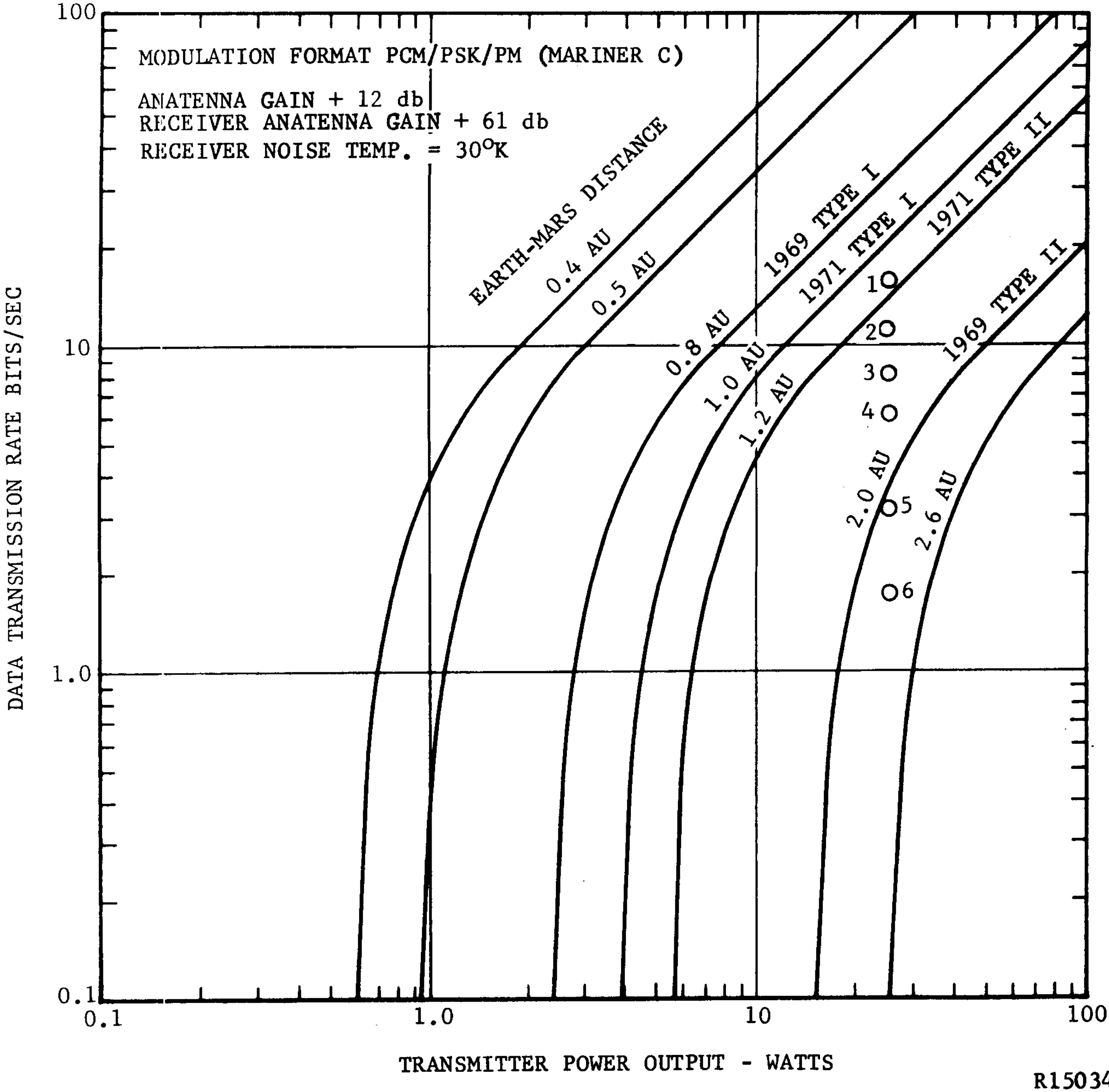

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FIGURE 3-1. BIT RATE VERSUS POWER - MARS-EARTH

TABLE 3-II

DATA OUTPUT OF SCIENTIFIC PAYLOADS

			I	II	III	IV	V	VI	VII	VIII
ALL DIGITAL EXPER 1 TIME			5×10^4	5×10^4	2.5×10^4	2×10^4	7.5×10^4	0.3×10^4	1×10^4	3.8×10^4
ALL DIGITAL EXPER 10 TIMES			—	5×10^5	2.5×10^5	2×10^5	7.5×10^5	0.3×10^5	1×10^5	3.8×10^5
ALL DIGITAL EXPER 40 TIMES			2×10^6	—	—	—	—	—	—	—
60° x 210° x 0.1° RES SCAN 1 TIME			—	—	4.9×10^6	—	—	—	—	—
60° x 420° x 0.1° RES SCAN 1 TIME			—	10^7	—	—	—	—	—	—
60° x 584° x 0.1° RES SCAN 1 TIME			1.4×10^7	—	—	—	—	—	—	—
TOTAL BIT LOAD			1.6×10^7	1.05×10^7	5.15×10^6	2×10^5	7.5×10^5	0.3×10^5	1×10^5	3.8×10^5
TRANSMISSION TIMES										
AT 700 BITS/SEC (RELAY) HRS			6.36	4.16	2.04	0.08	0.3	0.012	0.04	0.16
DIRECT LINK										
BIT RATE (AVERAGE)	MONTHS AFTER LANDING									
16/SEC	1	TOTAL DATA	9.86×10^6	9.7×10^6	4.78×10^6	0.333×10^5	1.25×10^5	5000	0.167×10^5	0.634×10^5
		TRANSMISSION TIME	170	170	83	0.6	2.2	0.1	0.3	1.1
11/SEC	2	TOTAL DATA	2.00×10^6	3.36×10^5	1.26×10^5	0.333×10^5				
		TRANSMISSION TIME	50	8.5	3.2	0.84	3.2	0.126	0.421	1.6
8/SEC	3	TOTAL DATA	1.45×10^6	2.41×10^5	0.84×10^5	0.333×10^5				
		TRANSMISSION TIME	50	8.4	2.9	1.16	4.3	0.173	0.580	2.2
6/SEC	4	TOTAL DATA	1.08×10^6	1.78×10^5	0.68×10^5	0.333×10^5				
		TRANSMISSION TIME	50	8.2	3.2	1.54	5.8	0.230	0.775	2.9
3.1/SEC	5	TOTAL DATA	0.56×10^6	0.95×10^5	0.346×10^5	0.333×10^5				
		TRANSMISSION TIME	50	8.5	3.1	3.0	11.2	0.448	1.50	5.7
1.7/SEC	6	TOTAL DATA	0.31×10^6	0.525×10^5	0.20×10^6	0.333×10^5	1.25×10^5	5000	0.167×10^5	0.634×10^5
		TRANSMISSION TIME	50	8.6	3.3	5.5	20.4	0.820	2.7	10.4

TABLE 3-III

ESTIMATED BATTERY WEIGHTS

	I	II	III	IV	V	VI	VII	VIII
Communication Power								
Transmission Time	420	212	99	13	57	1.9	6.3	24
Operation Power Watt-Hours	7900	4000	970	500	670	50	490	550
Continuous Power Watt-Hours	2150	2150	2150	2150	2150	40	2150	2150
Total Watt-Hours	10,050	6150	3120	2650	2820	90	2640	2700
$\frac{\text{70 Watt-Hours}}{\text{Pound}}$ Thermal Battery Weight	1000	505	238	31	136	3.6	15	57
$\frac{\text{40 Watt-Hours}}{\text{Pound}}$ Primary Battery Weight	251	154	78	66	70	2.4	66	68
Total Battery Weight	1251	659	316	97	206	6.0	81	125

3.2.4 ENTRY VEHICLE PARAMETERS

The entry vehicle was defined to be a Langley tension cone entry body and consisted of the following subsystem.

(1) The scientific payload weight which was considered to be the instruments, processing equipment, and structure necessary to perform the selected experiments.

(2) The communications system, power supply, and thermal control were considered as supporting subsystems and were not included in the science payload weight.

(3) The impact limiter and interior structure required to integrate the science payload and the subsystems in (2) above is considered to complete the landed payload weight.

(4) The entry vehicle system then consists of the retro separation motor to effect entry, the orientation system to maintain attitude during initial entry, the mass damper and separation system to achieve dynamic stability during aerodynamic entry, the parachute deceleration system, and the structure and heatshield of the entry body.

The weight estimates for the total entry vehicle subsystems were based on a ballistic coefficient (W/C_DA) of 10 pounds per square foot, the 10 millibar atmosphere for Mars, and an entry velocity of 20,000 feet per second. The payload ratios were established using an entry vehicle synthesis program developed at Aeronutronic. Since this study was completed, more definitive data for the tension cone vehicle have been incorporated into the program. Thus, the values of entry vehicle weight developed in this study tend to be conservative. This does not alter the value of the trends developed, but care should be exercised in comparing the total entry weights with those developed later in the study.*

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* Many parameters used in this study differ from those used in the ABL design point preliminary design study, including, in addition to the entry vehicle parameters, the details of the atmospheric model and the payload composition. Thus, no direct comparison between these two studies is intended or should be attempted. The study objectives were different in the two cases and, in addition, the studies were separated in time by 6 to 9 months.

A complete tabulation by type of experiment and weight are given in Table 3-IV for each of the payload configurations studied, resulting in a range ot nominal scientific payload weights from 10 to 600 pounds.

3.3 CONCLUSIONS

Although this was a very short study effort, several pertinent conclusions can be drawn from it.

(1) It is not evident in the numerical results, but the weight of the more complex scientific payloads requiring chemical processing are sensitive to the number of repetitive experimental cycles performed. This is reflected in Payloads I and II which leave the same experimental complement. By reducing the number of repetitive cycles from 40 to 10 and dropping the core hole drill and remote sampling requirement, the scientific payload weight was cut in half, from 632 pounds to 350 pounds. The significant percentage of total payload weight in consumable chemical supplies, for complex payloads, was also confirmed by the subsequent ABL preliminary design study.

(2) In the process of developing the weights associated with the various experiments, a definite correlation between biologically oriented experiments and chemical processing exists. Environmental experiments used to support the biological experiments tend to be relatively independent of supply requirements, except for power and data processing.

(3) Total entry vehicles weights ranged from 50 to 6000 pounds. The 50 pound vehicle does not actually carry a biologically oriented experiment since it measures only atmospheric parameters. Thus, lander systems carrying biologically oriented laboratories can be expected to range from 500 pounds upward for the total entry weight. It is interesting to note that Payloads III, IV, and VII were considered at the outset to be nominally 50 pound scientific payloads. The increases of the scientific payload weight associated with more detailed estimates ranged from 50 to 200 percent. Again, the amount of increase correlated with the increase of the number of experiments requiring chemical processing.

(4) A severe weight penalty is seen to accrue to a power supply system based on batteries alone, particularly as the complexity of the laboratory and hence the data output increases. There is definitely some point in size for a biological laboratory where other power supply systems than batteries are appropriate. This is particularly true where high peak powers are required for relatively short times.

(5) While the upper entry vehicle weight may be acceptable for currently available booster systems, it should be pointed out that the diameter required to achieve the required ballistic coefficient can exceed the limits of the booster shroud. Thus, the large payloads can become size limited as well as weight limited for the booster system if ballistic coefficients below 10 pounds per square foot are required during entry.

TABLE 3-IV

COMPARATIVE PAYLOAD SUMMARY

EXOBIOLOGICAL LABORATORY PAYLOADS

	PAYLOAD I	PAYLOAD II	PAYLOAD III	PAYLOAD IV	PAYLOAD V	PAYLOAD VI	PAYLOAD VII	PAYLOAD VIII
EXPERIMENTS								
Atmospheric constituents	X	X	X	X	X	X	X	X
Atmospheric temperature, pressure, & wind	X	X	X	X	X	X	X	X
Atmospheric humidity	X	X	X	X	X	X	X	X
UV insolation flux	X	X		X	X		X	X
Soil temperature and water content as functions of depth	X	X	X	X	X		X	X
Elemental soil analysis	X	X	X	X	X		X	X
Soil gas analysis	X	X	X		X			
Soil respiration					X			X
Surface structure and composition by α-scattering techniques	X	X			X			
Determination of mineralogical structure composition of surface by X-ray diffraction					X			
Detection of porphyrins by fluorimetry	X	X						
Detection of macromolecules by spectrophotometry	X	X						
Detection of organic materials	X	X	X	X	X		X	X
O^{18} exchange from oxyanions with water	X	X						
Optical activity by rotatory dispersion	X	X						
UV optical activity of water soluble macromolecules			X					
Detection of water soluble macromolecules by gas chromatography			X					
Optical rotation in the visible spectrum of water soluble macromolecules			X					
Detection of amino acids and optical activity					X			
Detection of catalytic activity					X			
Functional group analysis								X
Detection of soluble inorganic ions & pH determination								X
Identification of specific molecular species								X
Detection of increase in steroids	X	X						
Detection of increase in macromolecules	X	X						
$C^{14}O_2$ evolution and fixation	X	X		X	X			
Growth and metabolism-evolution of CO_2 by normal metabolism	X	X						X
Macro-imaging scan of surrounding terrain	X	X	X					
Infra-red scan of surrounding terrain	X	X	X					
Detection of macromolecules by ion exchange/molecular sieve					X		X	X
INSTRUMENTS - TOTAL WEIGHT	84.5	84.5	24.9	21.2	67.0	4.3	22.3	46.8
Atmospheric parameters sensors (T,P,q)	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
Water vapor detector	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Subsurface sonde	2.0	2.0	▨	▨	▨	▨	▨	▨
pH meter	1.0	1.0	▨	▨	1.0	▨	1.0	1.0
Soil mechanics-bearing and shear strength	4.0	4.0	▨	▨	▨	▨	▨	▨
Fluorimeter	▨	▨	▨	1.4	1.4	▨	1.4	1.4
Electrical conductivity	▨	▨	0.1	▨	0.1	▨	0.1	0.1
Soil respiration	▨	▨	▨	▨	1.0	▨	▨	1.0
Ionization detector	0.2	0.2	▨	0.2	0.2	▨	▨	▨
CO_2 detector	0.2	0.2	▨	▨	▨	▨	▨	0.2
IR radiometer	3.0	3.0	▨	▨	▨	▨	▨	▨
α-scattering counter	15.0	15.0	▨	▨	15.0	▨	▨	▨
X-ray diffractometer	▨	▨	▨	▨	15.0	▨	▨	▨
Atmospheric gas chromatograph	0.8	0.8	0.8	0.8	0.8	1.0	1.0	1.0
Gas chromatograph/mass spectrometer	13.0	13.0	▨	▨	13.0	▨	▨	13.0
Gas chromatograph-chemical analysis	▨	▨	9.6	8.9	9.6	▨	8.9	9.6
UV/Visible spectropolarimeter-190 mμ - 700 mμ	▨	▨	6.1	▨	▨	▨	▨	▨
UV spectrophotometer	▨	▨	▨	6.6	6.6	▨	6.6	6.6
IR spectrophotometer	▨	▨	▨	▨	▨	▨	▨	9.6
Spectral analyser (UV/Visible spectrophotometer, ORD, fluorimeter)	35.0	35.0	▨	▨	▨	▨	▨	▨
Macroimaging scan	7.0	7.0	5.0	▨	▨	▨	▨	▨
	▨	▨	▨	▨	▨	▨	▨	▨
SAMPLING EQUIPMENT - TOTAL WEIGHT	78.0	[illegible]	15.3	13.2	63.0	0.0	9.2	21.3
Local Sampling	▨	▨	▨	▨	▨	▨	▨	▨
Sample processing and grading	7.5	7.5	▨	▨	7.5	▨	▨	▨
Soil gas probe	5.5	5.5	5.5	5.5	5.5	▨	5.5	5.5
Pneumatic collector	5.0	5.0	▨	▨	5.0	▨	▨	▨
Surface scraper	5.0	5.0	▨	▨	2.0	▨	▨	▨
	5.0	5.0	2.1	▨	5.0	▨	▨	2.1

Core Drill	30.0	▨	▨	▨	▨	▨	▨	▨
Pneumatic sample collector and grader	▨	▨	7.7	7.7	▨	▨	3.7	7.7
Remote Sampling	▨	▨	▨	▨	▨	▨	▨	▨
Drag line	▨	▨	▨	▨	18.0	▨	▨	6.8
Trolley transported sampler	20.0	▨	▨	▨	▨	▨	▨	▨
CHEMICAL PROCESSING EQUIPMENT - TOTAL WEIGHT	87.5	82.5	38.5	9.0	26.0	0.5	21.5	38.5
Chemical reaction chambers-including pyrolysis/culture chamber	30.0	30.0	5.0	5.0	15.0	▨	5.0	20.0
Ultra-filtration chamber	22.5	22.5	22.5	▨	▨	▨	7.5	7.5
Ion exchange/molecular sieve	10.0	10.0	▨	▨	▨	▨	5.0	5.0
Internal transport mechanism	5.0	5.0	3.0	2.0	3.0	▨	2.0	2.0
Pumps and compressors	5.0	5.0	3.0	▨	3.0	▨	▨	2.0
Plumbing and wiring	15.0	10.0	5.0	2.0	5.0	0.5	2.0	2.0
CHEMICAL PROCESSING CONSUMABLES - TOTAL WEIGHT	282.0	95.0	31.2	13.8	83.7	2.7	29.9	64.5
Chemical reagents and containers	122.0	28.0	5.7	7.5	50.5	▨	7.1	26.1
Chemical processing supplies	90.0	45.0	16.1	▨	13.2	▨	13.0	23.4
Gas chromatograph carrier gas and container	20.0	10.0	6.4	3.3	8.0	2.7	5.8	10.1
Wash and flush media and container	40.0	10.0	3.0	3.0	10.0	▨	3.0	3.0
Waste storage	10.0	2.0	▨	▨	2.0	▨	1.0	2.0
ELECTRONIC CONTROLS AND PROCESSING - TOTAL WEIGHT	40.0	30.0	14.0	14.0	12.0	2.0	14.0	19.0
Power conversion and regulation	5.0	5.0	2.0	2.0	5.0	1.0	2.0	2.0
Programmer/computer including memory	30.0	20.0	10.0	10.0	2.0	▨	10.0	15.0
Data processing and conditioning	5.0	5.0	2.0	2.0	5.0	1.0	2.0	2.0
STRUCTURE AND MISCELLANEOUS WEIGHT	60.0	30.0	19.0	7.0	24.0	1.0	10.0	19.0
TOTAL SCIENCE PAYLOAD WEIGHT	632.0	350.0	142.9	78.2	255.7	10.5	106.9	209.1
COMMUNICATIONS - TOTAL WEIGHT	18.0	18.0	18.0	18.0	18.0	16.0	18.0	18.0
Receiver-transmitter	12.0	12.0	12.0	12.0	12.0	10.0	12.0	12.0
Antennas and supports	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
ELECTRICAL POWER - TOTAL WEIGHT	1,251.0	659.0	316.0	97.0	206.0	6.0	81.0	125.0
Communications power - thermal batteries	1000.0	505.0	238.0	31.0	136.0	3.6	15.0	57.0
Operational power - primary batteries	251.0	154.0	78.0	66.0	70.0	2.4	66.0	68.0
THERMAL CONTROL - TOTAL WEIGHT	39.0	22.2	14.6	11.0	16.2	1.0	11.3	14.5
Atmospheric circulation and purification	13.0	7.0	7.0	7.0	7.0	▨	7.0	7.0
Insulation	7.0	5.0	2.8	2.0	4.5	▨	2.3	4.0
Active thermal control	19.0	10.2	4.8	2.0	4.7	1.0	2.0	3.5
INTERIOR STRUCTURE WEIGHT	97.0	52.4	24.5	10.4	24.4	1.0	10.9	18.4
IMPACT LIMITER WEIGHT	386.0	209.0	98.2	40.9	99.0	4.1	43.5	73.5
GROSS PAYLOAD WEIGHT	2,423.0	1,310.6	614.2	255.5	619.3	38.6	271.6	458.6
VEHICLE SYSTEM - TOTAL WEIGHT	3,739.0	1,749.4	626.8	216.5	645.7	22.3	224.1	418.5
Parachute system	268.0	56.0	29.0	12.0	30.0	3.0	12.4	22.0
Mass damper and separation fittings	279.0	144.0	68.0	21.0	70.0	2.0	23.0	39.0
Structure and heat shield	2,774.0	1,328.4	450.8	158.5	464.7	14.4	163.6	311.1
Orientation system	196.0	106.0	32.0	8.0	34.0	0.7	8.6	15.4
Retro-separation motor	221.0	114.0	46.0	17.0	47.0	2.2	17.3	31.0
TOTAL LANDER WEIGHT	6,161.0	3,059.0	1,240.0	472.0	1,265.0	60.9	495.7	877.1
TOTAL LANDER WEIGHT IN ROUND NUMBERS	6000	3000	1000	500	1000	50	500	1000

NOTE:

1. All weights are in earth pounds.
2. Mission duration is six months.
3. Weights for Payload I are based upon forty complete experimental cycles. All other payloads are based upon ten cycles.

SECTION 4

LABORATORY AUTOMATION STUDIES

4.1 IMPLICATIONS OF AUTOMATION

4.1.1 NATURE OF AUTOMATION

Automation means many different things to different individuals, even when those individuals are specialists working in one of the many areas relating to automation. Titles of numerous books and papers in the field embrace the entire field of automation when, in fact, they relate to extremely limited aspects of the entire subject. This fact does not necessarily reflect upon their usefulness or competence, but does reflect upon the many sided and fragmented nature of the subject. There are papers, for example, that cover the mathematics of information theory or cybernetics in such a way as to imply that these subjects are "automation." There are, at the same time, those engaged in designing conveyor lines for production facilities who are firmly convinced that they too are practicing "automation." Between, and including, these two extremes lies the extensive area of science, technology, and art, which is, in fact, automation.

This very broad field has one unifying theme, however, namely the accomplishment of specified functions without human intervention. With this objective in mind, such diverse disciplines as information theory, cybernetics, computer design, data processing, mechanical design, and any of the scientific or engineering disciplines, become tools for use in the accomplishment of the system objective. In the case of ABL, the principal areas of science and technology which apply are shown on Figure 4.1-1. As can be seen, the ABL automation problem, as all automation problems, rests initially upon a foundation of the applicable mathematical disciplines. These, in turn, give rise to the scientific disciplines, appropriate to the ABL automation problem, of cybernetics (sensing and control), information science, and computation. The literature and methods of these scientific disciplines, in turn, contribute to the indicated system engineering areas applicable to ABL automation. As indicated by the arrows, the interaction between the primary science relating to automation and the specific systems engineering areas applicable to ABL is diffuse, i.e., each area of science contributes to many areas of automation engineering. For this reason, and because the problem being considered by this study is one of determining engineering feasibility of an automated ABL (rather than research into the fundamentals of automation), the study was conducted, and will be discussed, in relationship to the principal engineering disciplines. The science and mathematical foundations are considered in the light of their influence and support of these engineering disciplines.

The work statement for the ABL study specified that:

> "Automation shall consider automatic sampling, recycling..., programming and sequencing of exobiological experiments, resterilization, data storage, communications, redundancy of critical components, and reprocessing..."

From Figure 4.1-1, it is clear that these subjects are specific investigations within the system engineering functions previously defined. Other important areas of investigation are also seen to be pertinent to the ABL automation problem and have been considered in this study.

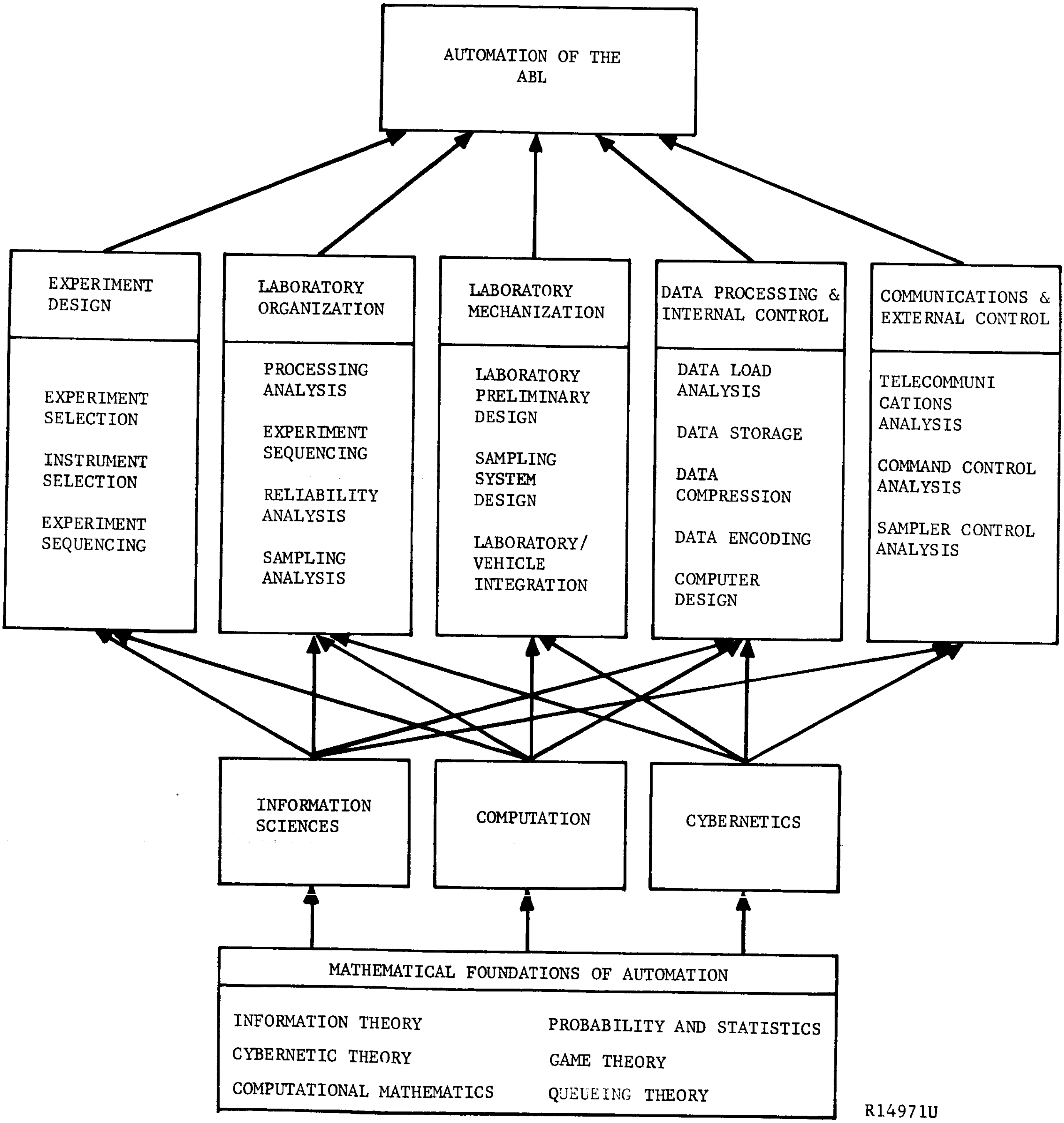

FIGURE 4.1-1 ABL AUTOMATION FUNCTIONS

The multiplicity of disciplines contributing to the automation of the ABL has an important implication relative to the organization of this report.

All evaluation of the automation problem clearly cannot be confined to this section on automation, but must be considered as well, an integral part of the anlysis in each of the separate areas of investigation. Those areas which could conveniently be broken out as relating largely to the automation problem are discussed in this section. These studies include conceptual automatic sampling, experiment sequencing, internal laboratory organization, and the laboratory reliability analysis. The implications of automation relating to experiment selection, instrument selection, laboratory preliminary design, sampling system preliminary design, laboratory vehicle integration, data processing, communication, and control are covered in the sections of the report relating to these specific subjects. Whether or not a particular subject is discussed in this section or elsewhere does not reflect in any way upon the importance attributed to it in this study relative to automation but, rather, is a function of the convenience with which the subject could be broken out independently from other related material.

4.1.2 CONCEPTS IN AUTOMATION

The forgoing has indicated what subject can be considered in automation, but did not attempt to define what automation concepts could or should be considered for ABL. For example, should ABL automation be any different that that, say, for the orbiting observatories, Ranger, Surveyor, or Mariner? These vehicles operate remotely (i.e., without human intervention) and are, to a very great degree "automatic." Figure 4.1-2 indicates a simplified schematic diagram of the essential automatic control inherent in these systems. Certainly, a great deal of the control requirements on an ABL could be handled by these same techniques.

At the opposite extreme of complexity, one finds considerable literature relating to far more sophisticated automation concepts. Concepts, for example, that involve a form of "learning" on the part of the automated system;(1) the so-called adaptive system. Learning is used in the context

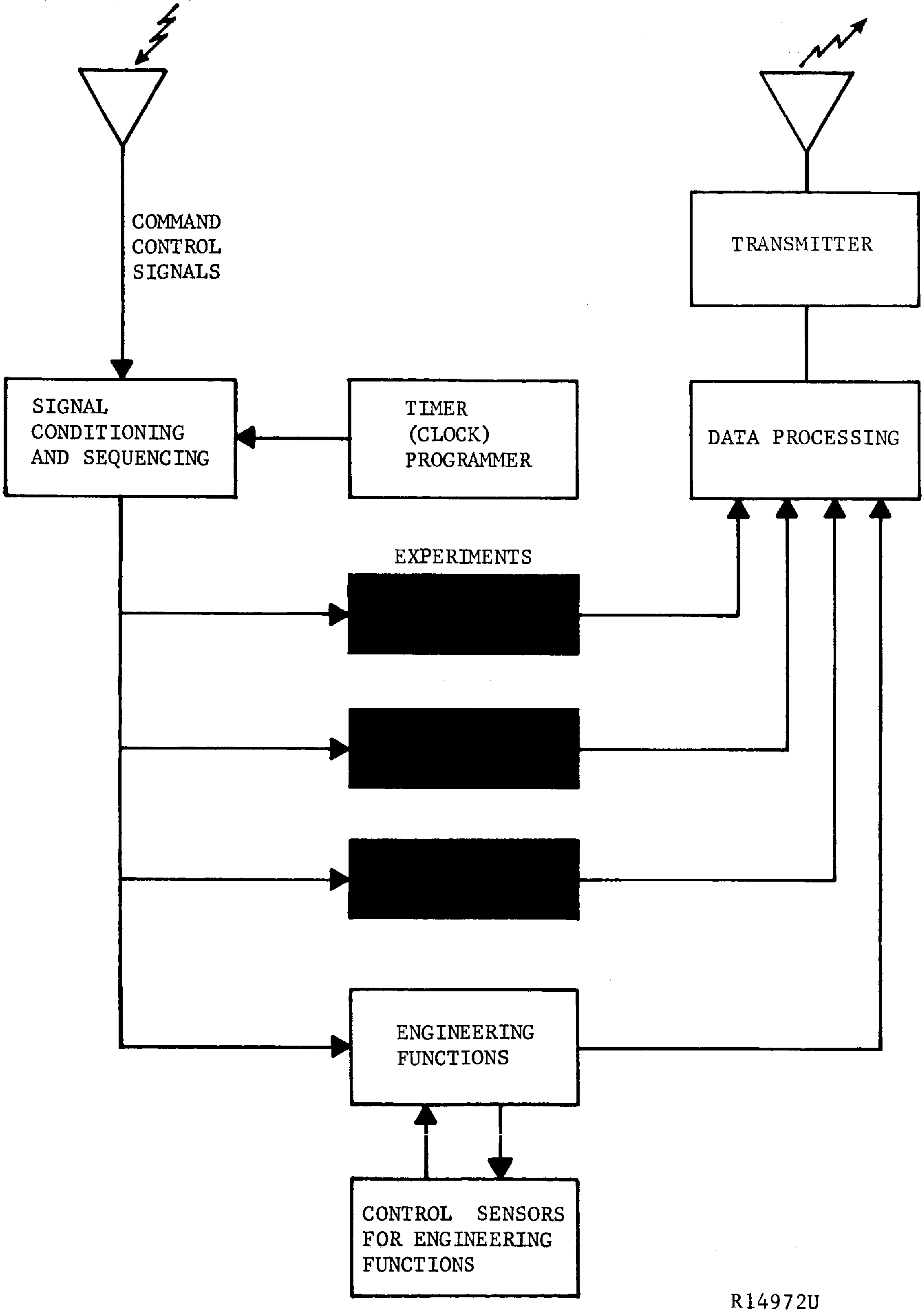

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FIGURE 4.1-2 AUTOMATIC CONTROL CONCEPT OF TYPICAL PRESENT GENERATION SPACECRAFT here that, starting with a basic program (or even, in some cases with no program in the usual sense), the automated system modifies this initial state as a result of repetitive trials in such a way that desirable performance is maximized. A number of potential applications for such a system on ABL can be visualized. Reprogramming to emphasize experiments yielding the most productive results is one such possibility. Control of laboratory operations to maximize experimental results and minimize failure rate, damage, power consumption, etc., is another interesting possibility. Such systems, at least at the present time, are characterized by two limitations, however:

(1) First they must have some criteria by which to judge performance and against which to maximize that performance. While some such criteria could be provided, a priori, the very fact that in the ABL the unlooked for result may be the most interesting would urge caution in establishing a priori criteria for successful operation too early in the program. Since the experimental results must eventually be transmitted to Earth in any case, a more sound approach would seem to be to relegate such decision-making to the scientists on Earth best qualified to make the decision, and to modify the experimental or operational program accordingly by means of control commands sent from Earth.

(2) A second consideration is that complex learning systems, such as would be involved in handling previously untried experiments with multiple variables, require many repetitive trials to achieve optimum adaption to the criteria. The current ABL concept does not envision large numbers of repetitive, experiments, but rather series of sequential experiments repeated infrequently.

Optimizing operations during the diurnal cycle (i.e., for optimum time of day or night) might be useful, although sufficient knowledge of this environment is expected by the time of the ABL mission to optimally accommodate most variables. Nonrepetitive variables, such as storms or surface conditions can be easily handled by open loop sensors and do not appear to warrant the complexity of adaptive systems.

Another often referred to application of the adaptive system is that of pattern recognition. Interesting applications have included systems which can be trained to select certain visual patterns from a source containing a random sequence of patterns. Aeronutronic(2,3) and others have investigated the concept of combining such a system with certain kinds of image data preprocessing which will yield characteristic patters which are a function of the class of scene being viewed. Such a system has two interesting potential applications on ABL.

First, a system, such as that described in Reference (2), has the potential of achieving almost the ultimate in image data compression. For example, if a given image (e.g., micro, macro, spectral response) could be accurately categorized into a unique characteristic category, that category could be represented by a simple coded symbol. While not providing sufficient data for reconstruction of the information contained in the initial image, considerable information can be implied from the data, with a tremendous reduction achievable in the data quality. This application is discussed in greater detail in Paragraph 6.3 of this report dealing with data processing.

Second, a similar technique for processing and analyzing image data also could conceivably be employed as a control scheme. For example, if the desirable characteristics of sampling sites could be identified beforehand, (e.g., color, texture, spectral response, surface particle size, or containing objects having characteristic shapes or symmetries) a pattern recognition system could be designed, at least in principal, to select such sites from a general background. This information could be used to direct sampling operations to the selected site without having to transmit the image data to Earth for analysis. Other examples of the use of pattern recognition for control purposes can be visualized.

Between the extremes of present day spacecraft automatic operation, and the sophisticated and potentially attractive adaptive systems described above, there lies infinite degrees of automatic system sophistication and complexity. When considering the question of what level of automation sophistication to be adopted for ABL, the following considerations need to be carefully evaluated.

First, the automation concept should be selected which will accomplish the required functions as simply, in concept and mechanization, as possible. In other words, the automation concept should be matched to the complexity and sophistication of the mission. To put it still another way, advanced sophistication and/or complex techniques in automation should not be employed simply because the technology exists, but should clearly demonstrate the optimum solution to the specific automation problem under consideration.

Secondly, any selected automation concept must be carefully evaluated relative to its expected state of development in the time period of the mission of interest. Clearly more complex systems are feasible for the later time periods than for 1971-1975, for example.

4.1.3 ABL REFERENCE DESIGN POINT CASE

For the ABL design point case considered in this study and defined above in Section 2, the following constraints can be considered to apply:

a. Automation Control. The automatic control functions of the system should be based on current, or very minor extrapolation of, today's state of the art. The rationale for this constraint lies in the critical central nature of the automatic control function in the ABL, with the resulting requirement for its high level of reliability. This, in turn, demands a practical design, development, and qualification sequence to achieve this state of development. As is pointed out in Paragraph 6.3 of this report, these considerations apply not only to hardware items but also to the computer program software as well, which must be subjected to a similar sequence of design, development, debugging, and evaluation to properly check all possible contingencies of operation.

These criteria eliminate the inclusion of highly sophisticated adaptive control systems from consideration at this time, principally because of the lack of adequate criteria upon which to base the adaptive control functions. It also eliminates from consideration elaborate image recognition techniques for the same reason, and also because of the relative undeveloped current state of the art.

Nothing in these conclusions implies any judgment about the "absolute" value of these techniques, but only their appropriateness for the current application. In fact, because the rate of development in these areas is very rapid, this decision should be re-evaluated periodically as the development of ABL progresses. Such re-evaluation is certainly appropriate when post-1975 missions are being considered.

It is fortunate that the above constraints do not render the ABL infeasible. Consistent with the first consideration enumerated in the previous discussion less sophisticated systems are capable of meeting all ABL control requirements, as is well documented in Paragraph 6.3 of this report. The extensive use of preprogrammed routines and stored decision tables in which experiment results can become the "conditions" for subsequent "actions," and with the capability for command override from Earth with either selection of preprogrammed routines or substitution of completely new routines, provides all the flexibility required to accomplish meaningful scientific ABL missions. The resulting automatic control concept for the ABL is shown in Figure 4.1-3. An aid in this approach is the relatively leisurely time sequencing of events in the ABL. The factor is discussed on the following pages.

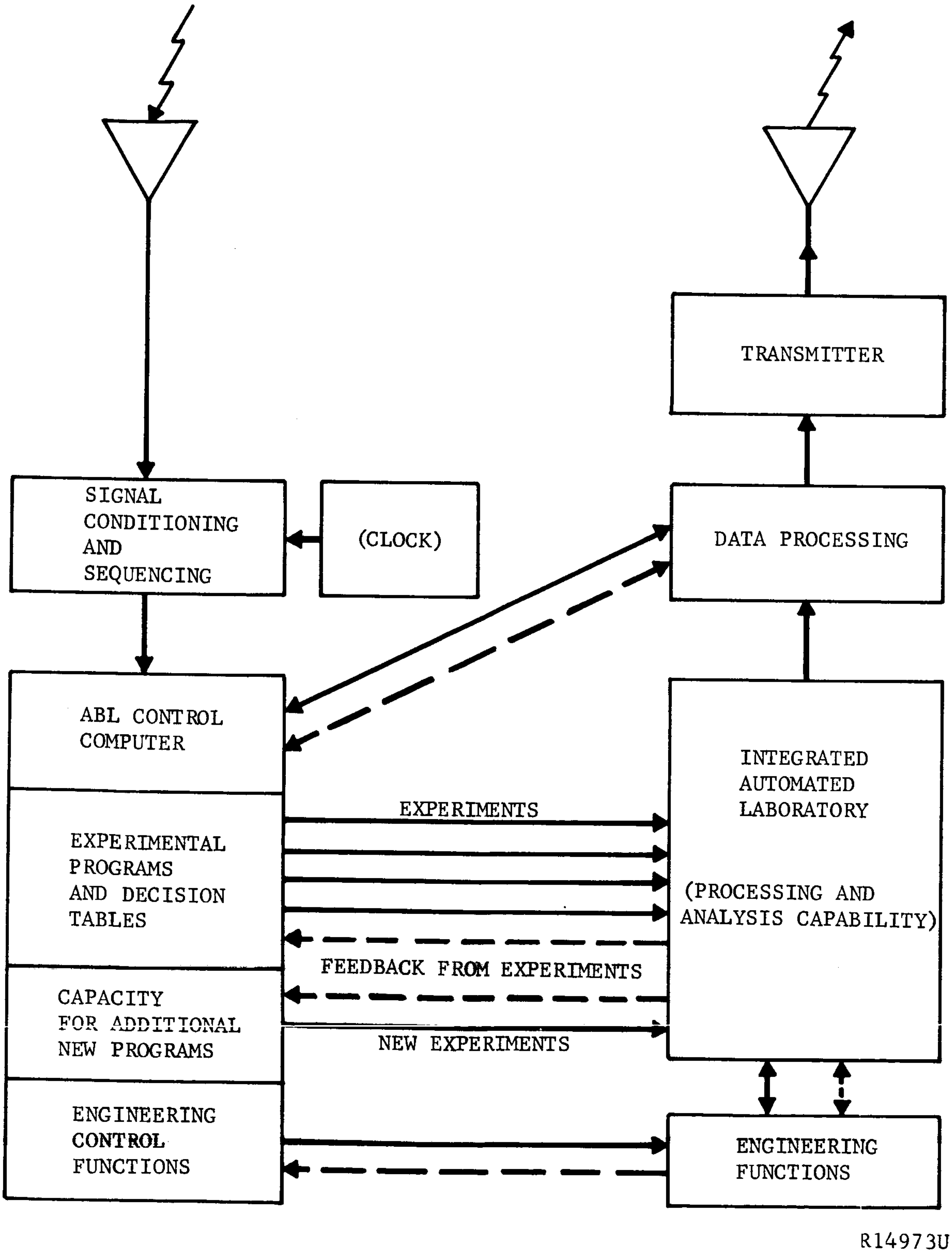

FIGURE 4.1-3. ABL AUTOMATIC CONTROL CONCEPT

b. Event Phasing and Sequencing. The absolute number of events that must be performed in an ABL, and their time phasing and sequencing, is an important basic input to the automation analysis. The events relating to the design point experiment complement defined in Volume II have been definitely established by the descriptions of the experimental procedures in Appendix 5 of Volume VI. The time phasing of these individual events and the related system engineering functions have been considered in detail for the entire two-year life-time in the analyses described in Paragraph 4.2 of this volume. These time-sequenced events were employed to define data output requirements used in the communication and data processing analyses and electrical power time-histories used in the preliminary design analysis. In addition, the requirements for both automatic and command control functions were identified and formed the basis for the automatic control analyses in Paragraph 6.3 of this volume. Various analyses are an inseparable part of the automation problem on ABL, but are more appropriately discussed in connection with the specific subsystem to which they relate.

It will be apparent from the analysis in Paragraph 4.2 that, in general, for the two-year total mission life, the time-sequencing of events is not "tight." This comes about because of the objective of obtaining data considerably spaced in time, i.e., to obtain data during each of the Martian seasons. Performing experiments continually during the full two years at the maximum capability of the equipment, would produce large quantities of redundant data having very low scientific value. In addition, such use of the equipment would place very heavy demands on chemical reagents and processing consumables, and on the communications link, including the ground control facilities which will, undoubtedly, have to be shared with other programs during the two-year interval. Thus, sophisticated control schemes principally useful in obtaining rapid and efficient time phasing of many events are not a critical requirement for the ABL.

c. Laboratory Internal Mechanization. The internal organization of the ABL and its mechanization for automatic operation received a significant portion of the entire preliminary design effort. There is very little precedent on which to base this aspect of the automation effort on ABL. Other space systems either have a much shorter design life or are much more simple. Terrestial analogies, such as large-scale chemical processing plants or automatic laboratory mechanizations that have been employed were found to have very little direct carry-over to the ABL. Three types of internal mechanization were considered for the ABL:

(1) Continuous flow processing.

(2) Fluid transfer batch processing.

(3) Mechanical transfer batch processing.

While the first of these has been employed in terrestrial laboratories, it finds its grestest application where large numbers of identical processes are performed. The ABL, on the other hand, is characterized by a fairly large number of different processes repeated infrequently. Continuous flow processing, in addition, places some severe engineering requirements on the system from the standpoint of processing fluid requirements and cleaning and contamination control. These factors are discussed in Paragraph 4.3.1.

The remaining two process concepts, as applied to the ABL design point instrument complement, were subjected to a detailed trade-off analysis. The results of this study are reported in Paragraph 4.3.2. While the advantages and disadvantages of each approach were related in this study to such quantitative matters as part counts and weight, the final designs were not so different as to make a choice between them apparent. However, when the alternative designs were submitted to practicing biologists and chemists for review and the factors of cross contamination between experiments and the potential effect on laboratory functions from possible failure mode were evaluated, the choice was clearly in favor of the mechanical batch processing scheme. The details covering this selection are presented in Paragraph 4.3.2. While the resulting system mechanization appears complex, it must be remembered that the design point system provides for the repetitive conduct of 35 experiments involving wet chemical processing and other functions for a period of two years. No other system to date has been built with this capability and <u>any</u> such system, regardless of the way in which it is mechanized, will appear complex by standards of today's space payloads. The importance of the analysis reported in Paragraph 4.3.2 is that the mechanical batch processing approach is essentially no more complex than any other form of mechanizing and has important other advantages, principally related to its noncatastrophic modes of failure. The reliability analysis reported in Paragraph 4.4 also demonstrates that, on an absolute basis, the mechanical system is capable of achieving satisfactory levels of performance. An advantage of the mechanical system is that it is amenable to rigorous analysis based on extensive test performance of the multiple subcomponents and parts.

d. <u>Laboratory Organization</u>. In addition to the internal processing mechanization considered was the question of the basic organization of the analytical capability within the ABL. At least two extreme possibilities are evident, namely, use of individually mechanized experiments, each of which would provide all analytical and processing capability to perform one experiment, and the integrated approach which would employ common equipment wherever feasible to do so. An initial analysis of this problem was conducted early in the ABL study before the design point instrument complement identified in Volume II was established. Consequently a more or less arbitrary selection of nine experiments was picked from those under consideration at that time (most of which were subsequently selected for the design point complement). These were mechanized according to the two described concepts by means of a preliminary design analyses. The results of this analysis are reported in Paragraph 4.3.3. Even with the relatively small number of experiments selected in this analysis, the weight advantages accruing to the integrated approach was confirmed and was adapted for this study. Of course, the even more important aspects of improved scientific research which will result from such laboratory organization, and which was discussed at length in Volume II of this report, is fundamental to the ABL concept.

At the conclusion of the ABL preliminary design analysis, a similar comparison was performed between the two concepts using the detailed information generated during the preliminary design for 35 experiments and the results from this earlier study were confirmed. The later evaluation, in fact, showed the expected result of the leveling off of weight with increasing capability, due to increasing common usage of equipment, for the integrated approach, while the individually mechanized experiments tend to continue to increase in weight as capability is expanded. The results of these comparisions are discussed in Paragraph 5.4 of this volume.

e. Reliability Analysis. It may appear somewhat incongruous that the reliability analyses for the ABL appear under the discussion devoted to automation studies. Such is not the case, however. The automation function, and particularly the uniqueness of the mechanization of the laboratory functions, in the ABL is vital to the success of this concept. Other features of the payload, such as communications and electrical power, for example, are less of a departure from established space payload practice and have considerable experience upon which to draw for their development. The automation aspect, or in total, the mechanization of the science payload, was therefore felt to deserve the entire amount of the somewhat limited effort that could be devoted to the question of reliability in a study of this magnitude. This study was therefore conducted on the basis of the probable success from the experimental payload, assuming that the necessary support functions were performed. Obviously, the resulting values cannot be related to total mission success without introducing the results of analysis covering these additional functions. The values generated do provide useful first cut indications of the relative contributions to failure rate from the science payload and, further, have identified within that payload the critical components contributing to those failures. The results of this analysis are best appreciated by referring to the data in Paragraph 4.4.

f. Sampling. Sampling, as identified in the work statement quoted at the beginning of this discussion, is an important aspect of the mechanical portion of the automation of an ABL, in addition to an important consideration in the valid design of experiments from a scientific point of view, as discussed in Volume II. The wide range of possible sample collection transport and mechanical processing concepts were evaluated in a series of conceptual sampling studies which are reported in Paragraph 4.5. From these studies, it was possible to pick a range of devices for sampling from the ABL for use in the design point study. These studies are not to be considered the final word on this subject, however. The number and complexity of the variables affecting the selection is large and deserves considerably more study. These variables include Martian soil physics of which a better understanding can be obtained through certain laboratory studies. Other effects deserving further study include probable quantitative effects of the lander on the quality of the sample in the immediate area of the landing and the probable required range and navigational capabilities of samplers for ranging beyond the capability of the ABL-fixed devices. Two required features that appeared to be mandatory for ABL, as a result of the studies performed and from the recommendations of other groups, such as the Committee on Martian Landers of the _ad hac_ Bioscience Working Group, (reported in Appendix 8), were that:

(1) Large sample quantities are required.

(2) A multiplicity of sample collection techniques also are required.

The first is dictated by the number of experiments and by their sensitivity and the probable concentration of biological material in the Martian sample. The second is, of course, dictated by our total lack of information on the Martian surface on the scale of the sampling devices (a few cm). The design point ABL therefore includes devices for sampling the surface and deep subsurface directly below the lander surface and immediate subsurface at intermediate and long ranges (up to 800-1000 feet) from the lander, and at controlled azimuth and range within these limits. This latter capability, attained with drag line or wire-trolley deployed systems, was felt to be sufficently comprehensive that, for the 1975 mission, separately roving samplers were not warranted. These would have caused the weight goal for this payload to have been significantly exceeded. The rover capability to _significantly_ exceed the 1000-foot range attainable with the deployed sampler, and to have performed a two-way navigation (collections of the sample and return to the laboratory for analysis) was well beyond the class of payload under consideration in this study. Studies of missions for later time periods, or with other design limits, however, should re-evaluate this concept as well as that of roving the ABL itself.

The following paragraphs discuss the details of those analyses relating principally to automation. Aspects of the automation problem are discussed at length in other portions of this report as identified in the preceding paragraphs.

4.1.4 REFERENCES

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2. Techniques for Classifying Extra-Terrestrial Environments, Aeronutronic Publication No. P-15111, 30 April 1965.

3. Recognition and Transmission of Video Patterns, Aeronutronic Publication No. P-15098, 23 April 1965.

4.2 EXPERIMENT TIME PHASING STUDIES

4.2.1 REQUIREMENTS AND OBJECTIVES OF TIME PHASING STUDIES

As indicated in Paragraph 5.3 of Volume II, the design point ABL has an experimental list of 35 procedures, employing 29 instruments. In addition to this equipment, there is an assortment of sample collection, chemical processing, and transport mechanisms required to support the experiments. All of these procedural steps and equipment must be phased and programmed in terms of equipment availability, power demands, and control requirements in order to achieve the organization necessary to operate an automatic laboratory. As the number of experimental procedures and types of equipment increase, the task of phasing becomes increasingly complex, and in fact, cannot be accomplished for all possible modes of operation when command modifications can be incorporated in the programmed routine. Thus, to simplify the phasing task, it was approached in an incremental fashion. The first objective selected was the collection of as much data as possible in the shortest length of time after landing, based on the premise that failure rate will increase with time after landing. The second objective selected was the determination of phasing on the basis of equipment availability in order to define critically used components and estimate quantitative requirements. The third objective was to evaluate the phasing in terms of power demand to eliminate peaks which would influence the sizing of the primary and secondary power supplies. The final objective was then to evaluate the phasing in terms of data output and control requirements. It soon became apparent in this study that phasing for a system as complex as the design point case is influenced strongly by many of the initial assumptions and conditions that are imposed. Some of these are the number of sampling sites that are to be investigated, the number of experimental cycles necessary to achieve statistical reliability in the data, and the degree to which Earth-based control is applied. With this in mind, the goal in establishing time phasing for the design point ABL was to achieve a realistic and reasonable phasing of experiments. "Optimization", as such, cannot be fully realized in any case at this stage of development.

Before proceeding with a discussion of phasing, it is appropriate to present the assumptions leading to the initiation of the surface operations for the ABL. A schematic diagram of the command and control network for ABL is shown in Figure 4.1-3. The Earth to Mars communication link is discussed in Paragraph 6.2. The operations of the ABL can be classified as either scientific or engineering modes. For the purpose of developing the experimental phasing, certain engineering operations must be carried out before scientific operations can be initiated. A more complete discussion of the initial erection sequence is given in Paragraph 5.6.4. The important consideration for developing the phasing study is that it will take one complete day from sunrise to sunset to erect the laboratory and complete the final orientation to properly point the high gain antenna. It is assumed that the initial landing is made sometime before sunrise of day "one". This could be during daylight hours of the day before. During this first day, the experiments listed in Table 4.2-I can be conducted. Experiment Number 5 is required to obtain the data needed to complete the final orientation of the laboratory. In the first day, the mode of operation for this experiment is altered from its normal mode. It is used as a sun tracker rather than as an integrating isolation radiometer. The data from the remaining experiments must be stored until the high gain antenna is deployed and the command link is established and verified.

TABLE 4.2-I

FIRST DAY EXPERIMENTAL OPERATION

Experiment Number	Title
1	Atmospheric Pressure, Temperature, and Wind
2	Atmospheric Humidity
3	Wind Transport Particulate Matter
4	Acoustical Monitor
5	Ultraviolet and Visible Insolation
7	Atmospheric Constituents
34	Motion Detection

4.2.2 REPRESENTATIVE EXPERIMENT SCHEDULES

To approach the time phasing study in a logical manner, it was first necessary to take the experimental procedures and illustrate them graphically as functions of time on an individual basis. These individual time line diagrams are presented in Appendix 5. Procedural steps involving processing are indicated by circles with the appropriate procedural step number in it. Command and control requirements were coded at each step where they were required. Analytical instrument procedures are indicated with a square box to provide a distinction from the purely processing steps involved in preparing the sample for analysis. These detailed time lines identify the types of equipment used and the length of time each type is in use. In generating these detailed time lines, it became apparent that several time scales were required because of the wide variation in time required to perform the various experiments. This makes it difficult to present the phasing in graphical form. Thus, the phasing was developed in steps. The detailed experimental time lines used minutes and hours as the primary scale. The actual phasing of the experiments was performed using a scale of Martian days. The Martian day was selected as the basic unit since some experiments must also be phased with respect to the time of day or night. Finally a summary phasing diagram using Earth months was used to present the overall mission phasing for the 2-year lifetime.

Figure 4.2-1* shows the experimental phasing for the first 90 days of operation on the Mars surface. Time zero is the first sunrise after the laboratory has been oriented and the communications link has been verified. It is seen that Experiment numbers 1, 2, 3, 4, and 34 are a type that are continuously monitored, and data are either extracted on demand or whenever some minimum threshold value is exceeded. These experiments are essentially self-contained and do not influence the phasing of remaining experiments. The macroimaging or picture-taking system is designated as one of the two most primary. This experiment is therefore initiated at the earliest possible time. It was not initiated during the time spent in tracking the sun for two reasons. First, the equipment in the form mechanized to take pictures also functions as the sun tracker and is committed to this use. Second, it is desired to take the picture after final orientation so that the relationship between the laboratory coordinate system and the surrounding terrain is not altered. The first picture taken is a full panoramic scan with lower resolution than subsequent pictures. From this panoramic scan, promising areas to investigate at remote locations are identified. As shown in the phasing chart, all but six of the experiments have been completed for soil samples taken from the sample site located at the laboratory. Since this indicates lower activity, a high resolution scan which produces a high data output is scheduled for the thirteenth and fourteenth days. These pictures coupled with the infrared scan are used to evaluate two possible remote sampling site locations with greater detail. While these pictures are being evaluated on Earth, the core drill operation is initiated. As will be shown later, the core drill is deferred to this point from a consideration of power demands. Since a peak power of 500 watts is estimated for drilling, the drilling operation is pursued for only one hour a day to allow the battery power supply to be recharged. This type of phasing prevents the battery from being sized by the core drill which is only used once. The drilling rate is estimated conservatively to obtain 1.25 feet of core per day which is returned to the laboratory and sections for analysis removed. At this rate, eight days are required to achieve the total depth of 3 meters. The core hole sonde is scheduled to traverse the hole at the end of each days drilling, beginning with the second day when the hole is deep enough to admit the entire probe. These traverses are to obtain data for the freshly exposed soil. Since the drilling operation may introduce transient conditions such as temperature, another traverse is scheduled seven days after drilling is completed. A core hole traverse is then scheduled every month to

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*Figure 4.2-1 is in the envelope in the back of this volume.

determine seasonal effects. Early in the study, one core hole traverse was scheduled for the entire lifetime of the ABL. In the final evaluation of phasing, it became evident that repeated traverses at intervals would incur no penalty for power or data load and would result in a more complete set of useful data.

The remote sampling was scheduled at 30-day intervals for several reasons. Since the remote sampling system uses two wires, 180 degrees apart, for sampler transport, it is desirable to deploy these in the directions which will include the largest number of potentially promising sample sites. The deployment of these wires will be based on the evaluation of the panoramic scan and two high resolution scans and the associated infrared scans. In this regard, it is pointed out that an infrared scan is taken simultaneously with the visual scan and then repeated at midnight covering the same area. Phasing the infrared scan in this manner should provide more information on thermal anomalies and assist in interpretation of the visual scan. Another reason for delaying the remote sampler deployment is that the soil sample is stored and dispensed from the cyclone particle collector of the sample processing system. At the end of 30 days, only enough soil remains to provide for two of the long duration experiments which can be dispensed into the culture dishes and held in stand-by storage without influencing any of the other experiments. Finally, some small additional risk of damage to the laboratory is associated with deployment of the remote sampling system. It is desirable to delay this risk until the major portion of the first experimental cycle is completed. Deployment at the end of 30 days also allows two weeks to evaluate the first three pictures on Earch. Another high resolution scan is taken on the twenty-sixth day with an additional two-and-one-half days to evaluate this picture and confirm the most desirable deployment direction.

The discussion thus far has considered (1) experimental phasing from the standpoint of relative importance to mission success, and (2) those experiments which exert no influence on the phasing of the more complex experiments. The phasing of those experiments involving wet chemical processing and growth culturing are influenced by the availability of chemical processing and culturing equipment. The chemical processor as developed in this study can be used in either a wet chemical processing mode or as a culture chamber and thus represents a critical piece of equipment with regard to phasing in terms of the number that are available. Experiments 29 and 32 each require six chambers while Experiments 30 and 31 each require four chambers. These experiments also require long incubation periods which means the chemical processing unit involved is not available for other experiments. It is seen from the phasing chart of Figure 4.2-2 that it requires 43 days to complete the experimental cycle for soil samples taken at a given sample site if two sets of culture chambers are used. These four experiments then demand ten chemical processor units used in a culturing mode. The remaining experiments require

MISSION PHASING AND POWER PROFILE SUMMARY

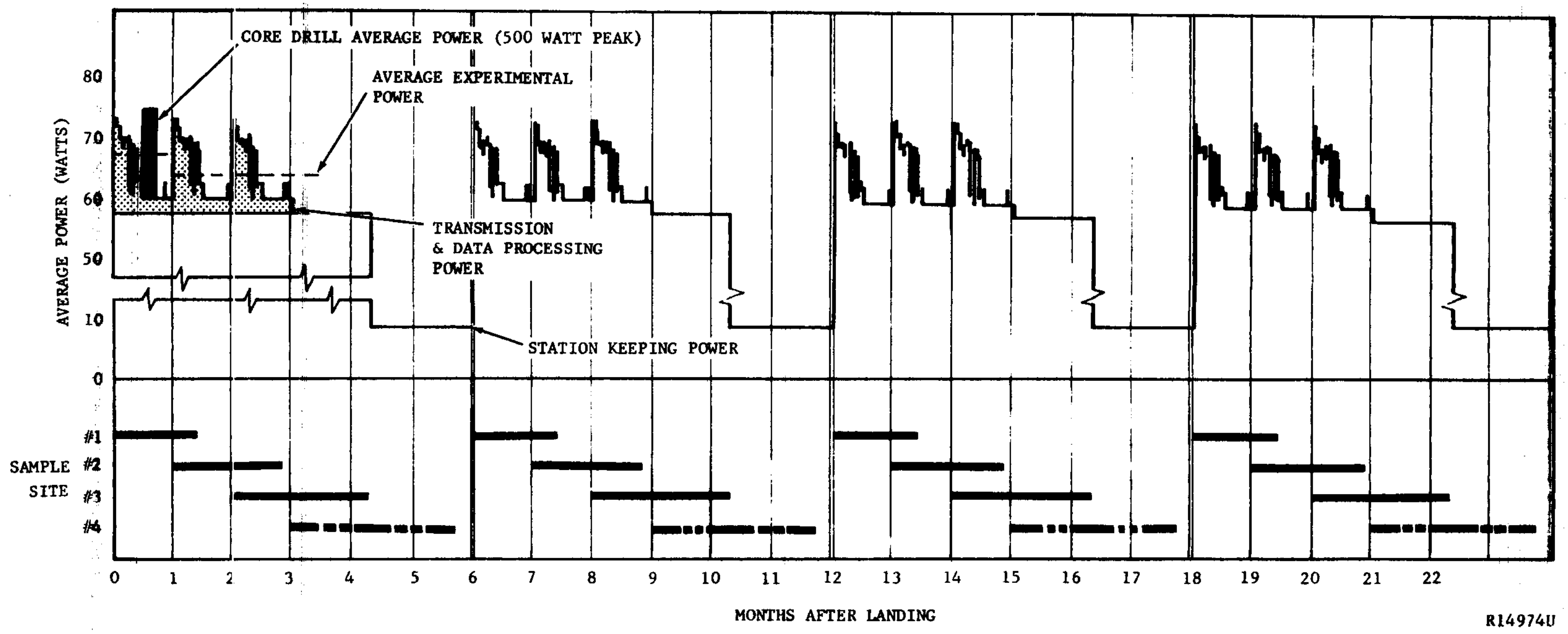


FIGURE 4.2-2. MISSION PHASING AND POWER PROFILE SUMMARY

three additional units for the phasing shown. Thus for the phasing as developed, a total of 13 chemical processors are required. Two units could be eliminated if the phasing of Experiments 15 through 28 were rearranged to occur over a longer period of time; however, this would not be consistent with the first objective, defined in Paragraph 4.2.1, to obtain as much data as quickly as possible. Since these units weigh only six pounds each and incur a relatively small volumetric penalty, the elimination of two units does not affect the design as shown in Paragraph 5.3; therefore, a total of 13 chemical processing units was used. An additional benefit in this approach is the improved reliability provided by allowing experiments to be rescheduled without influencing the phasing of the next sampling cycle.

The overall mission phasing is shown in Figure 4.2-2. The basic unit of time is Earth months after landing and the phasing is illustrated in terms of complete experimental cycles per sample site. It is seen that the total time to completely process the sample taken from each site is progressively longer. This is caused by the fact that Experiments 29 through 32 have not been completed when the next sampling cycle is initiated. The same total time would not be affected if the sample collection were delayed until the end of the 43 day period required to complete an experimental cycle. This was not done because it did not seem reasonable to delay 13 experiments for a period of half a month, leaving the majority of the laboratory equipment idle during this time. The phasing as shown in Figure 4.2-2 indicates that a fourth sample cycle could be included on a seasonal basis. The limiting factor here is the amount of chemical reagents and supporting supplies required which would have increased the size and weight of the laboratory. This lull in activity can be used in several ways. It can be used to reschedule experiments as required by component failures or as desired on the basis of preceding results. It is possible that during periods of high experimental activity the internal atmospheric control system might not be able to remove gases and chemicals as rapidly as they are evolved. This lull period could then be used to recycle the internal atmosphere and equipment back to its original condition so that the laboratory may start each seasonal cycle with the same level of cleanliness and sterility.

Also shown in Figure 4.2-2 is the power history for the two-year period. Except for the core drill power, each seasonal power history is the same. The power history shown is essentially the daily average. Peaks up to 400 watts occur for very short periods of time such as one minute. The battery power supply is used to supply these peaks. The power requirements for the core drill emphasize the effect on the phasing of its operation. If it were put into operation earlier in the experimental cycle, it would have raised the average power level from 70 watts to 145 watts. Under these conditions, this piece of equipment would have sized the battery. The average experimental power requirement is on the order of 7 watts for normal operational cycles and 10 watts for the cycle with the core drill. Data processing and transmission power account for an average power level of 58 watts.

4.2.3 IMPLICATIONS FOR AUTOMATION AND CONTROL

The ABL uses a high gain antenna which has a fan-shaped beam. Data transmission and receipt of commands is limited to a fixed portion of each day depending on the relative positions of Mars and Earth. When this is coupled with the fact that round trip transmission times will vary from a minimum of 8 minutes to a maximum of 44 minutes, the use of Earth-based decisions and commands to control steps or sequences within any given experimental procedure as it is being performed is precluded. This is true since most of the procedures measure the time to proceed from one step to the next in terms of a few minutes. Earth-based logic and control is then restricted to modifying experimental routines stored in the computer, initiating an experiment, or terminating an experiment prematurely. If a remotely controlled roving sampler were to be employed with visual guidance, the roving vehicle would have to proceed in incremental steps guided by directions stored in its control computer to the limits set by the resolution and detail achieved in the preceding picture. Such a technique would be laborious and would tend to favor a roving laboratory which could perform experimental sequences between moves.

Another aspect of the experimental phasing which should be considered is that as more and more cycles are completed, the need for the completely comprehensive program that is desirable at the start of the mission will diminish as results are obtained. Since failure rate and degradation of equipment will increase with usage and in some cases time, the experimental phasing should reflect these trends by gradually reducing the operational load on the laboratory. This trend was not shown in the phasing developed in this study in order to obtain an upper limit estimate of supply quantities. This approach is reasonable in that increased activity can be initiated early in the mission if desired and to ensure that sufficient supplies are available to perform modified experimental routines which fall outside the initial scope of the mission.

The command and control coding employed in the detailed experimental time diagrams were used to provide the basis for estimating the requirements of the control computer in terms of memory storage and power. The analysis of the command control system is given in Paragraph 6.2.

4.3 LABORATORY MECHANIZATION FOR AUTOMATION

4.3.1 CONTINUOUS FLOW PROCESSING

Continuous flow processing was evaluated to determine its applicability to the ABL. The advantage of being able to conduct a large number of experiments with such a system, using a relatively small number of instruments is outweighed by the quantities of reagents, solvents, and cleaning fluid required for operation, and by the difficulty of cleaning equipment between experiments to prevent contamination. Continuous flow processing is primarily applicable to performing a large number of identical processes rather than many different processes.

a. Concepts in Continuous Flow Processing. The basic principle of continuous flow processing is that the sample to be analyzed moves from station to station. Different operations or analyses are performed at each station. The heart of the system is the transport mechanism, tubing and pumps and some transport fluid. The most common chemical analyses use a liquid sample, or a solution or a suspension of the sample which is transferred from one operation to another through tubing. Each operation (heating, mixing, agitation, colorimetry, digestion, etc.) is performed on a continuous basis. The sample is moved through the tubing by proportioning pumps.

The streams are usually segmented with gas bubbles such as air or dry nitrogen, which serves the dual purpose of (1) providing a barrier between successive samples, preventing one sample from contaminating another, and (2) sweeping residual material from the tube walls. The most nearly analogous system of this kind are those developed by the Technicon Co., and described in Reference 1.

The stations which perform the operations on the sample are all designed to work on a continuous basis and can act on the sample as it flows through the apparatus. A dialyzer, for example, is comprised of a matching pair of plastic plates whose mating surfaces are mirror-grooved to provide a continuous channel when the plates are brought into contact. With a cellophane semipermeable membrane sandwiched between them, the plates are clamped together, leaving the continuous pathway separated only by the membrane. Other instruments utilized have included the dual-beam colorimeter, flame photometer, mixers, gas injectors, gas separators, heating baths, cooling baths, etc., all of which function on a continuous basis.

b. Example of Continuous Flow Processing. To perform an analysis using the continuous flow processing techniques, the various stations are connected in the proper order by selector valves to perform the desired operations. In addition, the flow rate controlling system or proportioning pump, must be adjusted to supply the proper amounts of reagents to the sample.

As a typical analysis consider the determination of phosphate in a soil extract. The process is shown schematically in Figure 4.3-1. A convenient method uses the molybdenum blue color reaction. The reducing agent in this case is stannous chloride, and amino naphthol sulphonic acid (ANSA) is used in the presence of 8N HCl to prevent interference from silica. It has been found by Masters(2) that all three reagents (ANSA, ammonium molybdate, and acid) can be combined into a single solution. In this analysis, the sample is pumped through the proportioning pump and is segmented by air which is also forced through the proportioning pump. The sample solution, segmented by air, is then passed through a branch, where the molybdate reagent is added in an amount controlled by the proportioning pump. The solution is then passed into a mixing coil. After the stannous chloride reagent is added and additional mixing performed, the reaction takes place. The solution is then passed through a colorimeter which detects the amount of phosphate in the soil extract. The output of the colorimeter can be compared either to an internal standard or to a standard solution run through the system following the sample.

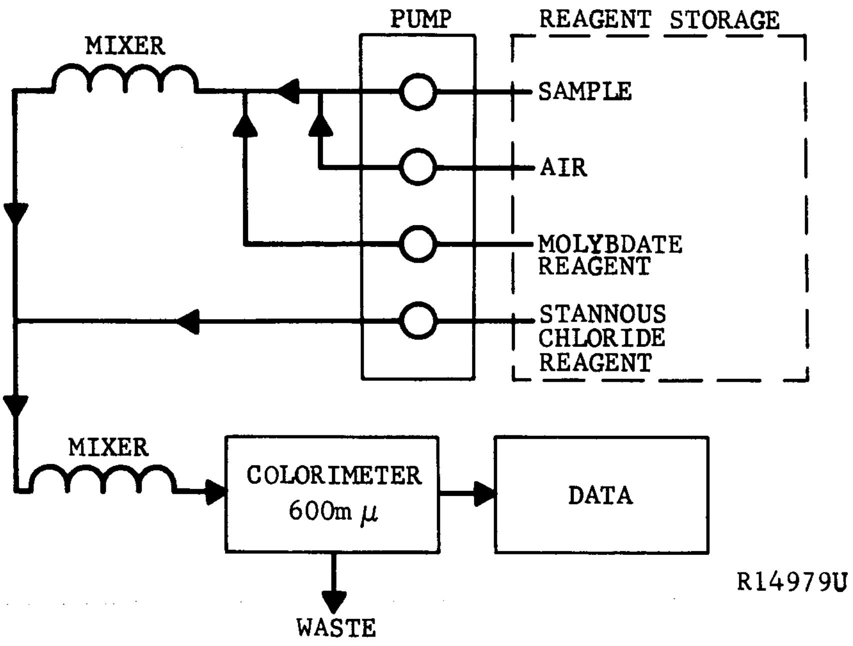


FIGURE 4.3-1. PHOSPHATE DETERMINATION BY CONTINUOUS FLOW PROCESSING

With only minor modifications in the setup shown in Figure 4.3-1 and the appropriate changes in the chemistry, the total amount of organic matter in a soil extract sample also can be determined. In this case, the extract is reached with a dichromate reagent and the released carbon dioxide is separated and measured by a color reaction. This is illustrated in Figure 4.3-2.

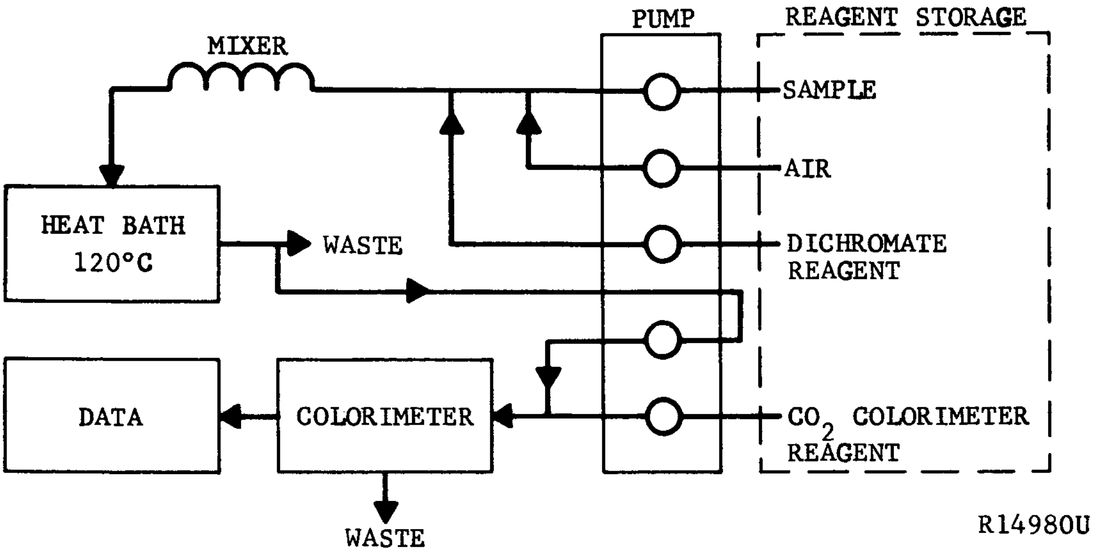


FIGURE 4.3-2. ORGANIC MATTER DETERMINATION BY CONTINUOUS FLOW PROCESSING

By comparing the equipment used in the above two determinations, it can be seen that the continuous flow concept is very flexible. Many determinations can be performed with much the same equipment. However, the equipment must be rearranged and the appropriate changes must be made in the reagents for each determination.

c. Limitations of Continuous Flow Processing for ABL. The advantage of continuous flow processing that may be attractive for the ABL is that a large number of experiments can be performed with a relatively small number of instruments by arranging them in the proper sequence, and supplying the correct reagents. However, the very nature of continuous flow processing has many inherent disadvantages for a Martian exploratory mission.

(1) Continuous flow processing requires a continuous flow of the transport fluid. This is not an economical use of solvent, probably water. Not only must the sample be dissolved, but it must be

separated from the following sample by a large quantity of water to prevent cross-contamination. The reagents, which are injected continuously into the stream, are combined with the sample as well as the water barrier and with cleaning solutions. Thus, if one segmentation in the stream is a sample, the second is a cleaning solution, and the third is a water barrier, two-thirds of the water and the chemicals used in the analysis are wasted. The analyzing instruments, which run continuously, use two-thirds more power than if they were used to analyze a single batch containing the sample alone.

(2) The repeated use of one container for many samples can lead to contamination. Since the many samples of unknown physical properties are processed through the same lengths of tubing, cleaning and contamination can become a serious problem. In order to assure that no amount of the previous sample remains on the tubing walls, joints, etc., drastic cleaning steps must be taken. Even if the tubing is flushed many times, there is still a statistical probability that a certain amount of contamination will remain. There is no convenient way in which the walls of the tubing can be physically cleaned.

This is also true of other components of the system, such as the colorimeter cuvette.

(3) The system must be rebuilt for each determination. Continuous flow processing is well suited to make a large number of similar determinations, but difficulties arise when the system must be used to make a variety of analyses. Connecting and disconnecting the large amounts of tubing necessary for the analyses will lead to low reliability.

(4) The size of the continuous chemical processing unit could be considerable for some processes. Many operations require appreciable time, such as dissolutions. Some operations take as long as 48 hours. This would require a timing coil of such proportions that it would be impractical to include it in planetary exploration payload.

(5) The number of repetitions of any single experiment does not warrant the complexity of continuous flow processing. A major characteristic of continuous flow processing as used today is the long runs of a large number of similar samples through the experiment once it has been set up. Examples of this are in the oil refinery processing plants and in hospitals where hundreds of samples are run through the same test during the operating day. This is not the case in the ABL. On Mars the number of similar experimental runs will not be large.

In summary, the advantageous features of continuous flow processing, i.e., few components, large flexibility, etc., do not coincide with the requirements of the ABL, i.e., minimal complexity, small weight, economy of weight and power, etc. Continuous flow processing should be considered where large amounts of material must be processed, but it is not feasible where a large number of different experiments, each run only a few times, is required.

d. References.

1. Technicon Symposium on Automated Analytic Chemistry, 1964.
2. Masters, J. F., Symposium on Automated Analytic Chemistry, Technicon Corp., N.Y., 1963.

4.3.2 MECHANICAL AND FLUID TRANSFER BATCH PROCESSING

Chemical processing by the batch process refers to those operations in which a volume, or "batch" is formulated by progressive combination of a number of specific chemicals. The nature of the biological experiments described in Volume II, Paragraph 5.2, in combination with the limitations of the continuous flow process described above, indicated that some form of batch processing was required.

The chemical processes required can be implemented by using either of two methods, or a combination of the two methods. In one, the transfer of all samples, reagents, and their by-products is effected by a system of piping connecting chemical storage tanks and various laboratory components. This method is referred to as fluid transfer method batch processing. It differs from continuous flow processing described above in that flow is intermittent, and processing takes place on stationary batches. In the mechanical transfer method, the samples, reagents, and their by-products are transported between components by a mechanical device. The latter implies that all chemicals are stored in small quantities and transported to the chemical processor as required by the experimental process.

During the ABL study, both methods of batch processing were investigated in detail. However, prior to a meaningful comparison of the two methods, it was necessary to define the extent of chemical storage required to satisfy the experimental complement.

a. ABL Chemical Storage Requirements. The selected experiment complement, defined in Volume II, Paragraph 5.1.3 was used as a basis for defining all chemicals that must be supplied to the chemical processor. All chemicals are readily storable in bulk tanks for integration into the fluid transfer method. The volume of some of the chemicals is such that small volume (or "ampule") storage integrated into the mechanical transfer method is not feasible. Wash water and solvent, for instance, is required in such substantial quantities that the number of operations required to transfer the liquid from storage to component would be prohibitive. The same reasoning applied to the storage of all gases, and, for this phase of the study, they were assumed to be stored in bulk form.

To this extent the mechanical transfer method became a combination of bulk and ampule storage. Table 4.3-I summarizes the liquid reagent requirements established by each experiment. The table delineates the experiment number, the step within which the reagent is required, the name of the chemical, and the volume required. The volumes shown in Table 4.3-I are based upon one experimental cycle.

In addition to the reagents summarized in Table 4.3-I, it was necessary to provide storage volume for cleaning water, cleaning solvent, and waste storage. It was assumed an equal volume of cleaning water and cleaning

TABLE 4.3-I

ABL LIQUID REAGENT REQUIREMENTS

Experiment Number	Step	Reagent	Volume
1 -	Atmospheric Pressure, Temperature, Wind Velocity and Direction	None required	
2 -	Determination of Atmospheric Humidity	None required	
3 -	Wind-Transported Particulate Matter	None required	
4 -	Acoustical Monitor	None required	
5 -	Ultraviolet Insolation	None required	
6 -	β and γ Radiation Background	None required	
7 -	Determination of Atmospheric Constituents	None required	
8 -	Soil Temperature and Water Content as a Function of Depth	None required	
9 -	Soil, Electrical Conductivity	None required	
10 -	Soil Density by γ -Ray Sonde	None required	
11 -	Soil Mechanics Determination	None required	

TABLE 4.3-I (Continued)

Experiment Number	Step	Reagent	Volume
12 - Soil Sample Encapsulation and Preservation			
		None required	
13 - Elemental Soil Analysis			
		None required	
14 - Soil Gas Analysis			
		None required	
15 - Determination of Soluble Inorganic Ions and pH			
	6	Water	3 ml
	6	Water	3 ml
	6	Water	3 ml
16 - Detection of Organic Material in Soil			
		None required	
17 - Soil Gas Exchange			
	6	C^{14} Labelled Substrate	1 ml
	11	S^{35} Labelled Substrate	1 ml
18 - Amino Acid Analysis			
		None required	
19 - Detection of Amino Acids and Optical Activity			
	6	Water	10 ml
	6	Water	10 ml
	6	Water	10 ml
	15	D-Sec-Butyl Alcohol	5 ml
20 - Detection of Porphyrins			
	5	4:1 Ethyl-Acetate Acetic Acid	3 ml
	13	EDTA (Ethylene Diamine Tetraacetic Acid)	1 ml
	24	4:1 Ethyl-Acetate Acetic Acid	30 ml
		EDTA	10 ml

TABLE 4.3-I (Continued)

Experiment Number	Step	Reagent	Volume
21 - Detection of Flavins			
	10	1N H_2SO_4	3 ml
	17	Chloroform	4 ml
	30,34	1N NaOH	5 ml
	44	Chloroform	4 ml
22 - Detection of Non-Saponifiable Lipids			
	7	2:1 Ether Acetone	50 ml
	15	1N NaOH	1 ml
	20	Chloroform	2 ml
	31	Dimethyl Formamide	0.1 ml
23 - Detection of Saponifiable Lipids			
	7	2:1 Ether Acetone	50 ml
	15	1N NaOH	1 ml
	20,26	Chloroform	4 ml
	32	Petroleum Ether	2 ml
24 - Macromolecules by Visible Absorption			
	7	0.5N NaOH	3 ml
	18	0.002 M Neutral Buffer	1 ml
	22	0.001 M Neutral Buffer	1 ml
25 - Macromolecules by UV Absorption			
	7	0.5 N NaOH	3 ml
	10	H_2O	3 ml
	18	0.002 M Neutral Buffer	1 ml
	19	0.001 M Neutral Buffer	3 ml
26 - Water Soluble Macromolecules by Optical Activity			
	6	1 percent NaCl Solution	3 ml
	6	1 percent NaCl Solution	3 ml
	6	1 percent NaCl Solution	3 ml
	22	0.002 M Neutral Buffer	1 ml
27 - Water Soluble Macromolecules by Pyrolysis Gas Chromatography			
		None required	

TABLE 4.3-I (Continued)

Experiment Number	Step	Reagent	Volume
28 - Functional Group Analysis			
	4	$CC\ell_4$	20 ml
29 - Light Stimulated $C^{14}O_2$ Fixation and Dark $C^{14}O_2$ Fixation as a Function of Temperature			
	48	Aqueous Culture Media	6 ml
30 - Evolution of CO_2 by Normal Metabolism			
	18	Aqueous Culture Media	4 ml
	21	Water	40 ml
31 - $C^{14}O_2$ Evolution from Labeled Substrates			
	4	Formaldehyde C^{14} Substrate	1 ml
	6	Glucose U-C^{14} Substrate	1 ml
	20/21	Water	40 ml
	24 (4)	Formaldehyde C^{14} Substrate	1 ml
	(6)	Glucose U-C^{14} Substrate	1 ml
	(20/21)	Water	40 ml
32 - $C^{14}O_2$ Uptake in Light and Dark and Subsequent Evolution by Metabolism			
	23	10 N HCL	3 ml
	62 (23)	10 N HCL	3 ml
33 - Culture Evaluation and Growth Detection			
	3	Aqueous Culture Media 1	10 ml
	3	Aqueous Culture Media 2	10 ml
	3	Aqueous Culture Media 3	10 ml
	3	Aqueous Culture Media 4	10 ml
34 - Motion Detector			
		None required	
35 - Macroimaging and Infrared Scan			
		None required	

solvent was required. It was also assumed that a wash and rinse cycle required four full volume flushes of the equipment to be cleaned. The volumes required for water and solvent are summarized by experiment in Table 4.3-II.

TABLE 4.3-II

WATER AND SOLVENT STORAGE REQUIREMENTS

Experiment	Volume Required (mℓ) Water	Volume Required (mℓ) Solvent
15	10	4
18	10	4
19	10	4
20	10	4
21	20	18
22	20	6
23	20	6
24	20	10
25	20	6
26	20	18
28	20	18
29	130	104
30	30	22
31	60	44
32	120	109
Total	520	377

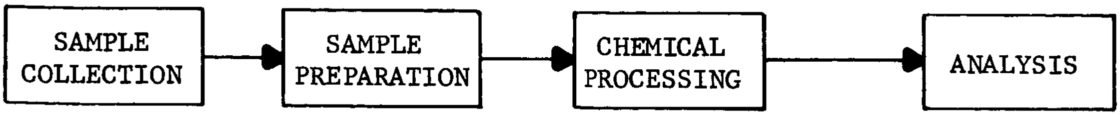
The storage techniques for all required chemicals used in defining and evaluating the mechanical transfer method are summarized in Table 4.3-III.

TABLE 4.3-III

MECHANICAL TRANSFER CHEMICAL STORAGE

Ampule	Bulk
Aqueous culture media	Wash water
Carbon tetrachloride	Wash solvent
Chloroform	Argon
Dimethyl formamide	$C^{14}O_2$
D-sec-butyl-alcohol	$C^{12}O_2$
Ether acetone	Helium
Ethyl acetate-acetic acid	Hydrochloric acid
Ethylene diamine tetraacetic acid	Nitrogen
Formaldehyde C^{14} substrate	Oxygen
Glucose U-C^{14} substrate	
Neutral buffer solution	
Petroleum ether	
Sodium chloride solution	
S^{35} substrate	
Sodium hydroxide	
Sulphuric acid	
Water	

b. Conceptual Design Studies. The basic modes of operation within the ABL, once its experimental phase has begun, is presented in Figure 4.3-3.



SAMPLE COLLECTION	SAMPLE PREPARATION	CHEMICAL PROCESSING	ANALYSIS
Remote surface samples	Pulverizing	Soil extraction	Gas chromatography
Proximity surface samples	Grading	Culturing	Mass spectrometry
Aerosolized samples	Weighing	Pyrolysis	UV, V, IR Spectrophotometry
Subsurface samples		Filtering	Fluorimetry
		Liquid-liquid phase separation	Polarimetry

FIGURE 4.3-3 GENERAL PROCESSING STEPS WITHIN ABL

It is assumed that the first two steps - sample collection and preparation - and the fourth step - analysis - are basically identical regardless of the transport process used. The comparison which follows will be limited to a discussion of the chemical processing phase.

(1) Fluid Transfer Method. A schematic of the fluid transfer method of accomplishing the ABL experimental complement is shown in Figure 4.3-4. All chemicals required are stored in bulk tanks, which are connected to a common supply manifold by short feed lines. A combination solenoid-check valve is required in each line. Liquid chemicals are transported by pressurizing the supply tank with on-board nitrogen or scrubbed Martian atmosphere. Gaseous chemicals are stored under pressure, and supply their own transport.

Soil samples are transported pneumatically through the sample preparation equipment, and into the proper chemical processor(s). Thirteen processors are required to accommodate the experiment time phasing discussed in Paragraph 4.2 of this volume. Several conceptual designs were considered in which the reaction and culture chambers were separate components. Subsequent reliability considerations indicated that experiment mission success was enhanced by combining the two instruments into a single one, and providing thirteen of the dual purpose instruments. A conceptual

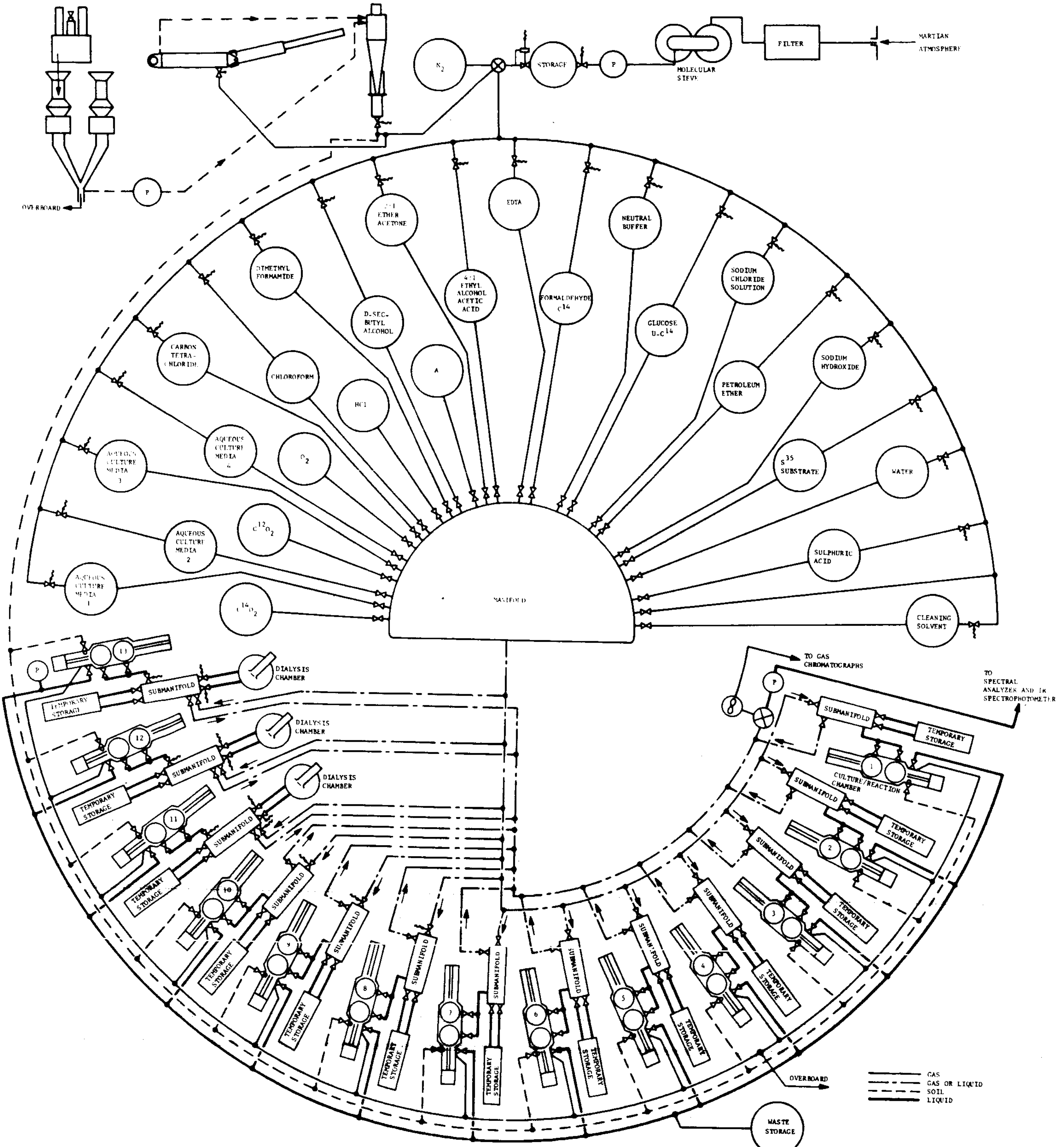


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FIGURE 4.3-4. ABL FLUID TRANSPORT PROCESS SCHEMATIC design of the instrument is shown in Figure 4.3-5. In this concept two metering heads are mounted in series on a common base. Chamber attachments (filters, suction units, culture dishes) are supplied in tape form with each unit. In operation as a culture chamber, a new filter is stepped into place under the soil sample entry line. A motor driven platen advances to seal the filter against the chamber base. After soil sample delivery, the platen is released, the tape advances under the metering head, and is once again sealed in place by advancing the platen. Gases are metered into the chamber by advancing the metering piston to the closed (lower) position, and opening the chemical tank and manifold valve. Gas quantity is controlled by timing the flow, and gas flow is controlled at the tank and in the manifold. Liquid reagents are metered into the chamber by advancing the metering piston to the closed position and opening the tank and manifold valve. This permits fluid to advance to the piston face, but no further. Withdrawing the piston fills the upper cylinder with a precise volume. Advancing the piston supplies chemicals in a regulated manner to the soil sample. Liquid waste passes through the sample and filter and into common storage. Evolved gases collect in the chamber and are carried to the gas chromatograph by operating the gas valve on signal from the pressure transducer. The metering needle is electrically isolated from the chamber case, thus serving as the culture chamber β detector. After analysis, the platen is released and filter and sample advanced into storage. A cover sheet is crimped over the sample to prohibit waste spillage and possible contamination of subsequent analyses. Water and solvent is spirally injected into the chamber for cleaning, and chamber drying effected by gaseous flush.

In operation as a reaction chamber, soil delivery to the filter sheet is accomplished as in the culture chamber. In addition, a collapsed bellows suction unit is also advanced into place below the chamber. The suction piston is advanced to the up position. Reagents and gases are metered onto the sample as described for the culture chamber. Retreating the suction piston draws the reagents through the sample. Advancing the piston forces the reagents up through the sample. This can be repeated as required. Stirring prongs are actuated by electromagnetic coils to induce turbulence in the mixture if required. The metering needle may be advanced and the metering piston withdrawn to accomplish liquid-liquid phase separation. A Strontium 90 source mounted in an annulus about the metering needle serves as an argon ionization detector. Liquid waste is evaporated by heating elements contained in the filter tape. Solid waste is sealed in the filter tape as in the culture chamber. The suction bellows is collapsed by advancing the suction piston, and then stepped into sealed storage.

A small secondary manifold is used to simplify chamber operation. The manifold serves as a switching unit on both intake and exhaust phases of chamber operation.

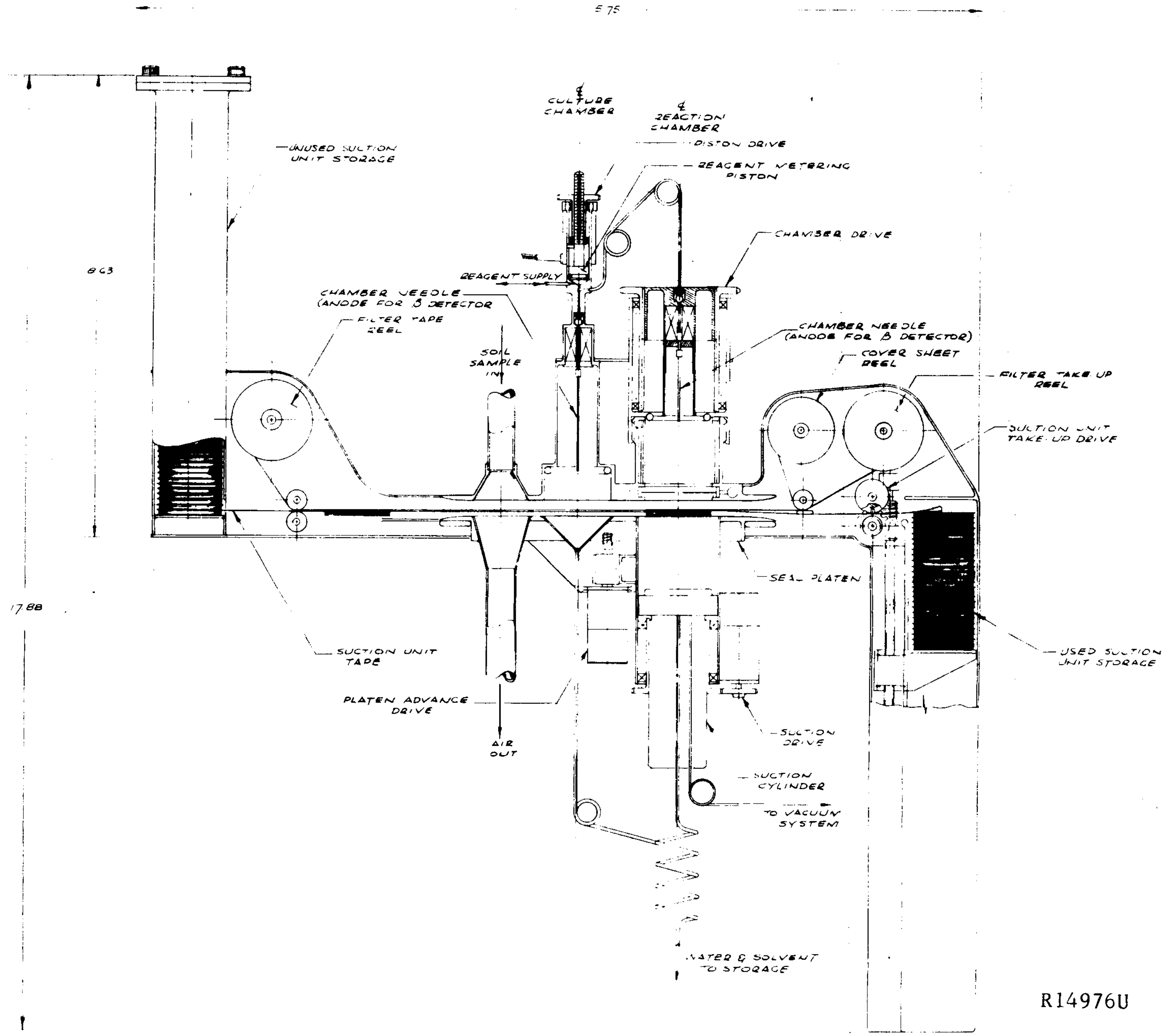

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FIGURE 4.3-5. CONFIGURATION ENVELOPE - FLUID TRANSFER METHOD CHEMICAL PROCESSOR

Liquid samples are delivered to the analysis section by motor driven pump. Evolved gases are transported to the gas chromatographs by a motor driven blower.

(2) Mechanical Transfer Method. A schematic of the mechanical transfer method of accomplishing the ABL experimental complement is shown in Figure 4.3-6. Gaseous chemicals, water, and cleaning solvent are stored in bulk form. They are connected directly to each of the thirteen chemical processors. The remaining reagents are stored in small ampules, which are transported to the processor by a motor driven transport mechanism. Processor attachments are transported to the transfer wheels by the same mechanism.

Soil samples are transported to the processor pneumatically as in the fluid transfer method. A detailed description of the design and operation of the chemical processor is presented in Paragraph 5.5.6 of this volume.

Evolved gases are transported to the gas chromatographs by a motor driven blower. Liquid samples are transferred to the spectral analyzer by the transport mechanism. Waste and unused liquids, and used chamber attachments are placed in storage by the transport mechanism.

c. Comparison of Transport Methods. The advantages and limitations of either method of transfer became evident when studied from a component failure standpoint. The more obvious properties of each system are discussed below.

(1) Fluid Transfer.

(a) Failure of a processor component does not necessarily render that chamber useless. Excepting the sealing platen, a portion of the processor that is functioning properly may be used in conjunction with a second processor to perform the desired process.

(b) Transfer of chemicals from tank to chamber requires few moving parts.

(c) Transfer of samples to and from chambers requires few moving parts.

(d) Lines and manifolds represent relatively large volumes of chemical that may contaminate or become contaminated.

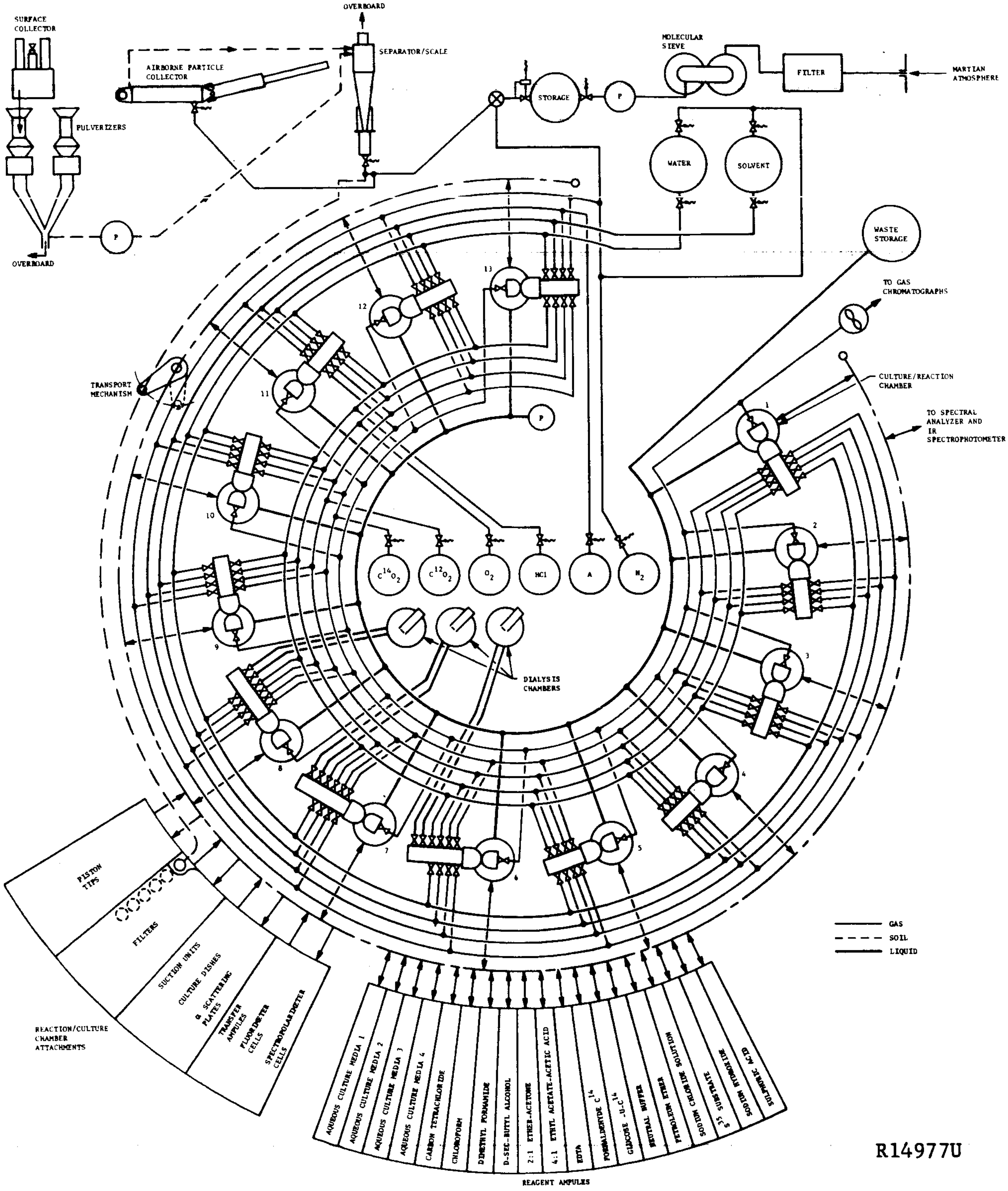

FIGURE 4.3-6. ABL MECHANICAL TRANSPORT PROCESS SCHEMATIC

(e) Lines and manifolds represent a complex cleaning requirement.

(f) Failure of single storage tank valve may render that supply unusable for remainder of mission.

(2) Mechanical Transfer.

(a) Failure of reagent ampule has virtually no effect on subsequent experiments due to small volume.

(b) Piston system in chamber and ampule storage and transfer represent simple cleaning concept.

(c) Single barrel chamber offers fewer alignment difficulties but requires more moving parts.

(d) Transport mechanism failure may prejudice entire experiment program.

(e) Large number of ampules and ampule storage feed requirements represents some weight penalty.

It can be seen that little in the way of a quantitative conclusion could be reached by the above comparisons. In order to approach a quanitative evaluation by a systematic technique, the influence of a single failure in each component was examined. The results are outlined in Table 4.3-IV. The component under examination is listed in Column 1. The number of components required to satisfy sixty experimental cycles (3 samples each from 5 locations once each Martian season for two years) is listed in the second column. The third column presents the difference in weight between the two methods for the component. The fourth column presents a weighted percentage of experiments that would be eliminated during subsequent cycles by component failure. The weighted percentage was derived by placing relative values on the experiments according to their priority. The fifth column presents the experiment number that is eliminated by component failure. An examination of the data included in Table 4.3-IV led to the following observations:

(1) Dual particulate pumps, or an alternate means of soil sample transfer, should be provided.

(2) The broad effect on subsequent experimentation attached to the cyclone collector/scale is due to need for an indication that a sample has been collected. If a back-up mode is used to detect the presence of a soil sample, failure of the weight sensing equipment would produce no effect on subsequent experiments.

TABLE 4.3-IV

COMPARISON OF TRANSPORT METHODS

Component-Subcomponent	Number of Components		Weight Differential (pounds)		Experiments Eliminated by Component Failure		Weighted Percentage of Experiments Eliminated	
	Fluid	Mechanical	Fluid	Mechanical	Fluid	Mechanical	Fluid	Mechanical
Surface Collector	2	2	0.0	0.0	None	None	0.0	0.0
Gearhead Motor	2	2	0.0	0.0	None	None	0.0	0.0
Drive Train	2	2	0.0	0.0	None	None	0.0	0.0
Auger Release	4	4	0.0	0.0	None	None	0.0	0.0
Pulverizer	2	2	0.0	0.0	None	None	0.0	0.0
Bearing	4	4	0.0	0.0	None	None	0.0	0.0
Blade Barrel	2	2	0.0	0.0	None	None	0.0	0.0
Armature Winding	2	2	0.0	0.0	None	None	0.0	0.0
Field Winding	2	2	0.0	0.0	None	None	0.0	0.0
Flapper Valve	2	2	0.0	0.0	None	None	0.0	0.0
Valve Solenoid	2	2	0.0	0.0	None	None	0.0	0.0
Particulate Pump	1	1	0.0	0.0	7,15,18,19,20,21, 22,23,24,25,26,27, 28,29,30,31,32,33	7,15,18,19,20,21,22, 23,24,25,26,27,28,29, 30,31,32,33	53.3	53.3
Atmospheric Dust Collector	1	1	0.0	0.0	3	3	1.7	1.7
Gas Generator	1	1	0.0	0.0	3	3	1.7	1.7
Rotary Head	1	1	0.0	0.0	3	3	1.7	1.7
Gearhead Motor	1	1	0.0	0.0	3	3	1.7	1.7
Cyclone Collector/Scale	1	1	0.0	0.0	3,13,15,16,18,19, 20,21,22,23,24,25, 26,27,28,29,30,31, 32,33	3,13,15,16,18,19,20, 21,22,23,24,25,26,27, 28,29,30,31,32,33	55.0	55.0
Gearhead Servo	1	1	0.0	0.0	3,13,15,16,18,19, 20,21,22,23,24,25, 26,27,28,29,30,31, 32,33	3,13,15,16,18,19,20, 21,22,23,24,25,26,27 28,29,30,31,32,33	55.0	55.0
Gear Drive Train	1	1	0.0	0.0	3,13,15,16,18,19 20,21,22,23,24,25, 26,27,28,29,30,31, 32,33	3,13,15,16,18,19,20 21,22,23,24,25,26,27, 28,29,30,31,32,33	55.0	55.0

TABLE 4.3-IV (Continued)

COMPARISON OF TRANSPORT METHODS

Component-Subcomponent	Number of Components		Weight Differential (pounds)		Experiments Eliminated by Component Failure		Weighted Percentage of Experiments Eliminated	
	Fluid	Mechanical	Fluid	Mechanical	Fluid	Mechanical	Fluid	Mechanical
Dump Valve	1	1	0.0	0.0	3,13,15,16,18,19 20,21,22,23,24,25, 26,27,28,29,30,31, 32,33	3,13,15,16,18,19,20, 21,22,23,24,25,26,27, 28,29,30,31,32,33	55.0	55.0
Dump Valve Solenoid	1	1	0.0	0.0	3,13,15,16,18,19 20,21,22,23,24,25, 26,27,28,29,30,31, 32,33	3,13,15,16,18,19,20, 21,22,23,24,25,26,27, 28,29,30,31,32,33	55.0	55.0
Inlet Filter	1	1	0.0	0.0	None	None	0.0	0.0
CO_2 Scrubber	1	1	0.0	0.0	None	None	0.0	0.0
Circulation Pump	1	1	0.0	0.0	None	None	0.0	0.0
Accumulator Tank	1	1	0.0	0.0	None	None	0.0	0.0
Inlet Valve	1	1	0.0	0.0	None	None	0.0	0.0
Regulator Valve	1	1	0.0	0.0	None	None	0.0	0.0
3-Way Valve	0	1	0.0	6.0	NA	None	0.0	0.0
4-Way Valve	1	0	8.0	0.0	None	NA	0.0	0.0
Chemical Storage								
Aqueous Culture Media 1	1	143	0.0	1.6	29,30,33	None	6.7	0.0
Aqueous Culture Media 2	1	23	0.0	0.4	33	None	3.3	0.0
Aqueous Culture Media 3	1	23	0.0	0.4	33	None	3.3	0.0
Aqueous Culture Media 4	1	23	0.0	0.4	33	None	3.3	0.0
Carbon Tetrachloride	1	240	0.0	2.9	28	None	1.7	0.0
Chloroform	1	240	0.0	3.0	21,22,23	None	10.0	0.0
Dimethyl Formamide	1	60	0.0	0.1	22	None	3.3	0.0
D-Sec-Butyl-Alcohol	1	60	0.0	0.7	19	None	3.3	0.0
Ether Acetone	1	1200	0.0	14.7	22,23	None	6.7	0.0

TABLE 4.3-IV (Continued)

COMPARISON OF TRANSPORT METHODS

Component-Subcomponent	Fluid	Mechanical	Weight Differential (pounds) Fluid	Weight Differential (pounds) Mechanical	Experiments Eliminated by Component Failure Fluid	Experiments Eliminated by Component Failure Mechanical	Weighted Percentage of Experiments Eliminated Fluid	Weighted Percentage of Experiments Eliminated Mechanical
Ethyl Acetate-Acetic Acid	1	360	0.0	4.3	20	None	3.3	0.0
EDTA	1	180	0.0	2.3	20	None	1.7	0.0
Formaldehyde C^{14}	1	120	0.0	1.7	31	None	1.7	0.0
Glucose U-C^{14}	1	120	0.0	1.7	31	None	1.7	0.0
Neutral Buffer	1	300	0.0	4.1	24,25,26	None	3.3	0.0
Petroleum Ether	1	60	0.0	0.8	23	None	1.7	0.0
Sodium Chloride Solution	1	180	0.0	2.3	26	None	1.7	0.0
S^{35} Substrate	1	60	0.0	0.8	17	None	1.7	0.0
Sodium Hydroxide	1	300	0.0	4.0	21,22,23,24,25	None	13.3	0.0
Sulphuric Acid	1	60	0.0	0.7	21	None	1.7	0.0
Water	1	1	0.0	0.0	15,18,19,20,21,22, 23,24,25,26,27,28, 29,30,31,32,33	15,18,19,20,21,22,23, 24,25,26,27,28,29,30, 31,32,33	50.0	50.0
Solvent	1	1	0.0	0.0	15,18,19,20,21,22, 23,24,25,26,27,28, 29,30,31,32,33	15,18,19,20,21,22,23, 24,25,26,27,28,29,30, 31,32,33	50.0	50.0
Argon	1	1	0.0	0.0	16,18,19,22,23,27, 33	16,18,19,22,23,27,33	20.0	20.0
C^{12} O_2	1	1	0.0	0.0	29,30,31,32	29,30,31,32	13.3	13.3
C^{14} O_2	1	1	0.0	0.0	29,32	29,32	6.7	6.7
Helium	1	1	0.0	0.0	7,14,17,33	7,14,17,33	13.3	13.3
Hydrochloric Acid	1	1	0.0	0.0	19,32	19,32	6.7	6.7
Nitrogen	1	1	0.0	0.0	22,23,29,32,33	22,23,29,32,33	16.7	16.7
Oxygen	1	1	0.0	0.0	20,29,32	20,29,32	10.0	10.0
Transport Mechanism	0	1	0.0	7.9	NA	12 through 33,35	0.0	73.4
Gearhead Motor	0	2	0.0	1.6	NA	12 through 33,35	0.0	73.4

TABLE 4.3-IV (Continued)

COMPARISON OF TRANSPORT METHODS

Component-Subcomponent	Number of Components		Weight Differential (pounds)		Experiments Eliminated by Component Failure		Weighted Percentage of Experiments Eliminated	
	Fluid	Mechanical	Fluid	Mechanical	Fluid	Mechanical	Fluid	Mechanical
Clutch	0	1	0.0	0.6	NA	12 through 33,35	0.0	73.4
Gear Train	0	2	0.0	1.5	NA	12 through 33,35	0.0	73.4
Primary Supply Manifold	1	0	4.0	0.0	Experiment effected dependent upon failure mode and component involved	NA	1.7 to 50.0	0.0
Supply-Check Valves	28	7	10.1	0.0		Dependent upon failure mode and component involved	1.7 to 50.0	1.7 to 46.6
Inlet Valve	20	0	9.6	0.0		NA	1.7 to 50.0	0.0
Chemical Processor	13	13	0.0	0.0	None	None	0.0	0.0
Gearhead Motor	90	39	19.2	0.0	None	None	0.0	0.0
Clutch	0	130	0.0	32.5	NA	None	0.0	0.0
Gear Train	65	178	0.0	22.6	None	None	0.0	0.0
Tape Feed								
Filter	13	0	10.2	0.0	May eliminate from 0 to 79 subsequent experiments	NA	0.0	0.0
Suction	13	0	9.7	0.0		NA	0.0	0.0
Cover Sheet	13	0	10.2	0.0		NA	0.0	0.0
Secondary Manifold	13	0	6.0	0.0	None	NA	0.0	0.0
Valve	58	0	16.6	0.0	None	NA	0.0	0.0
Exhaust Valve	26	13	3.7	0.0	None	None	0.0	0.0
Processor Attachments								
Piston Tip	0	2808	0.0	32.4	NA	None	0.0	0.0
Filter	996	996	0.0	0.0	None	None	0.0	0.0
Suction Unit	1080	1080	0.0	0.0	None	None	0.0	0.0
Transfer Ampule	0	1092	0.0	15.7	NA	None	0.0	0.0
Pyrolysis/Culture Dish	1800	1800	0.0	0.0	None	None	0.0	0.0

TABLE 4.3-IV (Continued)

COMPARISON OF TRANSPORT METHODS

Component-Subcomponent	Number of Components		Weight Differential (pounds)		Experiments Eliminated by Component Failure		Weighted Percentage of Experiments Eliminated	
	Fluid	Mechanical	Fluid	Mechanical	Fluid	Mechanical	Fluid	Mechanical
Dialysis Chamber	3	3	0.0	0.0	None	None	0.0	0.0
Tape Drive	3	3	0.0	0.0	None	None	0.0	0.0
Gearhead Motor	6	6	0.0	0.0	None	None	0.0	0.0
Temporary Storage	3	0	3.0	0.0	None	None	0.0	0.0
Sample Transport Pump	1	0	1.2	0.0	14,16,17,20,21,22, 23,24,25,26,27,28, 33	NA	46.7	0.0
Sample Transport Blower	1	1	0.0	0.0	13,14,15,17,18,19 22,23,27,33	13,14,15,17,18,19,22, 23,27,33	35.0	35.0
Totals	4,317	11,979	104.3	162.0	43 of 77 failure modes influence subsequent experiments	25 of 75 failure modes influence subsequent experiments	681.7 to 826.6	852.1 to 897.0
Total Less Inert Chemical Storage and Chamber Attachment Units	413	442						

(3) Dual valving and/or multiple tanks for storing water and cleaning solvent should be provided.

(4) Dual valving should be provided for all gaseous storage systems.

(5) Failure of the transport mechanism influences subsequent experiments more than any other single unit. Every effort should be expended to develop a simple, reliable component.

(6) Sample transport pumps and blowers should be duplicated to assure procedural reliability.

The data listed in each column were totaled to summarize the overall comparison of the two systems. The discrepancy in component numbers is primarily a result of the large number of ampules and processor attachments required with the mechanical system. Excluding chemical storage and chamber attachments, the fluid system contains 413 components and the mechanical system 442 components. No meaningful difference in component parts or weight associated with either system is evident. The fluid system had more individual component types and more types that could effect subsequent experimentation. The weighted percentage totals indicated that both systems are generally comparable on the basis of the effect of component failure on experimentation.

d. Conclusions. It can be seen that, except for the number of component parts involved in the mechanical system, no overwhelming evidence in favor of one method was apparent. In comparing the two methods from an operational standpoint, one distinct disadvantage of the fluid transfer system was the anticipated difficulty of reliable cleansing operations. The use of common delivery lines, manifolds, and valves, for example, requires that after each dispensing operation, the complex must be thoroughly flushed before a second chemical could be supplied. Of even greater influence is the questionable aspect of removing all traces of tagged substances from the system. Experience in Earth-based laboratory processes with tagged chemicals demonstrates that even regular, thorough cleaning provides marginally successful results, and that discarding the component after its use is the most reliable solution.

Based primarily on these contamination considerations, a mechanical transport system was selected for use during the ABL preliminary concept phases.

4.3.3 INTEGRATED VERSUS INDIVIDUAL EXPERIMENT COMPARISON

As a further analysis of methods of ABL internal organization, nine typical experiments were defined and mechanized as an integrated laboratory and as individual experiments. These two approaches were compared on the basis of reliability, flexibility, and weight. The study necessarily compared batch processing with continuous processing because the first is appropriate for an integrated laboratory while the second naturally combines with individual experiment mechanization.

The study showed that, for this example analysis, all comparison criteria except weight are so subject to the basic assumptions that they are difficult to assess quantitatively. (See, however, the results of the similar comparison for the design point payload of 35 experiments on a reliability basis in Paragraph 4.4, as well as on a weight basis in Paragraph 5.4 of this Volume.) Other considerations being nearly equal, the weight comparison is the single most important criterion for a space payload, however, and a selection is possible on this basis. The study shows that the integrated laboratory approach is significantly lighter than the individually mechanized experiments for a number of experimental cycles.

a. Concepts of Laboratory Organization. In the development of an automated biological laboratory involving wet chemical processing, two questions invariably arise. One is the question of continuous flow processing discussed previously. The other is the question of an integrated laboratory versus individually mechanized experiments. The first question must be evaluated on the basis of the relative reliability of the supply transport system, control of quantitative processes, and the ability to recycle the equipment to prevent contamination. These are compared in Table 4.3-V. The second question must be evaluated on the basis of reliability of experimental performance, flexibility in experimental procedures, and total system weight. These are compared in Table 4.3-VI. Both of these questions regarding the approach to organizing an automated laboratory are strongly influenced by the quantity of supply required per experimental cycle and the total number of times an experiment is repeated in the lifetime of the laboratory. The primary influence is in system weight which is a fundamental method of comparison for any space payload. In examining Tables 4.3-V and VI, the generalization can be made that continuous flow processing and mechanization of individual experiments tend to go together while batch processing and the integrated approach also tend to combine.

b. Weight Comparison of Alternate Approaches. To determine the relative merit of the integrated laboratory versus the individually mechanized experiments, a comparison can be made on the basis of system weight.

TABLE 4.3-V

Criteria	Continuous Flow	Batch Process
1. Reliability of Transport	No indexing or positioning required to acquire supply.	Positive indexing and positioning required to acquire supply.
	Susceptible to line plugging and inoperative valves.	Loss of mechanical transport defeats all experiments dependent on it.
	Loss of common storage defeats all experiments requiring that supply.	Allows the use of ampule storage eliminating the effect of common storage.
	Not amenable to transport of solids except in finely divided form.	Independent of character of supply transported.
	Lost fluid supplies proportional to transport distance and size of trapped volumes.	No losses due to transport.
2. Control of Quantitative Processes	Flow or rate metering of small quantities are difficult. Requires addition of positive displacement metering.	Ampule storage allows use of fixed premeasured quantities. Mechanical transport is also amenable to precisely controlled dispensing of volumetric quantities.
	No long delay or wait times.	Independent of delay or wait times.
	Not compatible with processes starting with bulk quantities and terminating in small quantities.	Can accommodate large variations in processed quantity.

TABLE 4.3 -V (Continued)

Criteria	Continuous Flow	Batch Process
3. Recycle Capability	Difficult to purge and prevent contamination if common delivery and processing equipment is used.	Delivery system imposes no recycling limitations or adds any requirements.
	Cannot use throwaway components or elements.	May use throwaway components or elements.
	Wash and cleaning supplies increased.	Wash and cleaning supplies minimized.

TABLE 4.3-VI

Criteria	Individually Mechanized	Integrated
1. Reliability of Experimental Performance	Failure of single component defeats the remainder of that experimental cycle.	Failure of a single component may be compensated by using an alternate component.
	Experiments may be performed concurrently.	Experiments must be phased and programmed sequentially.
2. Flexibility of Experimental Procedures	Procedure is built in and cannot be modified after the fact.	Reprogramming can be accomplished to accommodate unexpected results within the limits of supplies and processing equipment.
3. System Weight	Common equipment and functions are duplicated for each experiment.	Common equipment and functions can be shared between experiments.

To obtain a weight comparison on a consistent basis, a set of nine representative experimental procedures were defined, as follows:

Experiment 1. Ultraviolet Optical Activity of Water Soluble Macromolecules

Experiment 2. Optical Rotation in Visible Spectrum Using Dye Solution of Water Soluble Macromolecules

Experiment 3. Gas Chromatograph Analysis of Water Soluble Macromolecules

Experiment 4. Soil Composition by Pyrolysis Gas Chromatography

Experiment 5. Gas Chromatography by Organic Soluble Soil Constituents

Experiment 6. Atmospheric Composition by Gas Chromatography

Experiment 7. Atmospheric Pressure and Temperature

Experiment 8. Soil Temperature Measurement

Experiment 9. Visual and Infrared Scan of Surrounding Terrain

The procedures and block diagrams which identify the major functional processes are presented in Appendix 5.

The basic assumptions selected for this weight analysis are:

(1) An operating lifetime on Mars of six months.

(2) Sampling requirements based on the model of Martian desert dune sand defined in Paragraph 1.2.

To determine weights for the individually mechanized experiments, the following assumptions are made:

(1) Recycling of wet chemical processing equipment is not attempted, i.e., solvent chambers and filters are not reused. Only the analytical instrumentation is reusable from one sample to the next.

(2) Each experiment is mechanized as a complete unit consisting of its own sample collection equipment, instrumentation, processing equipment, and consumable supplies.

(3) A common power supply, communications, data processing, and programming and control is used.

(4) The laboratory structure serves only as a mounting base for the experimental assembly.

To determine weights for the integrated laboratory, the following assumptions were used:

(1) The U.V. and Visible spectropolarimeter are combined into a single unit.

(2) Experiments 3 and 4 use the same gas chromatograph.

(3) Experiments 7, 8, and 9 are the same for both approaches.

(4) A single soil sampler of each type is used.

(5) A common chemical processing chamber is used to service each experiment and is recycled. Ultra filtration units are not recycled.

(6) Transport gas for the pneumatic soil sampler is used to a total of 25 cycles. For more than 25 cycles a motor drive compressor is used.

The supporting calculations for the weight estimates made on the basis of the preceeding assumptions are given in Appendix 7. The summary weight estimate for the individually mechanized experiments is given in Table 4.3-VII, in terms of the fixed weight and the variable weight which is a function of the number of repetitive experimental cycles. A similar summary for the integrated laboratory is given in Table 4.3-VIII. The results of these weight estimates are shown on the curve in Figure 4.3-7.

TABLE 4.3-VII

SUMMARY OF WEIGHTS FOR
INDIVIDUALLY MECHANIZED EXPERIMENTS

Experiment No.	Fixed Weight	Variable Weight
1. UV Spectropolarimeter	12.56	3.375 n
2. Visible Spectropolarimeter	11.54	3.120 n
3. Gas Chromatograph #1	14.88	3.518 n
4. Gas Chromatograph #1	14.51	0.399 n
5. Gas Chromatograph #2	14.88	2.00 n
6. Gas Chromatograph #3	0.82	0.178 n
7. Atmosphere Properties	5.12	---
8. Soil Probe	5.54	---
9. Television	5.00	---
Total	84.85	12.590 n

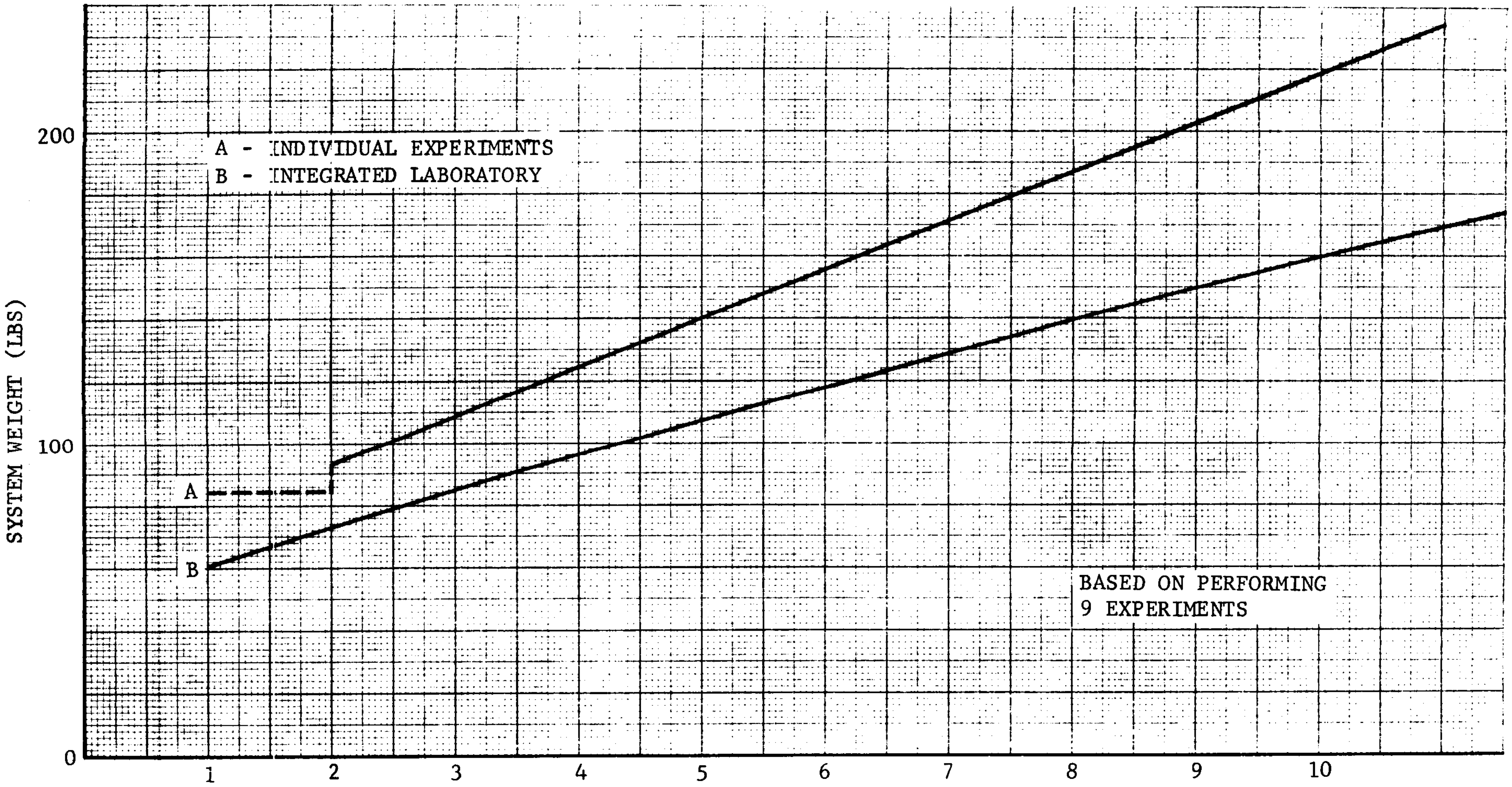

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FIGURE 4.3-7. WEIGHT COMPARISON OF INTEGRATED LABORATORY AND INDIVIDUAL EXPERIMENTS

TABLE 4.3-VIII

SUMMARY OF WEIGHTS
FOR INTEGRATED LABORATORY

	Items		Fixed Weight	Variable Weight
1.	Pneumatic Sampler ($<$ 6 cycles)		3.710	0.7480 n
2.	Pneumatic Sampler ($>$6 cycles)		7.710	---
3.	Auger Sampler		2.144	---
4.	Transport Mechanism		3.000	---
5.	Chemical Processor		5.000	---
6.	UV and Visible Spectropolarimeter		6.110	---
7.	Gas Chromatograph #1		8.930	---
8.	Gas Chromatograph #2		8.930	---
9.	Gas Chromatograph #3		0.823	0.1780 n
10.	A. C. Amplifier		0.500	---
11.	Power Inverter		0.500	---
12.	Pitot Sensing Head		1.935	---
13.	Reference Boiler Unit		3.189	---
14.	Soil Probe		5.540	---
15.	Television Camera		5.000	---
16.	Structure		5.500	---
17.	Filter Unit		---	0.0670 n
18.	Suction Cup		---	0.0912 n
19.	Piston Tip		---	0.0696 n
20.	Ultrafiltration Unit		---	4.5720 n
21.	Solvent Ampule		---	2.0112 n
22.	H_2O Ampule		---	0.5670 n
23.	Transfer Ampule		---	0.1246 n
24.	30 cc Cuvette		---	0.0930 n
25.	5 cc Cuvette		---	0.0810 n
26.	Calibration Standard		---	0.0576 n
27.	Lower Oven		---	0.9400 n
28.	Helium Carrier Gas		---	0.6080 n
	Total	$n < 6$	60.81	10.2082 n
		$n > 6$	64.81	9.4602 n

NOTE: n is number of cycles

c. Conclusions. Three basic conclusions can be drawn from this study. The first is that the integrated laboratory approach results in lower fixed weight. This is a result of equipment sharing in the integrated laboratory. The second conclusion is that the rate of increase of weight with repetitive experimental cycles increases more rapidly for individually mechanized experiments. This is a result of increased weight in the transport or stepping mechanism for the individual experiments whereas the integrated laboratory has a fixed weight for this mechanism. The third conclusion is that a slight reduction in the rate of weight increase with repetitive cycles for the integrated laboratory occurs at 6 cycles while the same reduction would not occur until 25 cycles for the individually mechanized experimental laboratory. This is explained by the fact that 25 cycles is the point at which stored gas supply can be replaced with a compressor or pump to provide the air for pneumatic transport of the soil samples. It occurs at six experimental cycles because of equipment sharing. Thus, not only the fixed weight but the variable weight can be reduced under certain conditions because of equipment sharing as postulated for the integrated laboratory.

4.4 LABORATORY RELIABILITY ANALYSIS

4.4.1 OBJECTIVES OF RELIABILITY ANALYSIS

A preliminary reliability analysis of the design-point ABL preliminary design was performed for the purpose of estimating quantitatively the feasibility of the concept; to determine critical experiments, equipments, and redundancy requirements; and, by expressing probabilities of success by experiment rather than by equipments, to permit experiment tradeoffs to be made.

4.4.2 CONSTRAINTS

Two salient considerations govern the approach to a numerical probability analysis of the ABL design: the definition of "mission success," and the selection of the terms in which it is expressed.

The success of the mission entails consideration of the probabilities of (1) the laboratory surviving launch and trans-Martian flight, (2) surviving Mars landing and environment, (3) successfully supplying power, programmed commands, and Earth commands to the laboratory, (4) executing the experiments, and (5) conditioning and transmitting the data signals. The scope of the reliability analysis was restricted to step (4) only (as previously discussed) i.e, determining the probability of successfully performing the experiments.

A general analysis was based upon obtaining 80 percent of the experimental data. It was further determined that some experiments were more important than others, and that some of the less critical experiments could serve as "backups" for others, thus leading to the following classification of experiments:

(1) "Most-primary": Experiments No. 12 (Soil Sample Encapsulation and Preservation) and No. 35 (Macroimaging - Facsimile and Infrared Scanning).

(2) "Primary": Experiments Nos. 1, 2, 7, 8, 14, 15, 16, 17, 19, 20, 21, 22, 23, 26, 29, 30, 31, 32, and 33.

(3) "Secondary" experiments not used directly as backups for a particular primary experiment. These include Experiment Nos. 3, 4, 5, 6, 9, 10, 11, 13, 18, 24, and 34.

(4) "Secondary" Experiments used as backups: Experiment Nos. 25 and 27 (used as backups for primary Experiment No. 26), and secondary Experiment No. 28 (used as a backup for primary Experiment Nos. 20, or 21, or 22, or 23).

In consonance with objective (3), a decision was made to compute system reliability in terms of the probability of each experiment's working successfully in lieu of the traditional approach of basing reliability predictions in terms of equipment success only. The chosen approach renders the analysis more complex and requires a few innovations in the methods of apportioning equipments, operating time, and reliabilities to each experiment, but it does yield results that can be utilized in making important experiment trade-off decisions, an overriding concern at this stage in the study program. In subsequent definition studies or development programs when the program emphasis shifts from scientific to engineering development objectives, the more detailed engineering system definition will permit a cross-check analysis of predicted ABL system reliability based on equipments rather than experiments.

The decisions to classify experiments and to express their reliabilities by each experiment leads logically to the mathematical model depicted in Figure 4.4.-1.

All blocks in series are considered necessary for 100 percent mission success. Those in parallel are backup experiments, and their function may be considered similar to those of redundant equipments in more orthodox equipment math models.

Not all experiments depicted in the series will be required to operate 100 percent successfully; in accordance with the "80 percent of the experimental data" objective, two most primary experiments, any 17 of the 19 primary experiments, and any 7 of the 11 secondary experiments (not utilized as backups in the math model) if conducted successfully will satisfy the established objectives. Furthermore, such a model is conservative because it does not take into account the possibilities of overlapping data that various combinations of experiments may yield.

These considerations, together with the math model, may be summarized in a system reliability equation:

$$R_{sys} = R_{pp_{12}} \times R_{pp_{35}} \times R_{p_{17/19}} \times R_{s_{7/11}} \qquad (1)$$

The success criteria must take into account time or test cycles. The most meaningful criterion is expressed in terms of the probability of successfully conducting the experiments during the early portion of the program. "T" (time in the assumed reliability function $R = e^{-\lambda t}$) in the analysis

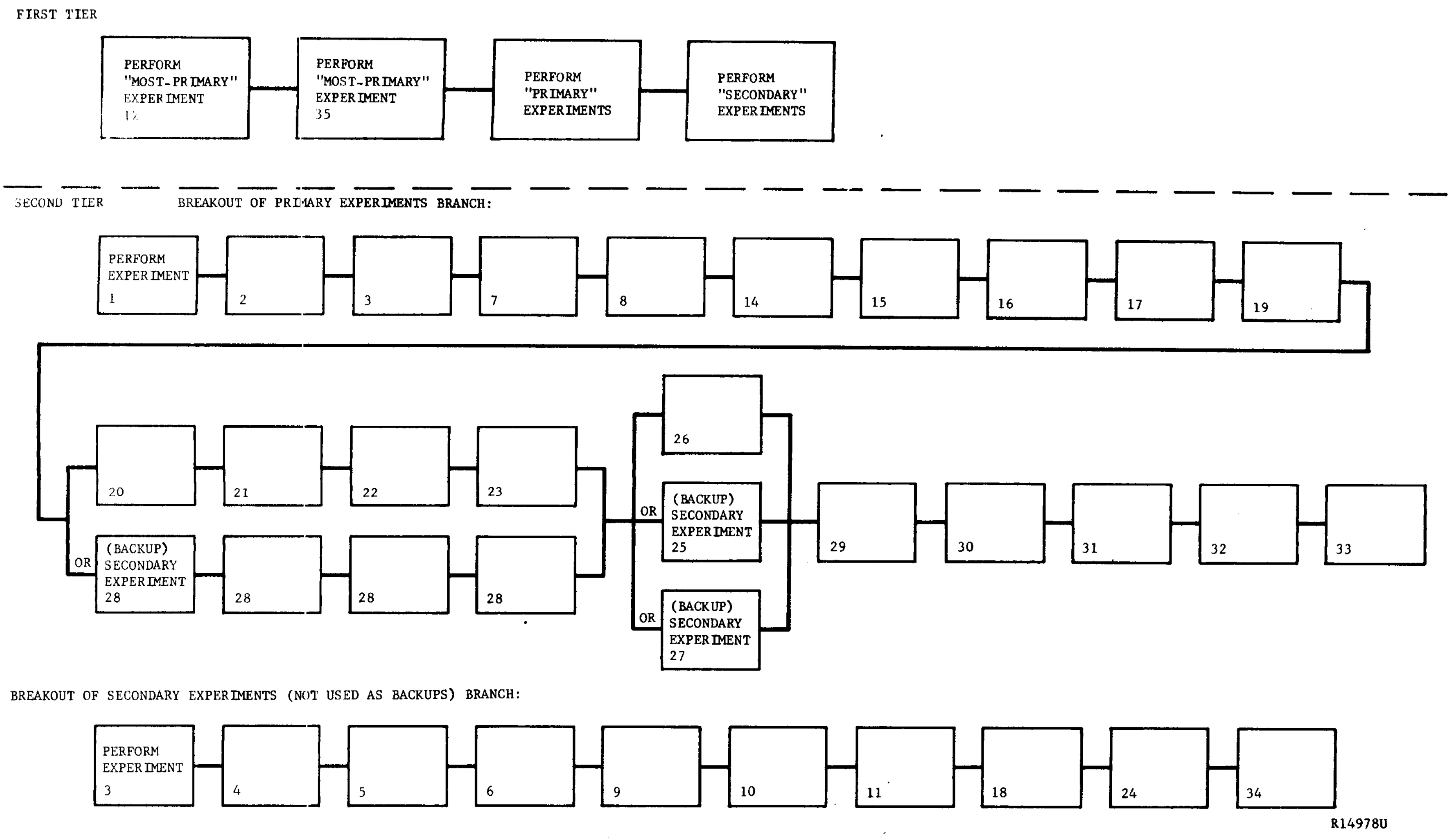

FIGURE 4.4-1. MATHEMATICAL MODEL FOR PERFORMING ABL EXPERIMENTS

was taken as one complete test phase or cycle - about 43 days or 1032 hours - for the following reasons:

(1) The first steps in some experiments are important because later operations may require successful completion of the early steps, e.g., soil preservation and encapsulation.

(2) Early returned experimental data will permit optimization of Earth-originated decisions to revise experiments, if necessary, and to issue commands outside the Mars-borne computer program.

(3) The Mars-to-Earth communication window will be time-sensitive and degraded toward the end of the two-year program.

(4) The ABL equipment, particularly continuously running and high-use equipment, may be degraded with time.

(5) Equipment may be affected by increasing environmental exposure with respect to time.

(6) Most of the important experiments are scheduled for operation during the first 43-day period.

(7) Many of the experiments performed late in the program provide confirmatory data or repeated data; data obtained early in the program are, in general, much more valuable.

(8) There is little chance that if an equipment fails during the early part of the program it will function successfully later in the program.

4.4.3 NUMERICAL STUDIES AND RESULTS

The results of the detailed prediction are tabulated in Table 4.4-I. The numbers were calculated according to predicted failure rates and estimated operating times or cycles for each piece of equipment required for the experiment. Table 4.4-II shows the number of cycles conducted for each experiment. From this table, detailed operating times were estimated for each equipment and for each component in an equipment item. Equipment required for each experiment is listed in Volume II of this report.

Failure rate data for each component or piece of equipment was derived from one of three sources: (1) published failure rate data for common components or equipments; (2) comparison with similar equipments or

TABLE 4.4-I

APPORTIONMENT OF ABL BY EXPERIMENTS

Most Primary Experiments		Primary Experiments		Secondary Experiments		Secondary Backup Experiments	
$R_{pp_{12}}$	0.997	$R_{p_{01}}$	0.982	$R_{s_{03}}$	0.999	$R_{s_{25}}$	0.986
$R_{pp_{35}}$	0.998	$R_{p_{02}}$	0.992	$R_{s_{04}}$	0.997	$R_{s_{27}}$	0.972
		$R_{p_{07}}$	0.986	$R_{s_{05}}$	0.999	$R_{s_{28}}$	0.917
		$R_{p_{08}}$	0.987	$R_{s_{06}}$	0.999		
		$R_{p_{14}}$	0.991	$R_{s_{09}}$	0.993		
		$R_{p_{15}}$	0.970	$R_{s_{10}}$	0.992		
		$R_{p_{16}}$	0.988	$R_{s_{11}}$	0.998		
		$R_{p_{17}}$	0.946	$R_{s_{13}}$	0.984		
		$R_{p_{19}}$	0.912	$R_{s_{18}}$	0.981		
		$R_{p_{20}}$	0.996	$R_{s_{24}}$	0.962		
		$R_{p_{21}}$	0.992	$R_{s_{34}}$	0.992		
		$R_{p_{22}}$	0.993				
		$R_{p_{23}}$	0.999				
		$R_{p_{26}}$	0.999				
		$R_{p_{29}}$	0.870				
		$R_{p_{30}}$	0.969				
		$R_{p_{31}}$	0.974				
		$R_{p_{32}}$	0.967				
		$R_{p_{33}}$	0.834				

TABLE 4.4-II

EXPERIMENT CYCLES

Experiment No.	Cycles Completed 43 Days	Cycles Completed Per Season	Total Cycles Completed 2 Years
1	Continuous	Continuous	Continuous
2	Continuous	Continuous	Continuous
3	Continuous	Continuous	Continuous
4	Continuous	Continuous	Continuous
5	6	18	72
6	8	24	96
7	2	6	24
8	20	60	240
9	1	0	1
10	1	0	1
11	2	3	12
12	2	3	12
13	10	15	60
14	2	3	12
15	10	15	60
16	10	15	60
17	3	4-3-3-3	13
18	10	15	60
19	10	15	60
20	12	21	84
21	12	21	84
22	12	21	84
23	12	21	84
24	12	21	84
25	12	21	84
26	10	15	60
27	10	15	60

TABLE 4.4-II (Continued)

Experiment No.	Cycles Completed 43 Days	Cycles Completed Per Season	Total Cycles Completed 2 Years
28	10	15	60
29	5	15	60
30	3	15	60
31	5	15	60
32	5	15	60
33	2	3	12
34	Continuous	Continuous	Continuous
35	8 TV	10-6-6-6	28
	16 IR	20-12-12-12	56

components with published failure rates; (3) engineering judgment in the case of unique equipments (such as the chemical processor system), based on a careful review of the component parts making up the equipment and their similarity to equipment having known failure rates. Several assumptions were necessary for the analysis:

(1) Sharing of continuously running equipments (such as pumps) by various experiments necessitated apportionment of the operating time on that equipment to each experiment that used it.

(2) Certain few equipments, such as the weight scale and the mass spectrograph (when used as a gas chromatograph detector), were not included as in-series equipments because they were not essential to the success of the experiments in which they are used.

(3) In certain cases, equipment or component redundancy was available because of the nature of the experiment or the experiment schedule. Examples are:

   a. Cyclone particle collector (4 available, 1 required).

   b. Evaporation ovens in chemical processor systems (13 available, 2 required).

c. Culture chambers in chemical processor system (13 available, 1 - 6 required).

d. Spectrum analyzer light sources (2 available, 1 required).

e. Spectrum analyzer photomultipliers (2 available, 1 required).

(4) First approximation analyses indicated additional needs for redundant equipments because of their high-use rate, their high estimated failure rates, or their criticalness to many experiments. Accordingly, the following equipments or components were subsequently made redundant:

a. Microphones (4 available, 1 - 2 required).

b. Vacuum ion pump (2 available, 1 required).

c. Vertical and radial drive motors for the internal transport mechanism (2 available, 1 required for each direction).

d. Vertical and radial drive shaft/clutch assemblies for internal transport mechanism (2 available, 1 required for each direction).

e. Pickup drive assembly for internal transport mechanism (2 available, 1 required).

f. Macroimaging facsimile system (2 available, 1 required).

(5) Five equipments (the soil sampler, the remote site soil sample deployment mechanism, the soil pulverizer, the pneumatic soil grader, and the cyclone collector) presented a unique problem to the apportionment phase of the reliability analysis. They are of original design, so their predicted failure rates were estimated conservatively on the high side. They are cycled (essentially) once during the first test phase. Also 22 to 23 experiments depend on their successful operation during this one "cycle." Simply apportioning their operating times to each using experiment's reliability calculation (i.e., $t = 1/22$ of a cycle) introduced an optimistic bias on the reliability number at the

system level. An approximation was made by multiplying the aggregate reliability of these five equipments (0.974) into the final ABL system reliability equation. Thus, system reliability Equation (1) is then modified to read:

$$R_{sys} = R_{pp_{12}} \times R_{pp_{35}} \times R_{p_{17/19}} \times R_{s_{7/11}} \times R_f \qquad (2)$$

where

R_{sys} is the probability of performing 80 percent of the experiments within the first 43-day test phase

$R_{pp_{12}}$ is the probability of performing most-Primary Experiment No. 12.

$R_{pp_{35}}$ is the probability of performing most-Primary Experiment No. 35.

$R_{p_{17/19}}$ is the probability of performing 17 of 19 primary experiments.

$R_{s_{7/11}}$ is the probability of performing 7 of the 11 secondary experiments not being utilized specifically as a backup for a primary experiment.

R_f is special factor $\doteq$ 0.974 for modifying the resultant system reliability number to account for the one-cycle soil sample test series shared by 22 to 23 experiments.

The numerical values for R_{pp12} and R_{pp35} are listed in Table 4.4-I. $R_{p17/19}$ was approximated by first taking the 19th root of the product of the primary experiments to get a "mean" $R_{primary}$, then using the combinatorial binomial expression for partial sums:

$$P = \sum_{s=r}^{n} \binom{n}{s} p^s q^{n-s}$$

where

P is the probability of getting at least n or more success of s ways possible

p is the individual probability of success of any one trial

q is $1 - p$

and then substituting, in our case,

$P = R_{P_{17/19}}$

p is "mean" probability of success for a primary experiment $= R_{p\ mean} = 0.964$.

$n = 17.$

$s = 19.$

$q = 1 - 0.964.$

Thus,

$R_{P_{17/19}} = 0.970.$

Similarly, for the probability of completing 7 of 11 secondary experiments,

$R_{mean\text{-}secondary} = 0.991$ and $R_{s_{7/11}} = 0.999.$

Substituting the above values in Equation (2), the system reliability is given as:

$$R_{sys} = R_{pp_{12}} \times R_{pp_{35}} \times R_{P_{17/19}} \times R_f \tag{3}$$

$R_{sys} = 0.997 \times 0.998 \times 0.970 \times 0.999 \times 0.974$

$R_{sys} = 0.94$ for 43 days.

A similar analysis for the full 2-year mission life resulted in

$R_{sys} \cong 0.5$

4.4.4 COMPARATIVE RELIABILITY ANALYSIS

Following the foregoing analysis of the design-point ABL system, a comparative analysis of alternative system mechanizations was performed on a parametric basis utilizing the design-point case. The effect of the following parameters was desired:

(1) Use of individually mechanized experiments in place of the integrated design-point configuration.

(2) Use of 100 percent performance criteria in place of the previous 80 percent criteria.

(3) Use of available alternative equipment in the ABL to obtain suitable equivalent data in place of failed analytical equipment. (The previous criteria assumed "backup" experiments but did not investigate substitute individual pieces of equipment. This was felt to be a significant feature of the ABL concept and deserved evaluation.)

The same individual component reliabilities previously determined were employed in this analysis for consistency. Where assumptions of new equipment or equipment apportionment had to be made, as for example in the case of the individually mechanized soil sampling equipments, they were made on a consistent basis with the previous analysis,using the same individual component reliabilities where possible.

When considering the basis for the alternative use of individual equipment items in the integrated case, it was recognized that only a small fraction of the total possible alternate arrangements could be evaluated in a reasonable analysis effort. Since, principally, the trends were of interest, it was decided to take only eight example cases and examine the effect from them alone. The selected examples are given in Table 4.4-III. Table 4.4-IV presents the results of the comparative analysis.

TABLE 4.4-III

EQUIPMENT SUBSTITUTIONS ASSUMED FOR THE COMPARATIVE RELIABILITY ANALYSIS

Experiment No.	Failed Component	Substituted Component
2	Gold Film Detector	Mass Spectrometer
	Gold Film Detector	Insulation Radiometer
7	Gas Chromatograph No. 1	Mass Spectrometer
	Mass Spectrometer	Gas Chromatograph No. 1
8	Gold Film Detector	Gas Chromatograph No. 1
	Gold Film Detector	Core Hole Sonde
13	α-Scattering	Core Hole Sonde
16	β-Ionization Detector and Fluorometer	Mass Spectrometer
20	Fluorometer	UV or IR Spectrophotometer
22	Gas Chromatograph No. 3 and Mass Spectrometer	IR Spectrophotometer
	Gas Chromatograph No. 3 and Mass Spectrometer	Gas Chromatograph No. 4 and Mass Spectrometer
23	Gas Chromatograph No. 3 and Mass Spectrometer	IR Spectrophotometer
	Gas Chromatograph No. 3 and Mass Spectrometer	Gas Chromatograph No. 4 and Mass Spectrometer

The matrix of results from these parametric analyses is given in Table 4.4-IV.

TABLE 4.4-IV

RESULTS OF COMPARATIVE RELIABILITY ANALYSES
(FOR FIRST 43-DAY EXPERIMENT CYCLE)

Parametric Criteria	Integrated Laboratory	Individual Experiments
80-Percent Data Acquisition Backup Experiments Used. No Alternative Equipment Used.	0.94	0.91
100-Percent Data Acquisition Backup Experiments Used. No Alternative Equipment Used.	0.40	0.14
100-Percent Data Acquisition Backup Experiments Used. Alternative Equipment Used in ABL*	0.47	0.14
80-Percent Data Acquisition Backup Experiments Used. Alternative Equipment Used in ABL*	0.98	0.91

* Per Table 4.4-III.

4.4.5 CONCLUSIONS AND IMPLICATIONS FOR LABORATORY MECHANIZATION

The results of reliability studies have indicated that it is possible to achieve a reasonably high reliability for the ABL experiments. To achieve the reliability, it will be necessary that special design considerations and techniques be recognized and utilized.

In particular, redundancy of components, equipment, or even complete experiments may be necessary in certain areas where utilization rates are high, where the predicted failure rates are high, or where proper operation is essential for laboratory mission success. Also, reliability emphasis should be placed on those equipments and experiments which are run early in the program because of the greater value of the data returned in this period.

The results of the comparative analyses can be summarized as follows:

(1) The integrated approach to laboratory mechanization always shows an improvement in reliability over the alternative individual experiment arrangement.

(2) While reliability for both concepts suffers appreciably when going from the criteria of 80 percent to 100 percent data return, the penalty in the case of the individual experiment arrangement is far greater (650 percent versus 235 percent). This is due to the fact that, when no specific experiment successful completion is specified (any 80 percent), the individual experiments payload does not suffer appreciably from individual experiment failure, since any combination of experiments remaining making up 80 percent will satisfy the criteria. When 100-percent successful operation is demanded, however, the individual experiment payload has no mechanism for attaining the required performance, while the integrated payload can substitute equipment and still attain the experimental objective.

An interesting qualitative conclusion that results from the study, although probably a very real one, is that the individual items of equipment will exhibit a reliability proportional to the development effort expended upon them, and, for a given program level of funding, the system utilizing the fewest different kinds of components should be able to develop these items to a much higher level of reliability attainment. Thus the integrated payload utilizing common multipurpose equipment should be able to demonstrate a much higher component, and therefore, system reliability than a system employing individually developed and mechanized experiments.

4.5 CONCEPTUAL SAMPLING STUDIES

4.5.1 SAMPLING STUDY OBJECTIVES

The acquisition of a sample represents the initial point in each experimental sequence. For those experiments which sample the general environment, such as atmospheric pressure and temperature or solar insolation, the acquisition of a sample is achieved by merely exposing the appropriate sensor to the environment. The more sophisticated life detection and chemical processing experiments in general require the acquisition of a soil sample which must be removed from its natural environment and preprocessed into a suitable condition for further processing. In performing this acquisition, it is desirable to deliver the sample with a minimum of modifying influences such as heat or solvents that are neither pertinent to the local environment or the experimental processing that follows. With these considerations in mind, the following objectives were established for the sampling analysis as applied to ABL.

(1) Establish the requirements which must be achieved in the sampling system in terms of experimental requirements such as the quantity of sample required and the quality or condition of the delivered sample.

(2) Develop and qualitatively evaluate various sampling concepts.

(3) Parametrically evaluate several selected concepts to establish feasibility and trends to a first order approximation.

(4) Define a sampling system which will match the level of sophistication implied in the experimental procedures and analysis.

4.5.2 SAMPLE ANALYSIS CRITERIA

The following criteria are formulated to assist in guiding the analysis effort for soil sampling methods and mechanization. The elements of a sample collector, as outlined in chart form in Figure 4.5-1 indicated the very large scope of the sample collection problem and that the analysis must be constrained in order to do an effective study. Some of the elements and possible combinations can be eliminated either qualitatively based on judgment or with fairly simple analysis. A fundamental philosophy underlying the sampling analysis was that no appreciable refinement of the known facts about the surface details of Mars will become available throughout the development of an ABL with a proposed flight date in the

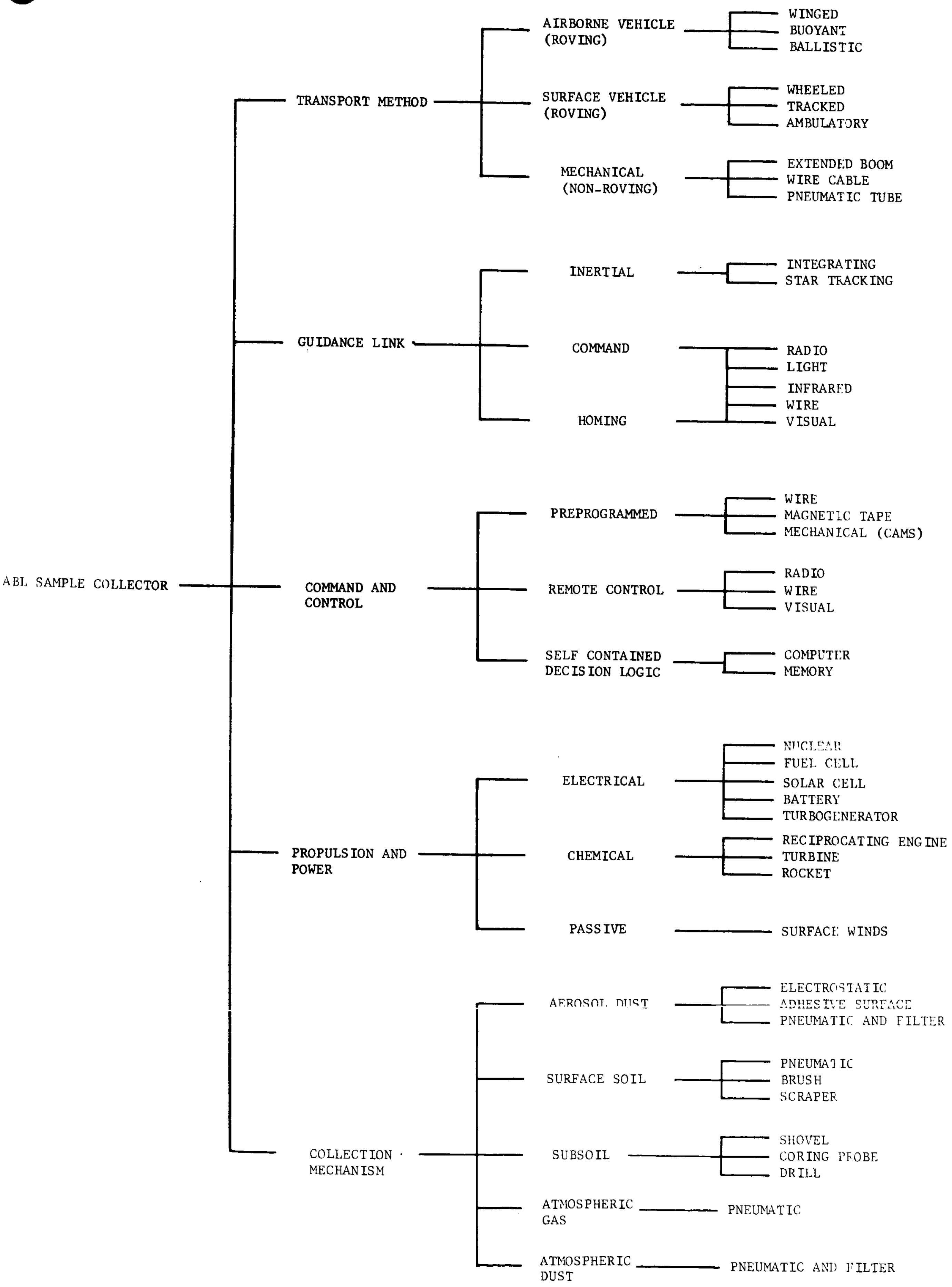

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FIGURE 4.5-1. ELEMENTS OF ABL SAMPLE COLLECTOR early or mid 1970's. Current resolution of surface detail is in the order of 100 kilometers which may be expected to be improved to 5 kilometers in limited areas by Mariner IV data. Neither of these resolutions provide sufficient detail to define the local topography on the scale of the sampling device (a few cm).

On the basis of this fundamental philosophy, the following detail criteria to be used in the sampling analysis are presented. They consist of two types, one of which is based on assumption and the other which is known or estimated requirements. Further subdivision into four categories which consist of site selection, sample gathering, sample grading and refining, and operations. Each criteria is supported with a statement of justification as indicated in Table 4.5-I.

TABLE 4.5-I

SAMPLING ANALYSIS CRITERIA

Criterion	Justification
TYPE: ASSUMPTION CATEGORY: SITE SELECTION	
1. Site selection is defined as the determination of the location from which a sample will be taken utilizing a choice between several possible locations.	1. By definition.
2. A sample site will be at the ABL location whether or not a roving sample collector is employed.	2. Increased reliability of mission success since the performance of a roving vehicle will have a higher probability of failure.
3. Multiple sample sites are desirable but are not considered to be mandatory.	3. Based on the inference that if life exists some sort of universal distribution will exist but will not necessarily be uniform.

TABLE 4.5-I (Continued)

SAMPLING ANALYSIS CRITERIA

Criterion	Justification
TYPE: KNOWN OR ESTIMATED REQUIREMENTS CATEGORY: SITE SELECTION	
1. In order to select sites with appreciably differenct characteristics they must be separated by several hundred kilometers. Estimated at 500 to 1000 kilometers.	1. Based on current resolution achievable and the size of observable characteristics such as canali and light or dark areas. Partly substantiated by inference from Earth conditions.
2. The sampling site must be located outside of the surface area affected by terminal retro-boost rocket motors, if used.	2. Soil surfaces exposed to rocket blasts will be eroded and will contain modified constituents. While positive life detection may be made, the uncertainties introduced dictate the collection of an unaltered sample.
TYPE: ASSUMPTION CATEGORY: SAMPLE GATHERING	
1. Sample gathering is defined as the mechanism of obtaining a sample only. It does not include the transport and handling necessary to deliver the sample to the ABL.	1. By definition.
2. The following possible sample classes are postulated. a. Atmospheric gases b. Atmospheric borne particles c. Soil d. Free water or ice e. Macroscopic life forms f. Microscopic organisms	2. Necessary conditions for these classes exist on Mars but not necessarily sufficient conditions.

TABLE 4.5-1 (Continued)

SAMPLING ANALYSIS CRITERIA

Criterion	Justification
3. The sample collector shall be capable of securing a sample for the completed range of possible sample classes and conditions.	3. The apriori information will not be sufficiently detailed to estimate the probability of encountering a particular sample class or classes.
4. The soil can be classified by type and structure in a manner similar to Earth. The gross soil structures are classified as follows: a. Bedrock b. Hardpan c. Pavement d. Lithified rock e. Loose aggregate	4. Based on an assumed commonality of origin of Mars and Earth.
5. Soil aggregates are graded by size as follows: a. Boulders ≥ 256 mm b. Cobbles $64 \leq d \leq 256$ mm c. Pebbles $2 \leq d \leq 64$ d. Sand $62 \leq d \leq 1000$ e. Silt $4 \leq d \leq 62$ f. Clay $.25 \leq d \leq 4$	5. Wentworth grade scale as defined in data sheet published by the American Geological Institute.
6. Soil sample collection is subdivided by location and method of collection as follows: a. Aerosol dust from surface b. Surface soil to 1 cm depth c. Subsoil to 10 cm depth d. Core drill to 3m. depth	6. This assumption is based on the scientific desirability of identifying where the biologically rich sample is collected.
7. Samples from solid basic rock formations will not be taken except for surface material.	7. There is no biological objective in obtaining internal rock samples.

TABLE 4.5-I (Continued)

SAMPLING ANALYSIS CRITERIA

Criterion	Justification
8. Macroscopic life forms shall be gathered intact if possible.	8. Allow direct morphological examination.

TYPE: KNOWN OR ESTIMATED REQUIREMENTS
CATEGORY: SAMPLE GATHERING

1. The sample gathering mechanism shall not alter or contaminate the sample in a biological sense, i.e., heat shall not be applied or chemicals added. Mechanical deformation is allowable.	1. Dictated by the primary mission objective of the ABL. Mechanical deformation is inherent in the act of collecting a sample.
2. The conditions existing at the sample site shall be recorded for support, i.e., temperatures, moisture, morphological form, background radiation, and sample class.	2. Required to correlate the results of the experimental techniques.
3. Sample size shall be large enough to satisfy all the ABL experiments and provide for a minimum of three experimental repetitions.	3. A qualitative requirement based on providing a reliable and an interpretive scientific result. This may not be possible with certain classes of samples because of abundance such as macroscopic life forms.
4. Two samples will be gathered, one for use in the ABL and the other for encapsulation for future reference.	4. To preserve samples for conditions existing at arrival of the ABL for future manned exploration.

TABLE 4.5-I (Continued)

SAMPLING ANALYSIS CRITERIA

TYPE: ASSUMPTION
CATEGORY: SAMPLE GRADING & REFINING

Criterion	Justification
1. Sample grading and refining is defined as the processing performed on samples delivered to the ABL to convert them to a form for suitable experimental processing.	1. By definition.
2. Sample grading and refining will not alter the sample except in a mechanical sense for soil samples. Each sample will be divided into subsamples where the quantity is sufficient - packaged and identified by site number, batch number, and subsample number.	2. This is based on the assumption that detailed experimental processing will be conducted over an extended period of time thus requiring storage of the sample in a manner to minimize sample deterioration.
3. Priorities will be assigned to sample classes for order of experimental processing as follows: a. Macroscopic life forms b. Free water or ice c. Surface soil samples d. Subsoil samples e. Core drill samples	3. Based on assumed possible experimental value and the probability of deteriorating changes occurring before experimental processing.
4. Atmospheric samples will be gathered and graded simultaneously as required by the experimental processing techniques.	4. This is the most easily gathered sample and the most bulky to store.

TABLE 4.5-I (Continued)

SAMPLING ANALYSIS CRITERIA

Criterion	Justification
5. Solid particles such as pebbles shall be separated as a subsample rather than being reduced by crushing.	5. Crushing solid stones will not increase the ratio of biological material to inert material but rather decrease it.

TYPE: KNOWN OR ESTIMATED REQUIREMENTS
CATEGORY: SAMPLE GRADING & REFINING

Criterion	Justification
1. Soil samples will be graded into subsamples with particle size distributions as follows: a. $d < 50$ b. $50 < d < 300$ c. $300 < d$	1. Based on preliminary estimates of trends and requirements of the experiment techniques as well as the concentration of biological material as a function of particle size.

TYPE: ASSUMPTION
CATEGORY: SAMPLER OPERATIONS

Criterion	Justification
1. Sampler operations are defined as those operations either performed by the sample collector or endured at some time in the ABL mission. These are classified as follows: a. Sterilization b. Prelaunch and boost environment c. Transfer trajectory environment d. Entry and landing environment e. Surface operations on Mars.	1. By definition.

TABLE 4.5-I (Continued)

SAMPLING ANALYSIS CRITERIA

Criterion	Justification
2. Surface operations on Mars for the sample collector are defined as follows: a. Rigging for sampler deployment b. Transport to sample site c. Probing sample site d. Collecting samples and handling e. Sample transport to ABL f. Sample transfer to ABL	2. By definition. These are phases required to acquire a sample for the ABL.
3. The sampler shall be capable of inserting probes to a depth of 10 cm to determine the following: a. Surface and subsurface temperature b. Soil strength c. Soil permeability d. Free water content e. Background radiation	3. This data is needed for the more sophisticated system to assist in selecting desirable sample sites. It is assumed that power requirements for actual sample collection will be much higher than probing.
4. The sampler shall incorporate an atmospheric probe to monitor the following: a. Wind velocity b. Atmospheric pressure c. Atmospheric temperature d. Relative humidity.	4. To provide background data of atmospheric conditions at the time the sample is collected.
5. The sample collection and handling shall provide for encapsulation of the sample until further processing is accomplished in the ABL.	5. To maintain the sample in its original condition as long as possible.

TABLE 4.5-I (Continued)

SAMPLING ANALYSIS CRITERIA

Criterion	Justification
TYPE: KNOWN OR ESTIMATED REQUIREMENTS CATEGORY: SAMPLER OPERATIONS	
1. Dry heat sterilization capability to provide a probability of transporting a viable organism not to exceed 10^{-4}. The sterilization requirements are as follows: a. 145°C for 36 hours - 3 cycles b. 135°C for 24 hours - 1 cycle c. Ethylene oxide wash	1. Tentative requirements established by NASA.
2. Prelaunch and boost environment shall consist of the following: a. Ground handling accelerations of ±3g along all axes. b. Steady state boost accelerations 6g axial 1.5g lateral c. Dynamic peak accelerations ±15g 20-2000 cps vibration 10g shock d. Temperature - 65°F to 165°F (-55°C to 75°C)	2. Estimated from similar requirements for existing missile and space systems.
3. Transfer trajectory environment. a. 8 to 10 months transit time b. No internal thermal control c. No operational functions.	3. Primary mission of ABL is scientific investigation of life on surface of Mars.

TABLE 4.5-I (Continued)

SAMPLING ANALYSIS CRITERIA

Criterion	Justification
4. Entry and Landing Environment. a. ABL protected from entry heating by entry vehicle. Peak temperature for ABL not greater than sterilization temperature of 135°C. b. Steady state accelerations (peak) 150g axial ±10g lateral c. Dynamic accelerations 500g shock (impact) axial	4. Estimated from entry vehicle studies.

4.5.3 DEVELOPMENT OF SOIL MODELS

As discussed in Paragraph 4.5.2, it is not expected that any refinement in surface characteristics for Mars will be known before a mission such as ABL is flown. Since soil sampling provides the basis for most significant biological experiments, it is important that some reasonable models be established for possible types of surface conditions on Mars. In this section, the attempt is made to establish soil models from the standpoint of physical characteristics such as particle size distribution, strength, and porosity. These parameters must be established to provide a consistent basis to size sampling equipment, estimate power requirements, and to evaluate mobility concepts. The last item cannot be completely evaluated unless models are also established for local terrain geometry. No attempt was made to establish this model since the detailed studies of mobility on the lunar(39) surface that have been made will suffice until more definitive information on the Martian terrain is obtained.

To arrive at the soil models established in this study, the characteristics of terrestrial soils were examined to determine trends and ranges of values. These were then adjusted on the basis of known or inferred facts about conditions on the Martian surface to establish two rock models, one frictionless cohesive soil model, two cohesive frictional soil models, and one dune sand model. The parameters examined were soil particle size distribution, soil porosity, and soil strength which are discussed in that order in the following paragraphs.

a. Soil Particle Size Distribution. Two basic characteristics are used to compare soils for particle size distribution. These are the standard deviation, σ, and the mean particle diameter, d_m. Because of the large range of sizes encountered, the particle size is normally plotted on a logarithmic scale. Two types of curves are normally used to present soil characteristics. These are the distribution curve and the summation curve shown in Figure 4.5-2 and Figure 4.5-3 respectively for two typical terrestrial soil models and the two Martian models postulated for this study. To arrive at these models the assumption was made that the soil would have a normal (Gaussian) distribution. Real soils do not necessarily have a true normal distribution but in general can be approximated with one. Since this kind of detail will not be available prior to an ABL, a normal distribution will provide a realistic model for design purposes.

Typical summation curves for particle size distributions ranging from cosmic dust through terrestrial soils and gravel to asteroids are given in Figure 4.5-4. Note that the summation curves showing the distribution of cosmic bodies, soils, and cosmic dust have the same general shape. The two exceptions noted are curves 5 and 10 for decomposed Hong Kong Granite and Upper Silesian Sand. To compare these distributions, as well as some obtained by Puri(21), some representative soil types were located on a probability plot. A straight line on this type of plot is the summation curve for a

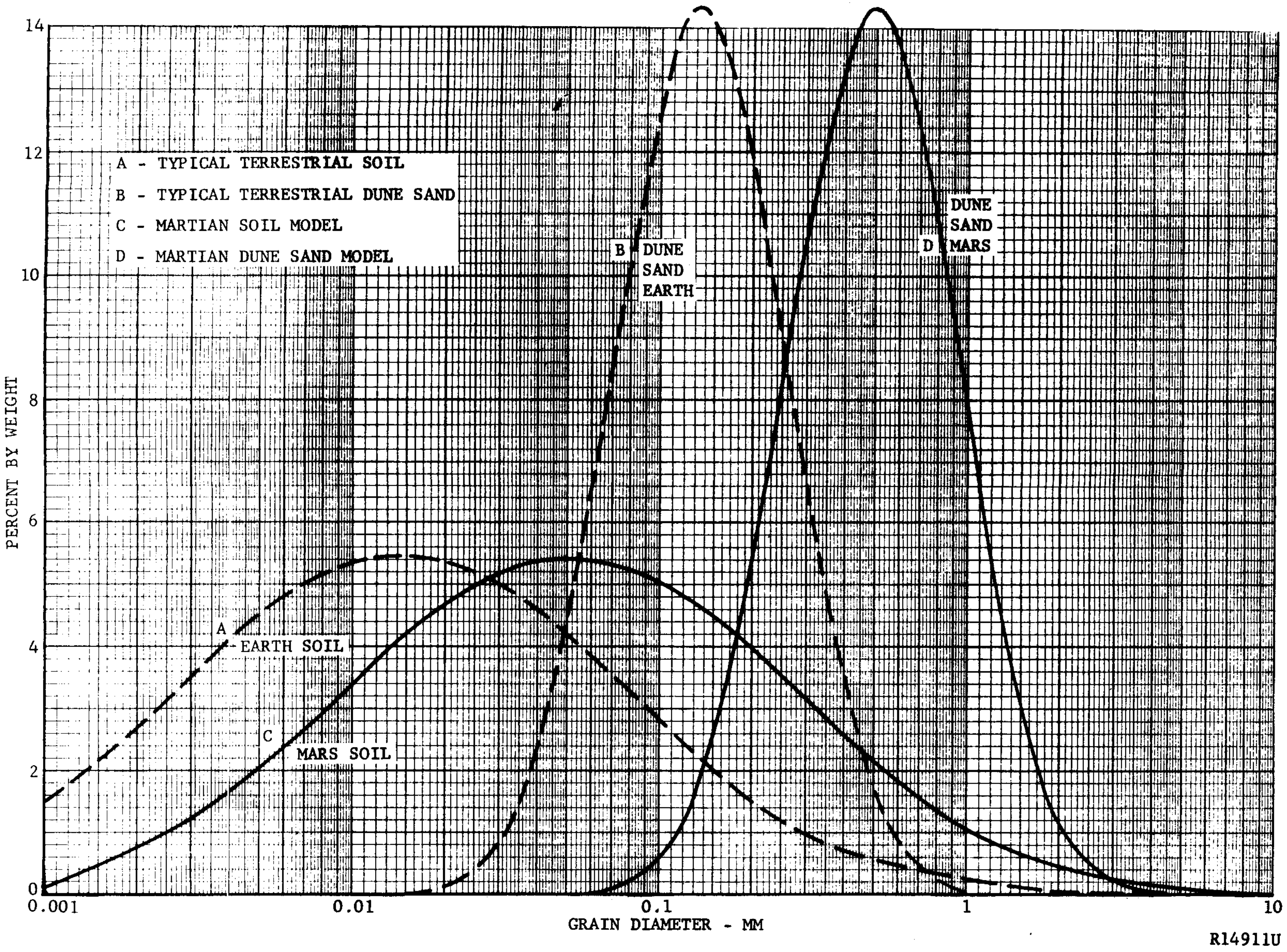

FIG 4.5-2 SOIL PARTICLE DISTRIBUTION
BY GRAIN SIZE

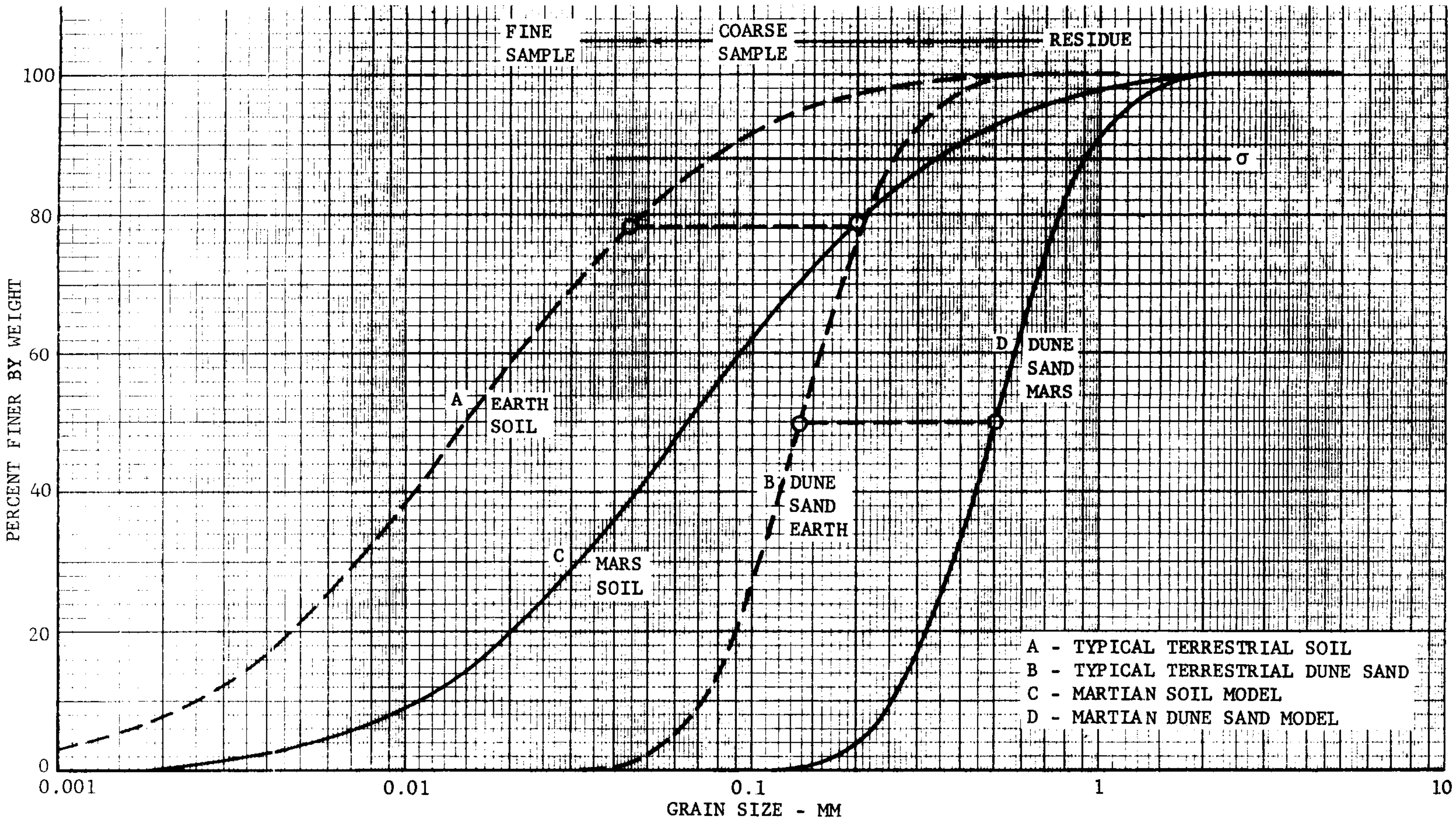

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FIG 4.5-3 SUMMATION CURVES FOR SOIL PARTICLE DISTRIBUTION

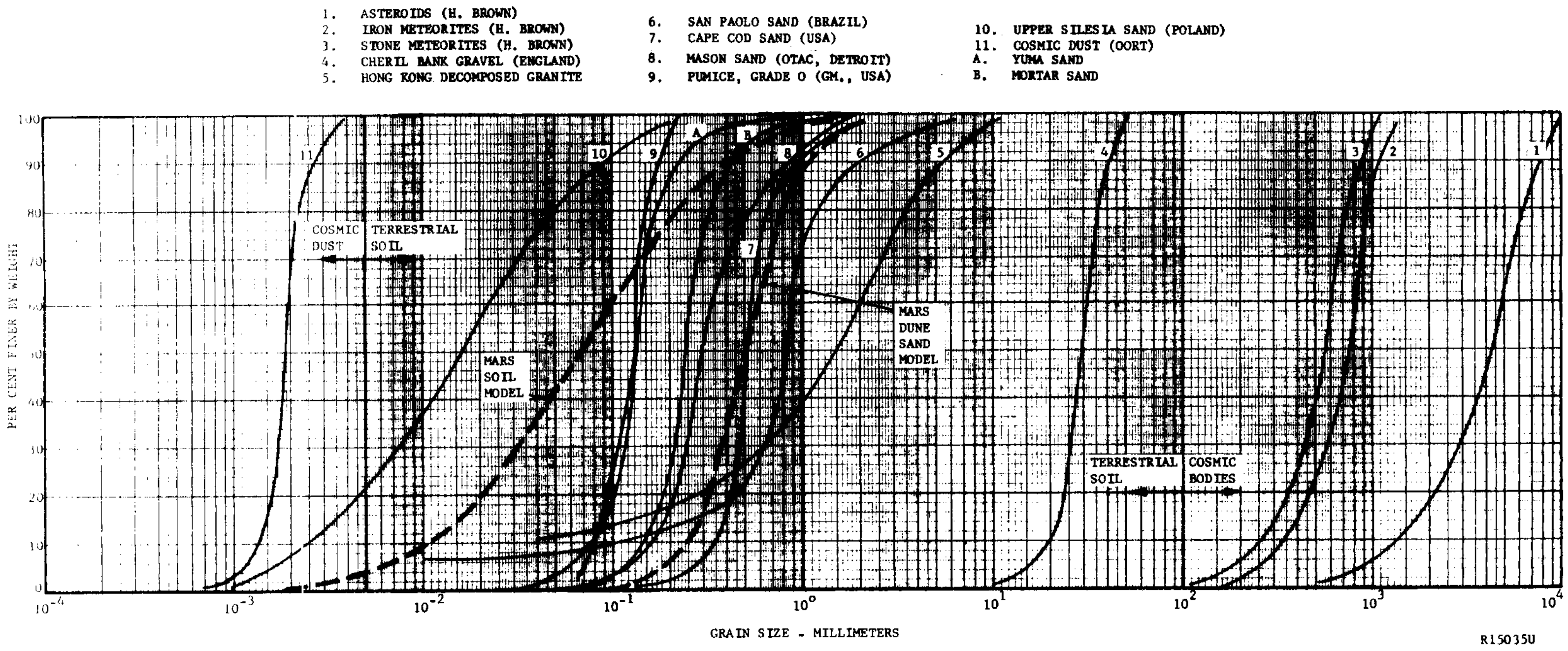


FIGURE 4.5-4. GRAIN SIZE DISTRIBUTION DIAGRAM (REF. 22 - PAGE 764 and 831)

normal (Gaussian) distribution and the slope of the curve gives the standard deviation. Figure 4.5-5 shows these plots, which indicate considerable scatter; however, some generalized trends can be deduced. Two basic standard deviations are closely fitted by the upper Silesian sand in one case and Yuma sand and Jarauwala bed silt in the other case. The other soils which are typically agricultural soils tend to follow the trend of the high standard deviation although they exhibit considerable variation. It is interesting to note that the black cotton soil tends to have a high standard deviation and a high mean grain size. However, if this soil is dispersed by placing it in NaOH for 24 hours, the mean grain size is considerably reduced. This effect is produced by the fact that this soil is an agglomeration of smaller grains bound together with organic material which the NaOH dissolves. The inference drawn from these data is that the soils having a low standard deviation have been subjected to some form of grading action while the high standard deviation soils are not subject to such action. The high standard deviation can also be achieved through a mixing action such as occurs in glacial soil deposits. The remaining fact which is inferred is that the mean grain size for the low standard deviation soil is an order of magnitude larger than for the high standard deviation soil. For terrestrial dune sands the mean grain diameter agrees rather well with the grain size for minimum wind velocity required to initiate movement. In Ryan's(11) work he estimates that the grain size for this condition in a 25 millibar atmosphere on Mars has increased to approximately 350 microns. He has also indicated that the trend to even larger sizes exists as the atmospheric pressure drops. Thus, the Martian dune sand model is established with a mean grain diameter at 500 microns with a standard deviation σ of 0.278. The remaining soil model with a high standard deviation was adjusted by noting that Stoke's law is obeyed to larger particle sizes on Mars than on Earth. In Paragraph 4.5.6, it is shown that this is an order of magnitude larger for the Mars atmospheric models than for Earth atmosphere. Based on the assumption that grading action does not occur for this soil, the distribution curve was adjusted by shifting the particle size at which Stoke's law ceases to apply on Earth to that compatible with the Martian atmospheric models. This results in a soil model with a mean grain diameter of 67 microns and a standard deviation σ of 0.722. These are the distribution curves previously shown in Figure 4.5-2 and 4.5-3. They are also shown in comparison with terrestrial soils in Figure 4.5-4 and would seem to represent reasonable estimates for design purposes.

From these considerations, it appears to be a valid assumption that the mean grain size diameter for Mars soils will be larger than on Earth even though the standard deviation may be the same. This assumption is conservative in terms of estimating soil sampling requirements if the criteria is used that soil samples will be graded into samples with grain diameter of 300 microns or less and assuming no grinding or crushing of the raw sample. The latter criteria is justified on the basis that grinding the sample will not increase the ratio of biological material to inert material but will, rather, decrease it.

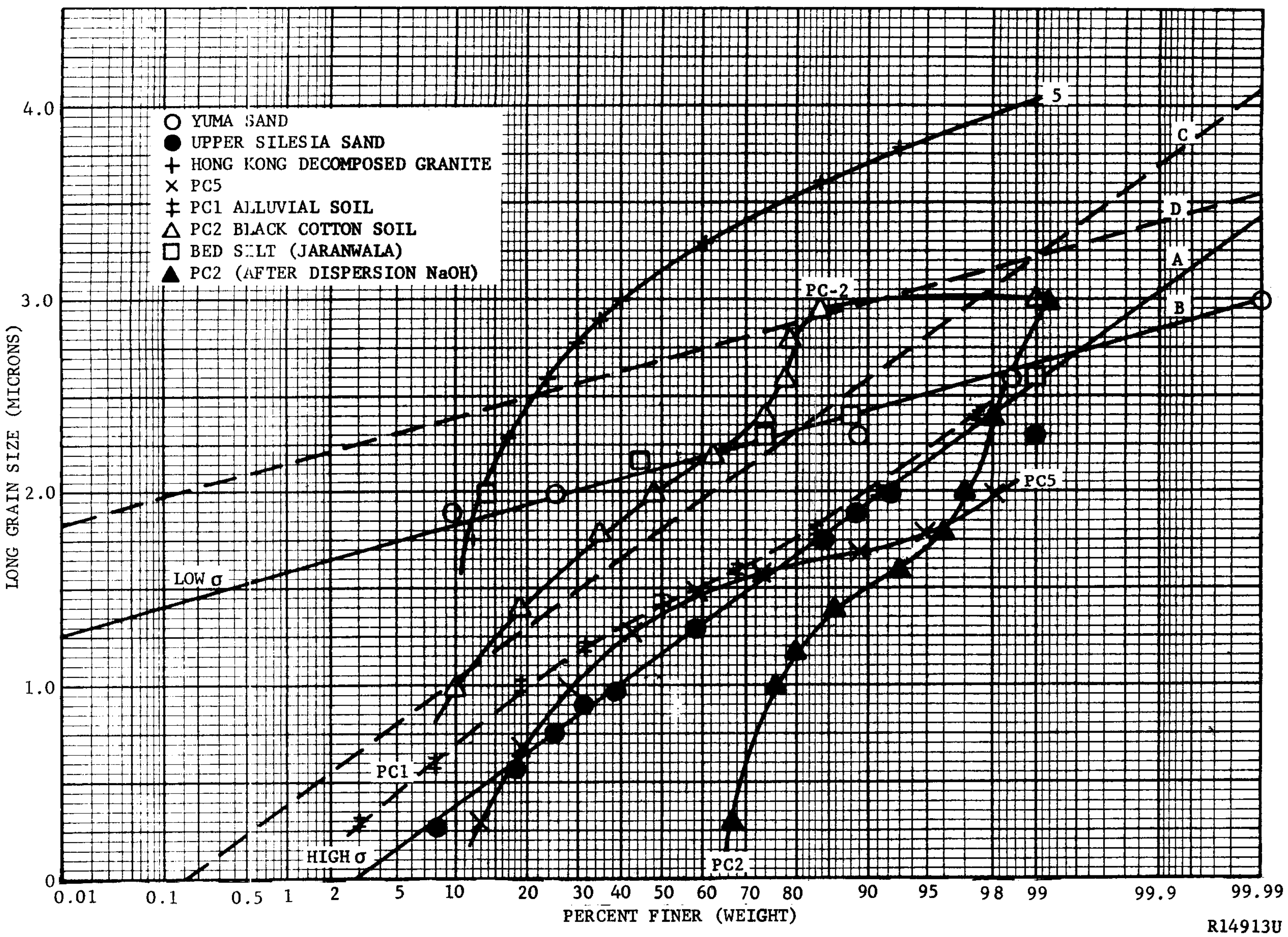


FIGURE 4.5-5. COMPARISON OF SOIL PARTICLE SUMMATION CURVES (LOG BASIS)

b. Soil Porosity Limits and Density Estimates. Knowing the weight of soil sample to be collected is not in itself sufficient to size the sample collection equipment. Some estimate of the effective porosity and soil density must be made. Van Tassel and Salisbury(30) argue that from a geological viewpoint the commonly postulated material of the Mars surface is limonite which is based on photometric and polarimetric comparisons of the infrared emission spectra for the Mars surface and limonite. It is also based on the lack of observation of the characteristic emission usually found in silicates. From the geological viewpoint of relative abundance and the apparent density of Mars, the surface should be mostly silicate. To explain the lack of observed infrared emission characteristic of silicates, emission characteristics of finely ground silicates were made by Van Tassel and Salisbury.

Andesite, basalt, angite, serpentine, granodiorite, obsidian, and chondrite were ground to particle sizes as follows:

80 percent smaller than 3 microns

10 percent $3 < d < 17\ \mu$

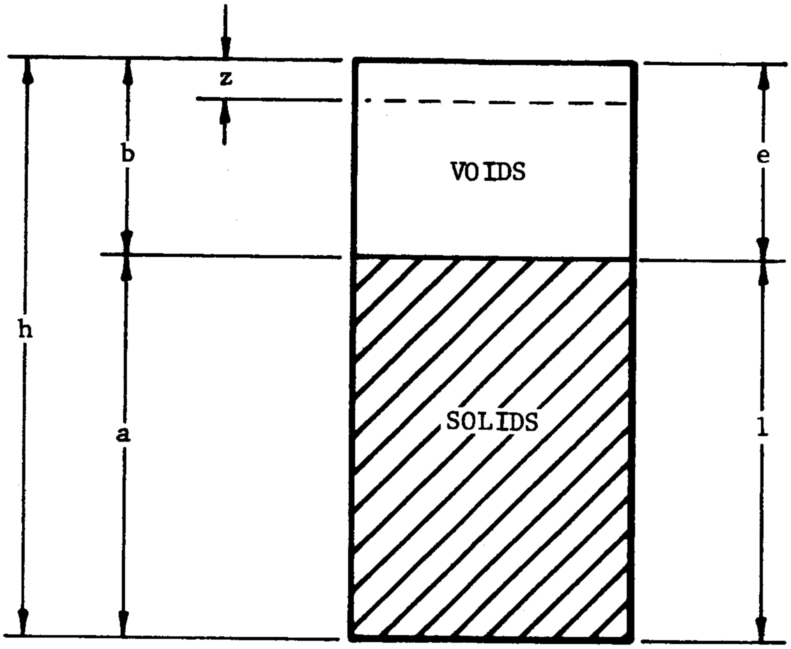
1 percent larger than $70\ \mu$

Olivine, quartz, and limonite were ground to two sizes as follows:

Flour	Sand
Quartz $1.2\ \mu$ average size	$50 < d < 100\ \mu$
Olivine 90 percent $0.8 < d < 4\ \mu$	$75 < d < 200\ \mu$

They found that the fine flour produced a flat or grey spectral response whereas the sand indicated a spectral response for silicates. Thus, they concluded that the surface soil could be either a finely divided silicate or a coarse grain silicate with a finely divided limonite coating which would also correlate with the observed color and spectral emission characteristics for Mars. The latter model is more consistent with the models established for soil particle size distribution and in fact seems to be a more reasonable estimate. Thus, an average specific gravity for the soil particles is assumed to be 2.6 for the purposes of subsequent calculations. This value corresponds to that for silica sands.

In order to estimate the effective bulk density of the soil the porosity must be known. Porosity is defined as the ratio of the void volume to the total volume as indicated in Figure 4.5-6.



h = TOTAL THICKNESS OF SOIL

b = EFFECTIVE THICKNESS OCCUPIED BY VOIDS

a = EFFECTIVE THICKNESS OCCUPIED BY SOLIDS

e = b/a VOID RATIO

$p = \frac{b}{a + b} = \frac{e}{1 + e}$ POROSITY

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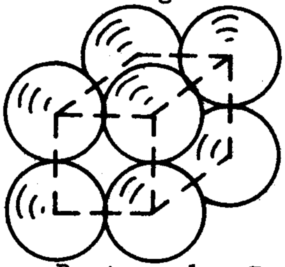
FIGURE 4.5-6. RELATIONSHIPS BETWEEN VOIDS AND TOTAL SAMPLE

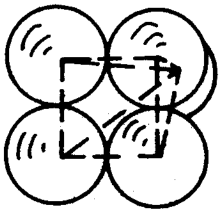
To more fully develop the idea of porosity, the theoretical values for certain packing geometries can be calculated for spherical particles of a uniform size. These are defined below.

Loose Rectangular Pack



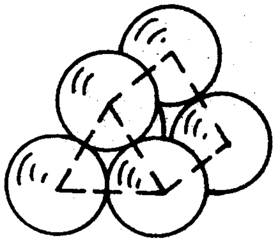
This packing is characterized by a cubic structure connecting the centers of each particle.

Dense Rectangular Pack



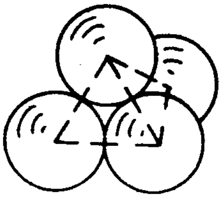
In this packing each alternate layer is displaced in such a manner that a particle that contacted only one other in the adjacent layer now contacts four others in the adjacent layer. The particle centers are connected by a pyramid structure with a square base.

Loose Triangular Pack



This packing arrangement has the particles packed in a triangular configuration rather than a square configuration in each layer.

Dense Triangular Pack



In this arrangement the adjacent layers are again displaced so that a particle that had contacted only one other now contacts three others.

The above theoretical packing arrangements result in a range of porosity values given in Table 4.5-II for uniformly sized particles.

TABLE 4.5-II

VALVES OF POROSITY FOR THEORETICAL PACKING ARRANGEMENTS

Packing Arrangement	Porosity (percent)
Loose rectangular pack	47.7
Dense rectangular pack	25.9
Loose triangular pack	39.5
Dense triangular pack	25.9

It is seen that both the equilateral pyramid with a square base and the tetrahedron packing structures yield a minimum porosity of 25.9 percent. In actual fact both are encountered simultaneously if the packing structure is examined in more than two layers of particles. The minimum unit volume is a polyhedron with six square faces and eight equilateral faces all sides of which equal the diameter of the particle. It is also noted that packing density or porosity is independent of particle size for uniformly sized particles. Porosity can only be reduced by introducing a mixture of smaller particles. The maximum size particle to fit into the intersitial voids was determined to be 0.414 and 0.225 of the uniform particle size, which can reduce the porosity from 25.9 percent to 18.8 percent. It is noted that this can only be achieved for the following ratios of numbers of particles as a function of particle size. The following ratio may be used: 10:9:24::d:.414d:.225d.

This trend in mixture proportions is not what is normally encountered in soil particle size distributions leading to the conclusion that 25 percent represents a lower limit. This has in fact been observed to be generally true for most soils. While upper limits of porosity of 90 percent can occur in loosely cemented terrestrial soils and volcanic pumice, the porosity of terrestrial sands will generally vary between 25 percent for closely packed sand to 50 percent for loosely packed sand. On the basis of these observations and the values obtained on a theoretical basis, it appears that upper and lower limits of 50 percent and 25 percent porosity should be used in conjunction with the Martian soil models.

c. Soil Strength Characteristics. In establishing strength models for the Martian surface soil, extensive comparisons for existing terrestrial soils were again made. It was found that data on both natural and artificial stone was readily available and physical properties were reasonably well defined as shown in Table 4.5-III and Table 4.5-IV. In most instances, soil strength data were sketchy and were oriented towards use for study of vehicle mobility or foundations for buildings. As a result, these data tend to be typical of weak or marginal soils which is conservative for the intended application. In general, they are unconservative for predicting requirements for the ABL such as power required to collect a soil sample or

TABLE 4.5-III

TYPICAL PROPERTIES OF STONE
(English Units)

					K						
Material	μ	ρ	E x 10^{-6}	P	P_1	P_2	A	σ_c x 10^{-4}	σ_t x 10^{-2}	τ x 10^{-3}	M_R x 10-3
Basalt	0.22/0.25	0.106/0.115	-	0.4/00.5	3.96	3.30		2.84/4.98	-	-	-
Quartzite	0.10	0.095/0.099	-	1.5/02.9	-	-		1.42/2.84	-	-	-
Granite	0.09/0.20	0.096/0.098	5.80/08.70	0.5/01.5	4.61	3.96		1.42/3.98	4.26/07.11	2.14/4.26	1.420/2.84
Marble		0.097/0.103	7.25/10.30	0.5/01.0	3.08	3.08		1.14/2.14	4.26/12.80	1.42/4.26	1.420/4.26
Sandstone	0.06/0.17	0.080/0.094	1.89/02.32	5.0/20.0	-	-		0.71/2.14	1.42/04.26	0.71/2.14	0.356/1.78
Limestone	0.12/0.25	0.083/0.098	3.34/03.92	3.0/15.0	*3.08 at 167° F	*2.86 at 86° F		0.57/2.00	4.26/08.54	1.42/2.84	1.070/1.78
Slate		0.098/0.101	8.70/13.10	-				0.995	35.6	2.14/3.56	-

μ = Poisson's Ratio

ρ = Density, lb/in.^{3}

E = Young's modulus of elasticity, lb/in.^{2}

P = Porosity percent pore space

K = Compressibility $\frac{1}{v}\frac{dv}{dp}$, lb^{-1}

A = Abrasion resistance

σ_c = Compressive strength, lb/in.^{2}

σ_t = Tensile strength, lb/in.^{2}

τ = Shear strength, lb/in.^{2}

M_R = Modulus of rupture, lb/in.^{2}

G = $\frac{E}{2(1+\mu)}$ = Shear modulus

P = Pressure, lb/in.^{2}

P_1 = 28,400 lb/in.^{2}

P_2 = 142,200 lb/in.^{2}

* for $0 < p < 170,000$ lb/in.^{2}

TABLE 4.5-IV

TYPICAL PROPERTIES OF MANUFACTURED STONE

Material	Density (lb/in.^{3})	H_2O (%) Absorption	σ_c (lb/in.^{2})	M_R (lb/in.^{2})	τ (lb/in.^{2})
*Hard Brick	0.686/0.759	5/12	2490/4000	398/796	-
*Medium Brick	0.686/0.759	12/20	1490/2500	299/398	-
*Soft Brick	0.686/0.759	>20	796/1490	199/299	-
±Concrete	0.869	-	5200	700	1500

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* Ref. 17

* True Specific Gravity 2.4/2.6

± Ref. ( )

Material	Density (lb/in.^{3})	μ	E (lb/in.^{2})	σ_c (lb/in.^{2})	σ_t (lb/in.^{2})
Pyrex	0.0813	0.21	10.2×10^6	18,000	9,860
Borate	0.0810 and 0.130	0.27 and 0.32	6.7×10^6 and 11.6×10^6	11,600	8,260
Phosphate	0.094 and 0.112	0.24 and 0.27	9.6×10^6 and 9.0×10^6	10,150 and 10,700	8,000 and 10,900

(Ref. ( )

penetrate the surface with a probe. Four idealized soil models are shown in Figure 4.5-7. The left column of figures show the stress strain curves and the right column shows the limiting condition of stress at failure, using O. Mohr's representation. Type A is representative of a solid homogeneous rock which fails in a brittle manner without yielding or plastic deformation.

Type B is representative of a plastic soil as wet clay which will deform continuously under load after the yield stress is reached.

Type C is a more realistic model of an actual soil which deforms elastically; the yield stress is exceeded and then deforms continuously under load at some lower stress.

Type D is typical of loose sand or granular material which has no tensile or cohesive strength.

Two sets of constants are assumed to represent the Type A models for a hard and soft rock. These were selected as qualitative upper limits for several classes of terrestrial rock. Upper limits are used rather than average values to provide pessimistic rather than optimistic conditions to be encountered by the sample collection and processing equipment. These constants are tabulated in Table 4.5-V and were derived from the data in Tables 4.5-III and 4.5-IV. Some values for the ratio of compressive strength to tensile strength are tabulated in Table 4.5-VI. Except for slate, it is seen that the compressive strength is typically 20 to 50 times the tensile strength. Here, a ratio of approximately 30 to 1 was used to establish the tensile strength for the models.

The constants given in Table 4.5-VII for the remaining soil models are based on estimates derived from typical values for terrestrial soils. Type B is an ideally plastic soil which does not truly exist, but can be used to describe the action on some saturated days. This type of soil is not expected on a large scale on Mars because of the predicted low percentage of free water. It might, however, be encountered in a microenvironment and is, therefore, included. This soil model will be used as a test for reliability for the various aspects of sample collecting rather than parametrically studied.

The remaining soil models are the most plausible other than Type A for solid rock. Type C has been subdivided into two classes just as Type A was. Type C-1 is a cohesive soil with a high degree of compaction and high value for the cohesive constant. This type of soil is felt to be analogous to a wind deposited "Loess" soil which has been cemented to some degree. Type C-2 is a loosely compacted cohesive soil with a lower value for the cohesive constant. This soil model is also primarily intended as a test for reliability and performance where low strength can cause performance degradation. Type D soil is a loosely compacted soil

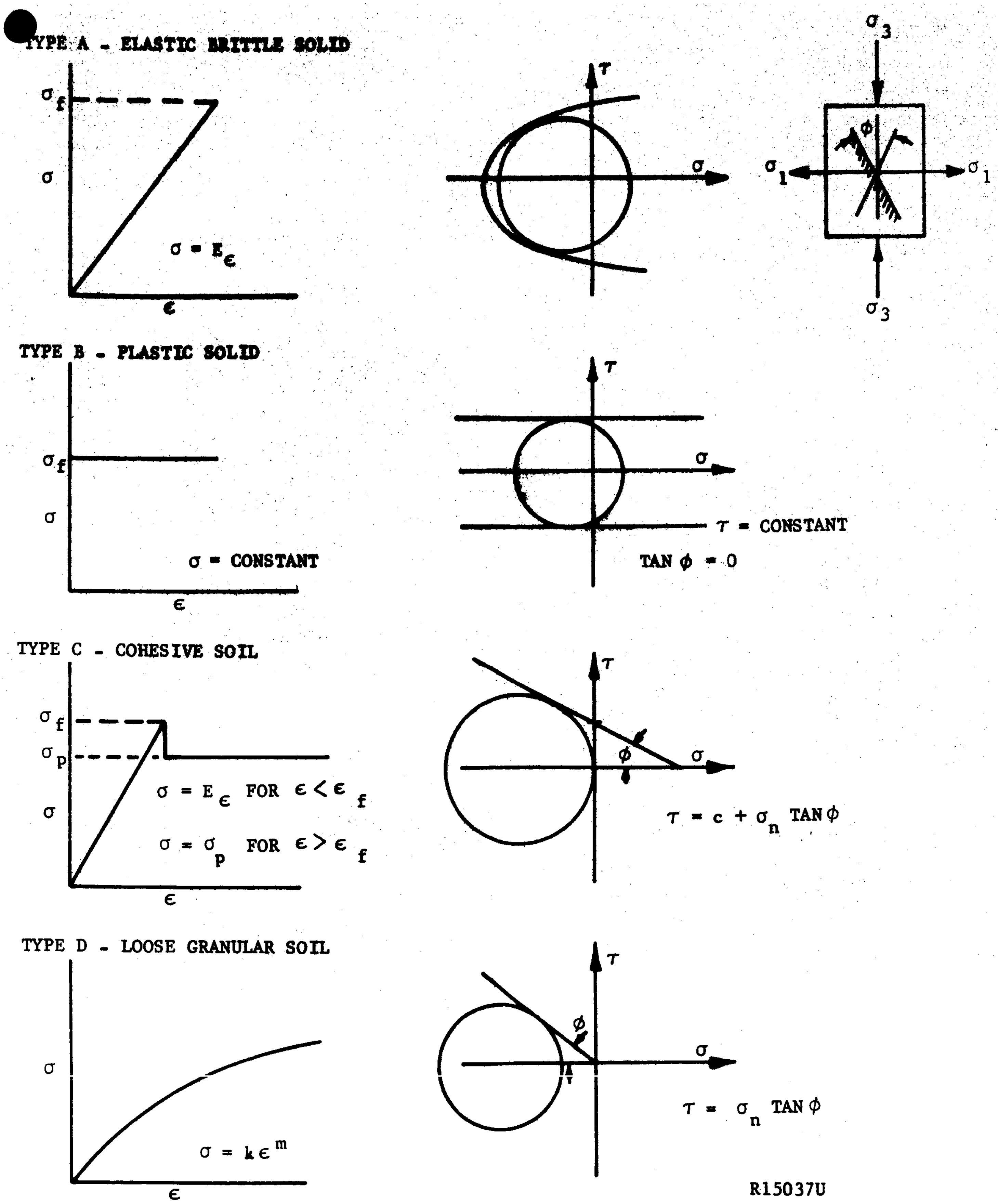

FIGURE 4.5-7 IDEALIZED SOIL MODELS

TABLE 4.5-V

ELASTIC ROCK MODELS FOR MARS

Material	μ	ρ	E	P	σ_c	σ_t	τ
Hard A1	0.25	2.6	8×10^6	1	30,000	1000	3000
Soft A2	0.15	2.6	3×10^6	10	10,000	300	1500

μ = Poisson's ratio

ρ = Density, specific gravity

E = Young's modulus of elasticity, lb/in.^{2}

P = Porosity percent pore space

$G = \frac{E}{2(1+\mu)}$ shear modulus

σ_c = Compressive strength

σ_t = Tensile strength

τ = Shear strength

TABLE 4.5-VI

RATIO OF COMPRESSIVE STRENGTH TO TENSILE STRENGTH FOR TYPICAL ROCKS

Granite	33.3 to 56.0
Marble	26.8 to 16.7
Sandstone	50.0 to 50.2
Limestone	13.4 to 23.4
Slate	2.72

TABLE 4.5-VII

SOIL MODELS FOR MARS

Material		μ	ρ	E_c	P	C	ϕ
Plastic	B	0.50	2.6	600	25	10	0
Cohesive	C-1	0.10	2.6	30,000	25	25	30°
Cohesive	C-2	0.05	2.6	10,000	50	1	30°
Cohesionless	D	0.00	2.6	3000	50	0	30°

μ = Poisson's ratio

ρ = Density, specific gravity of base grains

E_c = Compression modulus, $lb/in.^2$

P = Porosity percent pore space

C = Cohesive constant, $lb/in.^2$

ϕ = Internal friction angle

which is typically found in the deserts on Earth. This soil model should represent a surface condition on Mars which is highly probable. Where such soil occurs it is also likely to extend over fairly large areas. The value of internal friction angle of $\phi = 30^\circ$, selected for types C and D soil models, is based on that which most commonly appears in Earth soils. While values may be either larger or smaller than 30°, it is felt that a single value for use in the parametric evaluation will simplify the analysis and at the same time provide a good basis for comparison. The values of porosity chosen represent the theoretical upper and lower limits for spherical particles of a uniform size. For types C and D soils, the load/deflection relationship is given by Bekker as:

$$p = (\frac{K_c}{b} + K_\phi)\ z^n$$

where

p = pressure

z = deflection

K_c = cohesive deformation modulus

K_ϕ = internal friction deformation

b = width of loading area

n = exponent, usually equal to 1/2

This equation was developed by him in an effort to determine true constants or moduli that were independent of both the size and shape of the loaded area. A simpler form of this equation is given by $p = k\ z^n$. Although this does not yield a truly independent value of k when used for cohesive soils, it is the same as Bekker's equation when K_c is zero, which is the case for loose sand.

In estimating the cohesive constants for soil models C-1 and C-2, Jumikis in Reference (5) gives a range of values between 0.01 ton/ft^2 to 0.12 ton/ft^2 for the cohesive constant and occasional values as high as 1.75 ton/ft^2. The upper value was used in model C-1 while the mean value for the lower range was used to establish model C-2. The same reference gives values for the compressive modulus, E_c, as shown in Table 4.5-VIII. The value of compressive modulus for soils is defined in the slope of the load/deflection curve, $E_c = dp/dz$. In most soils this value is determined in initial compaction by the collapse of the void volume. In selecting the value of compression modulus for the soil models, a bias toward the upper limit as given in Table 4.5-VIII was used in order to be conservative.

TABLE 4.5-VIII

TYPICAL VALUES OF COMPRESSIVE MODULUS
FOR TERRESTRIAL SOILS

Soil Type	Compressive Modulus (Kg/cm²)	(lbs/in.²)
Peat	1 - 5	-
Clay, Plastic	5 - 40	71 - 570
Clay, Stiff	40 - 80	570 - 1,140
Clay, Medium Hard	80 - 150	1,140 - 2,130
Sand, Loose	100 - 200	1,420 - 2,840
Sand, Dense	500 - 800	7,100 - 11,400
Gravel, Sandy Gravel, Dense	1,000 - 2,000	14,200 - 28,400
Rock, Fissured and Jointed	15,000 - 30,000	21,300 - 426,000
Rock, Sound	30,000	426,000

d. Definition of Study Models. The soil models in this study were defined to provide the basis for the preliminary design of components in the ABL. The primary areas of interest are listed as follows:

- The hard rock models A-1 and A-2 are used to evaluate core drill requirements and in some cases anchor penetration feasibility.

- The plastic clay model B was not used in this study. It is included only to present a complete set of models and serve as a basis for qualitatively evaluating the effect of this type soil on the operation of the equipment.

- The cohesive soil models C-1 and C-2 are used to evaluate probe penetration and surface soil sampling power requirements as well as to define pulverization concepts.

- The loose sand model D is used to determine sample size and volumes and to evaluate the influence of a weak soil on equipment that must also operate in the stronger cohesive soils. This model is also pertinent to surface locomotion studies.

4.5.4 ELEMENTS OF SOIL SAMPLING SYSTEM

a. Experimental Sample Requirements. Before proceeding with parametric analyses of sampling equipment, an attempt was made to estimate the approximate gross amount of soil sample required. The size of the soil sample to be collected is determined by the following:

- The sensitivity of the particular experiment to the substance to be detected.
- The concentration of that substance in the soil sample.
- The type of soil collected in terms of particle size distribution and porosity.
- The losses due to mechanical grading of the soil sample as required to perform the experiment.

Table 4.5-IX gives a list of biological experiments for ABL and their associated minimum sensitivities in terms of organisms required to produce a detectable result using standard laboratory procedures. The experiments listed are only those which require soil extractions as would be performed by a wet chemical processing chamber. The solvent used in the extraction is also indicated. The sensitivities range from 5 x 10^4 for macromolecule detection using the dye-complex technique to 3 x 10^9 for detection of porphyrins.

One big proviso must be placed upon the use of the sensitivities reported in Table 4.5-IX for determining how much soil must be extracted. These sensitivities were calculated under the assumption that the substance being sought exists in cells only and does not accumulate in the soil apart from cells due to death or metabolic by-products of cells. Contrary to this, in many cases the substance being sought may be built up in soil.

Without a knowledge of Martian soil chemistry, it is very difficult to predict the chances for survival of organic compounds (absence of degradative chemical breakdown). However, in view of the low oxygen partial pressure and the very low humidity, compounds which on Earth are easily oxidized or hydrolyzed might be expected to survive in Martian soil.

Table 4.5-X presents data on the concentrations of micro-organisms in various soils (data taken from H. Weetall, N. Weliky, and S. Vango, JPL Space Programs Summary No. 37-28, Volume IV, pages 115-120). The numbers given are total for aerobes, facultative anaerobes, and anaerobes.

TABLE 4.5-IX

EXPERIMENTAL SENSITIVITIES

Experiment	No. Cells Required	Extraction Solvent	Amount of Sample (grams)
Detection of porphyrins by fluorometry	4×10^7	4:1 ethylacetate-acetic acid	40
Macromolecule detection by UV spectrophotometry	10^6	0.5 N sodium hydroxide	1
Macromolecule detection by visible spectrophotometry	5×10^{-5}	0.5 N sodium hydroxide	0.5
Detection of nonsaponifiable lipids	5.2×10^7	ether-acetone	52
Detection of saponifiable lipids	10^6	ether-acetone	1
Detection of amino acids	1.6×10^5	water	0.16
Detection of flavins	2.5×10^6	water	2.5
Analysis for optical activity	10^7	water or neutral buffer	10

TABLE 4.5-X

TYPICAL SOIL MICRO-ORGANISM CONCENTRATIONS

Soil	Organisms (g)
Common Garden	$> 10^9$
Colorado desert	$\sim 5 \times 10^5$
Lake Mead	$\sim 10^6$

Figure 4.5-8 shows a plot of soil sample quantity versus technique sensitivity for garden type (10^9 organisms per gram) and desert type (10^6 organisms per gram) soils. The data given in the last column of Table 4.5-IX are derived from this figure or from the equation for the case of desert soil.

$$\text{Amount} = \frac{\text{technique sensitivity}}{\text{organisms per gram}}$$

The weights specified are presumably from gross soil samples, i.e., samples that have not been refined by particle size separation schemes such as sieving or vortex-centrifuging. If it can be shown that concentration of biological material in a dry soil sample is possible by various mechanical means (for example, the Litton study results),(7) then the weight of the refined sample may be reduced. It is clear from the figure and Table 4.5-I that in the absence of accumulation of substances in the soil and the above mentioned dry concentration techniques, all but three of the experiments require a minimum of one gram of soil sample if Martian organisms have a population density comparable to terrestrial desert soils. However, in extreme cases, for example, detection of porphyrins, large sample quantities exceeding 10 grams are indicated. Clearly, the treatment of large samples is to be avoided. An approach which could be taken is to perform the initial porphyrin detection experiment on a reasonable sized sample, say 10 grams, hoping that porphyrins are more abundant than the above prediction. If a negative result is obtained, then the options available are as follows:

(1) Sacrifice the ability to analyze additional individual 10 gram samples and instead extract one very large sample perhaps in batches with recovery of solvent from a batch to use in extracting a subsequent batch.

(2) Select a more propitious sampling site on basis of other experimental results and again try to detect porphyrins in a 10 gram sample.

(3) Eliminate repetition of the experiment in favor of a more promising one.

The choice between these alternatives can be made at the time of the mission by the experimenter, himself. This flexibility of programs is one of the advantages of the integrated laboratory concepts.

Most of the experimental procedures detailed in Appendix 5 call for soil samples which have been graded and refined to particle sizes of 300 microns or that which will pass through a 40 mesh screen. Using the soil particle distributions given in Figure 4.5-8, the amount of usable soil sample that

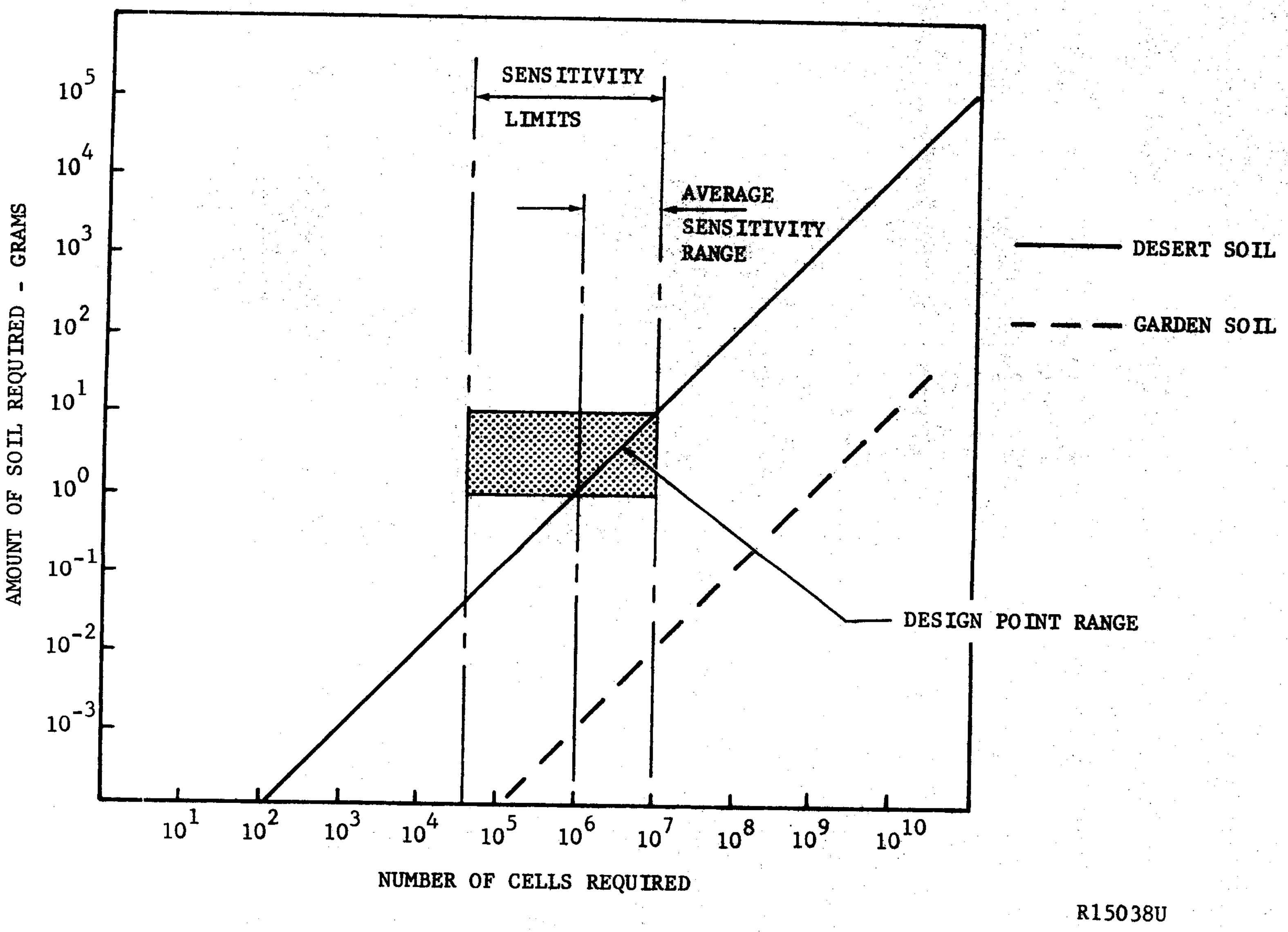

FIGURE 4.5-8 SOIL SAMPLE QUANTITY AS A FUNCTION OF TECHNIQUE SENSITIVITY

can be expected to be retrieved from a given amount of raw sample as percentage by weight is given in Table 4.5-XI.

TABLE 4.5-XI

PERCENTAGE DISTRIBUTION BY WEIGHT FOR MARS SOIL MODELS

Soil Model	Fine Sample $d < 50\,\mu$	Normal Sample $50\,\mu < d < 300\,\mu$	Residue $d > 300\,\mu$
Soil C	42%	44%	14%
Soil D	0.3%	17%	83%

In view of the fact that soil D is expected to have a high probability of occurrence on Mars, this model will size the sampling equipment. Using the percentages given in Table 4.5-XI, the ratio by parts is 1 gram of particles 50 μ or less, 57 grams for particles between 50 μ and 300 μ, and a residue of 277 grams from a total collected weight of 335 grams. The soil sample requirements to complete one experimental cycle of experiments as defined for this study are given in Table 4.5-XII.

TABLE 4.5-XII

SOIL SAMPLE REQUIREMENTS

Experiment No.	Sample Size $d < 300$ (gm)	Ungraded (gm)
12	-	1,000
13	1	-
15	-	2
16	-	5
18	1	-
19	2	-
20	10	-
21	1	-
22, 23	10	-
24, 25, 26	5	-
28	5	-
29	6	-
30	4	-
31	4	-
32	6	-
33	-	1,000
Total	55	2,007

Thus a total soil sample per experimental cycle that must be collected is

$$\frac{57}{335} = \frac{55}{X} \quad \text{and} \quad X = \frac{(55)(335)}{57} = 324 \text{ grams.}$$

To estimate the total soil sample requirements for the life cycle of the ABL, the following assumptions are made:

(1) Samples will be collected to a depth of 20 cm in 5 cm intervals. Thus, five sample batches per site are required including a special surface sample.

(2) Soil particle size distribution does not vary in this depth.

(3) Maximum soil porosity is 50 percent and a specific gravity of 2.6 for the particle density is used.

For purposes of identifying samples, the following identification sequence is defined. The sample site location is given in polar coordinates from the laboratory site giving the radial distance to the site and the angular displacement from a reference vector. This reference may be oriented to a specific geometry in relation to Mars or may be arbitrarily defined with respect to the laboratory. The total sample identification number consists of the following parts:

(1) Date of acquisition, months after landing

(2) Sample site location, ρ , θ.

(3) Sample batch number *

(4) Batch weight

(5) Experimental aliquot number

(6) Aliquot dash number and verification.

*Sample batch numbers are identified as follows:

Batch No. 1 - Aerosol dust from surface
Batch No. 2 - First 5 cm sample
Batch No. 3 - Second 5 cm sample
Batch No. 4 - Third 5 cm sample
Batch No. 5 - Fourth 5 cm sample
Batch No. 6 - Atmospheric borne particles

For those experiments requiring several samples simultaneously, a dash number is added to the experimental aliquot number to identify it with a particular storage site and chemical processing chamber. A minimum of 3 sample sites per season will yield 12 complete experimental cycles for a two year lifetime. Based on estimates of reagent and supporting supply weights this is probably a limit. It is assumed that the seasonal samples will be taken in approximately the same local area as the initial samples; i.e., at the laboratory landing site and two or three remote sites. The core drill sample is assumed to be taken only once at the laboratory site to a depth of 3 meters. The total soil samples collected to support the experimental schedule is summarized in Table 4.5-XIII.

TABLE 4.5-XIII

TOTAL SOIL SAMPLES

Batch No. 1 - Aerosol dust (70 gm) (4) (3)	=	840 grams
Batch No. 2, No. 3, No. 4, No. 5, (324) (4) (4) (3)	=	15,500 grams
Atmospheric dust (unknown)	=	1 gram
Preserved samples (1000) (3) (4)	=	12,000 grams
Core drill 2 cm dia x 300 cm	=	2,500 grams

The size of the preserved sample was somewhat arbitrarily set at 1 kilogram. This is very nearly the amount of raw sample required to serve the experiments with 4 surface soil batches. This sample is taken simultaneously with the experimental samples to the same depth. The criteria that the sample retain its identity as a function of depth below the surface was employed. Thus, all the experiments could be repeated with the preserved samples at a later date in a manned laboratory, if desired.

The soil requirements for Experiment 33 arise primarily from the preparation of a Martian soil extract growth media. This amount was estimated in terms of what would be required to prepare such an extract from terrestrial desert soil with an estimated organic carbon content of 0.1 percent. Of this, an estimated 50 percent can be extracted from the soil. A half-gram of extracted organic carbon is estimated as a reasonable quantity from which to prepare a growth media. Thus, the total amount of desert soil that must be processed is

(0.001) (0.5)W = 0.5 gram and W = 1000 gram or 1 kg.

To perform an extraction on this amount of soil, an estimated 5 kilogram of water or solvent is required. Thus, the estimate of 1 kilogram to prepare a growth media represents a lower limit which should not be reduced without a more detailed analysis.

b. Sampling Procedure. The sampling procedure is divided into three major phases. These are sample site selection, sample collection, and sample grading and refining. Each of these phases can be subdivided into procedural steps requiring command and control. A block diagram of a comprehensive sampling procedure is shown in Figure 4.5-9. Those features of this system retained in the design point used for the preliminary design are indicated in the heavy blocks.

Any level of sophistication can be employed in each phase of the sampling system. For example, samples can be obtained blindly and at random in order to eliminate earth based decisions and the requirement for a visual scan to select a desirable site. They may also be collected only at the laboratory site. In the same manner, collection methods can be as simple as collecting an indeterminant amount of surface soil or dust by scrapers, suction, or adhesion. This in turn could eliminate the need for the entire grading and refining portion of the system. The appropriate level of complexity and sophistication is determined by the complexity and quantitative analytical requirements of the subsequent experimental processing as well as the number of repetitive cycles required to achieve a statistically reliable set of data. In an integrated laboratory a common sample collection system will inherently demand a more versatile and complex sampling system but may fall back to less sophisticated modes of operation when failures or partial failures occur. For these reasons the design point ABL uses a sampling system which may obtain samples at the laboratory site and preselected remote sites. The remote site deployment system does not preclude a blind mode of random operation. The sample collectors have the ability to assess the surface condition but car still attempt a successful soil sample collection should this discriminating ability be lost. In a similar manner the grading and refining system may be bypassed by virtue of the variety of samples collected. For example, the aerosol dust sample is automatically graded by the nature of the collection system used. All these less sophisticated or alternate modes of sampling operations are not utilized without some loss in the ultimate reliability of the experimental analyses.

c. Design Point Sampling Requirements. The sample requirements set forth in Tables 4.2.4-IV and 4.2.4-V were used to establish the design point configurations for the preliminary design. The design point sampling requirements are listed as follows.

(1) Collection of Atmospheric Samples. This requirement is to collect an atmospheric sample, which consists of gases from which particulate matter

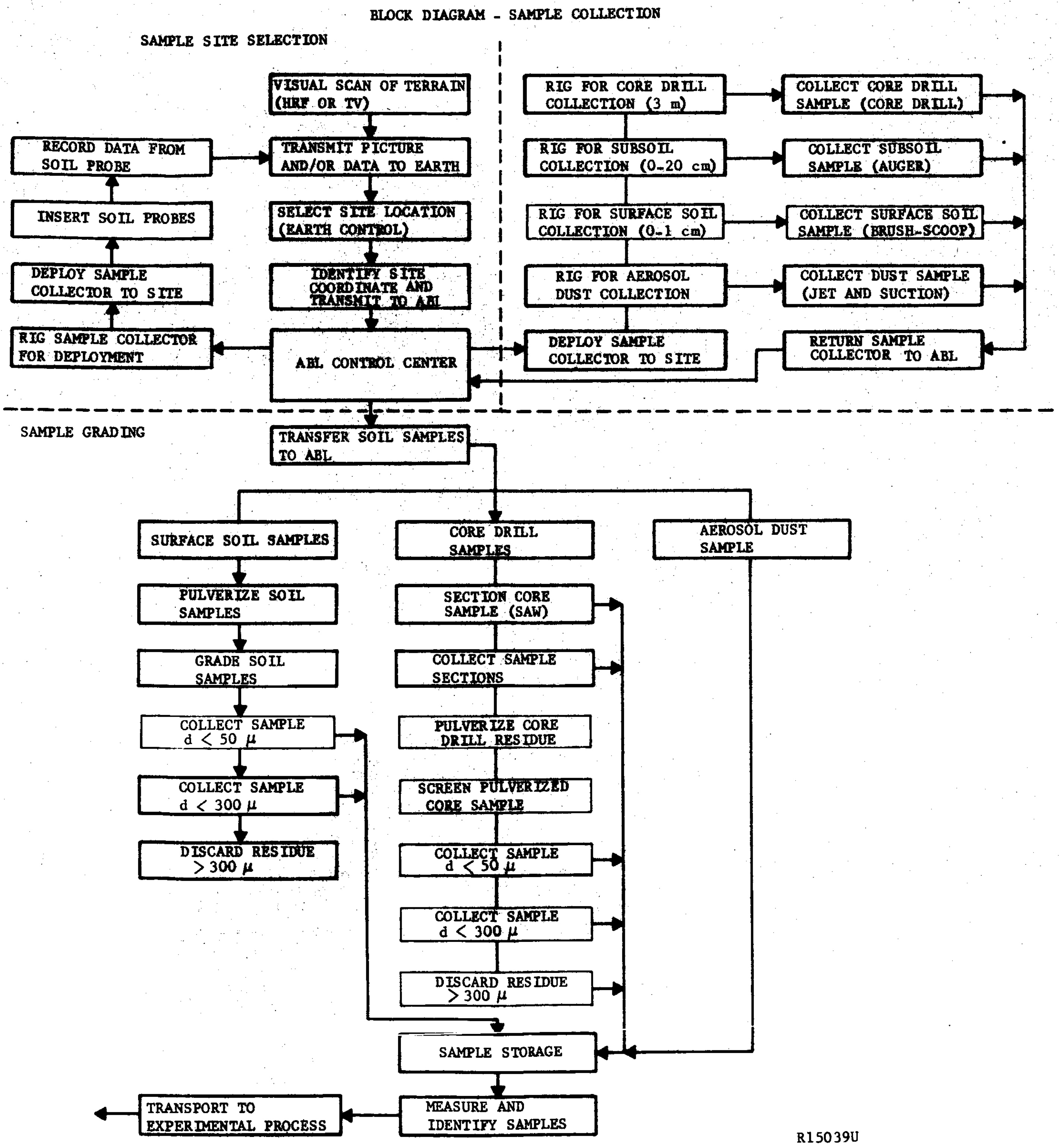

FIGURE 4.5-9. BLOCK DIAGRAM - SAMPLE COLLECTION

has been removed, for atmospheric constituent analysis. The particulate matter collected may be used for selected life detection experiments or the culture media evaluation dependent on the quantity collected.

Range of Parameters:

Amount of gaseous sample	10 mℓ at 15 psia
Amount of particulate sample	1 gram minimum

Sampling rate - approximately continuous for airborne dust; 6 times per season for gaseous sample.

(2) Collection of Aerosol Dust Sample. To collect a graded sample (d $\leq$ 300) of the surface soil to a depth of 1 centimeter.

Range of Parameters:

Particle size collected	d $\leq$ 300
Weight of sample collected	70 grams
Sampling rate	3 sites per season

(3) Collection of Soil Samples as a Function of Depth. Soil samples will be collected in discrete quantities starting at the surface and at finite intervals below the surface. Sample batches will be 7 centimeters in diameter by 5 centimeters long taken to a depth of 20 centimeters, producing a total of four batches.

Range of Parameters:

Weight of soil collected per batch	$\leq$0.3 kgm
Depth of penetration	0 to 20 cm
Sampling rate	3 sites per season

(4) Collection of Soil Sample for Preservation. This is a requirement to provide a specimen from each sample site to preserve for future reference as defined in Experiment 9.

Range of Parameters:

Size of sample	7 cm diameter by 20 cm long
Weight approximately	1 kilogram
Sampling rate	3 sites per season

(5) Collection of Core Drill Sample. To collect a core sample (2 cm diameter by 3 meters long) to extend the results of Experiments 8 and 13 to a depth greater than 100 centimeters.

Range of Parameters:

Size of core	2 cm dia x 3 meters long
Size of core hole	3.5 cm dia x 3 meters deep
Sampling rate	1 site only

(6) Soil Probe and Soil Gas Collector. This is a probe which is inserted to a depth of 1 meter or as far as practicable to make sub-surface measurements outlined in experiment 8 and to collect the gas sample for Experiment 11. This probe does not require a previously drilled hole to insert.

Range of Parameters:

Depth of penetration	$\leq$ 100 cm
Type of soil penetrated	sand or cohesive soil (no rock)

(7) Core Hole Traverse. This requirement is to perform a traverse of a core hole as a function of depth with an instrumented sonde. In the event that the surface soil is composed of loose sand deep enough to preclude a core hole drill, the sonde shall be capable of penetrating the sand to perform the traverse.

Range of Parameters:

Depth traverse in 2 foot increments.

(8) Soil Pulverization. This is required to break down cohesive soil samples to maximize the usable yield from a gross soil sample. It is not intended to grind or crush rock into smaller particles and must be capable of handling plant life or growth without choking.

Range of Parameters:

Processing capacity	0.3 kilogram
Particle size	up to 1 cm diameter

(9) Sample Grading. The pulverized soil sample is graded to produce a fine uniform soil sample for further processing.

Range of Parameters:

Particle size	$\leq$ 300
Quantity processed per cycle	3 kilograms

(10) Sample Division and Identification. This requirement is to provide the correct amount of soil sample and type to each experiment. A measured quantity of soil is weighed into the appropriate receptacle. For chemical processing this is a filter unit and for pyrolysis it is an insert for the oven. It is assumed that a batch is refined and processed experimentally before the next sample batch is refined. Since all sample batches from a single sample site are obtained at the same time, a temporary storage for the unrefined batches is required, preferably sealed and maintained at the collection temperature.

Range of Parameters:

Sample sites	3 per season, 12 total
Sample weights	1 to 10 grams per experiment 1 to 100 grams per batch

(11) Soil Sample Encapsulation and Storage. This provides the means of sealing and storing a soil sample as described in Experiment 9.

Range of Parameters:

Number of samples	3 per season 12 total
Volume of Sample	7 cm dia by 20 cm long

(12) Transport Sampler to Remote Sampling Site. This requirement provides the mechanism for obtaining a soil sample from a site located remotely from the laboratory; i.e., more than 20 feet. The function of transporting the soil sampler to a preselected sampling site and returning it to the laboratory with the soil sample is performed.

Range of Parameters:

Deployment range	0 to 800 feet
Deployment angle	0 to 360 degrees

(13) "In Situ" Sample Isolation. The purpose of this requirement is to isolate a soil sample on the Martian surface without removing it from its initial environment. Isolation of the sample is necessary in order to perform controlled experiments. The equipment used is assumed to be such that a minimum perturbation of the normally existing environment is made.

Range of Parameters:

Sample sites	3 per season

4.5.5 QUALITATIVE EVALUATION OF SAMPLING CONCEPTS

Because of the large variety of techniques available for mechanizing a sampling system, a qualitative evaluation of some postulated approaches to sample collection, sampler deployment and retrieval, and sample grading and refining were made. The intent was to provide a basis for selecting those concepts displaying mechanical simplicity as well as functional suitability for the ABL. The selected concepts were supported with parametric analyses to establish feasibility and verify the initial evaluation.

The concepts defined, the qualitative evaluation, and a qualitative estimate of reliability are presented in Table 4.5-XIV for the sample collection concepts, Table 4.5-XV for deployment concepts, and Table 4.5-XVI for soil grading concepts.

TABLE 4.5-XIV

SOIL COLLECTION TOOLS

Concept	Qualitative Evaluation	Estimated Reliability
1. Aerosol Dust-Pneumatic See Figure 4.5-10	This tool is designed to collect an aerosol dust sample from the surface before it has been disturbed mechanically. The size particles to be collected will be of a diameter $\leq$ 300 microns for a stony particle with a specific gravity of 2.6. This type of sample will provide information on the nature of the surface and should be high in biological material if it occurs at the surface. Can also be used for atmospheric sampling.	High for operation. Moderate for size of sample.
2. Surface Soil-Scraper See Figure 4.5-11	The sample is collected to a depth of 1 cm in the same area that the aerosol dust sample has been taken. The aerosol dust collection can continue simultaneously if desired. This sample provides additional information on the surface condition of the soil and should demand a minimum of power.	High for operation. High for sample size.
3. Subsoil-Plug Core See Figure 4.5-12	This tool is designed to collect a sample by simply inserting a hollow tube into the soil to a depth of 10 cm. Its use would be limited to granular material or weak cohesive soil and would work in a plastic material. Core diameter is probably limited.	High for operation. Moderate for sample size.
4. Subsoil - Modified Auger See Figure 4.5-13	This is an alternative to the plug core collector. It is expected to gather a larger sample under the same soil conditions. It will also retain the samples of loose granular soil or plastic material more reliably.	High for operation. High for sample size.

TABLE 4.5-XIV (Continued)

Concept	Qualitative Evaluation	Estimated Reliability
5. Subsoil - Coring Drill See Figure 4.5-14	This tool is expected to take a small diameter core to greater depths (up to 3 meters) in cemented soils or soft rock. The value of this type of sample is primarily to provide supporting information of the soil composition and soil environment. It will also allow the use of a core hole sonde.	Moderate for operation. High for sample size.

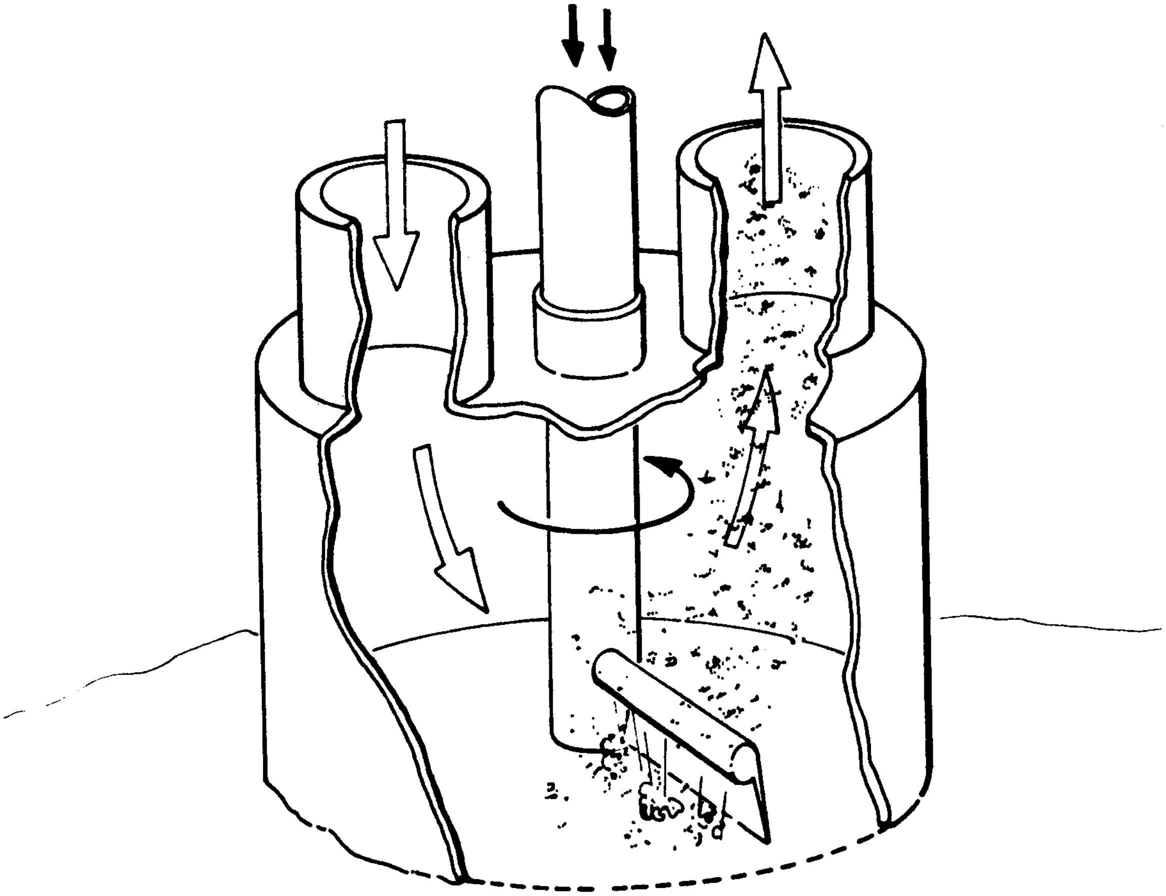

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FIGURE 4.5-10. AEROSOL DUST COLLECTION CONCEPT

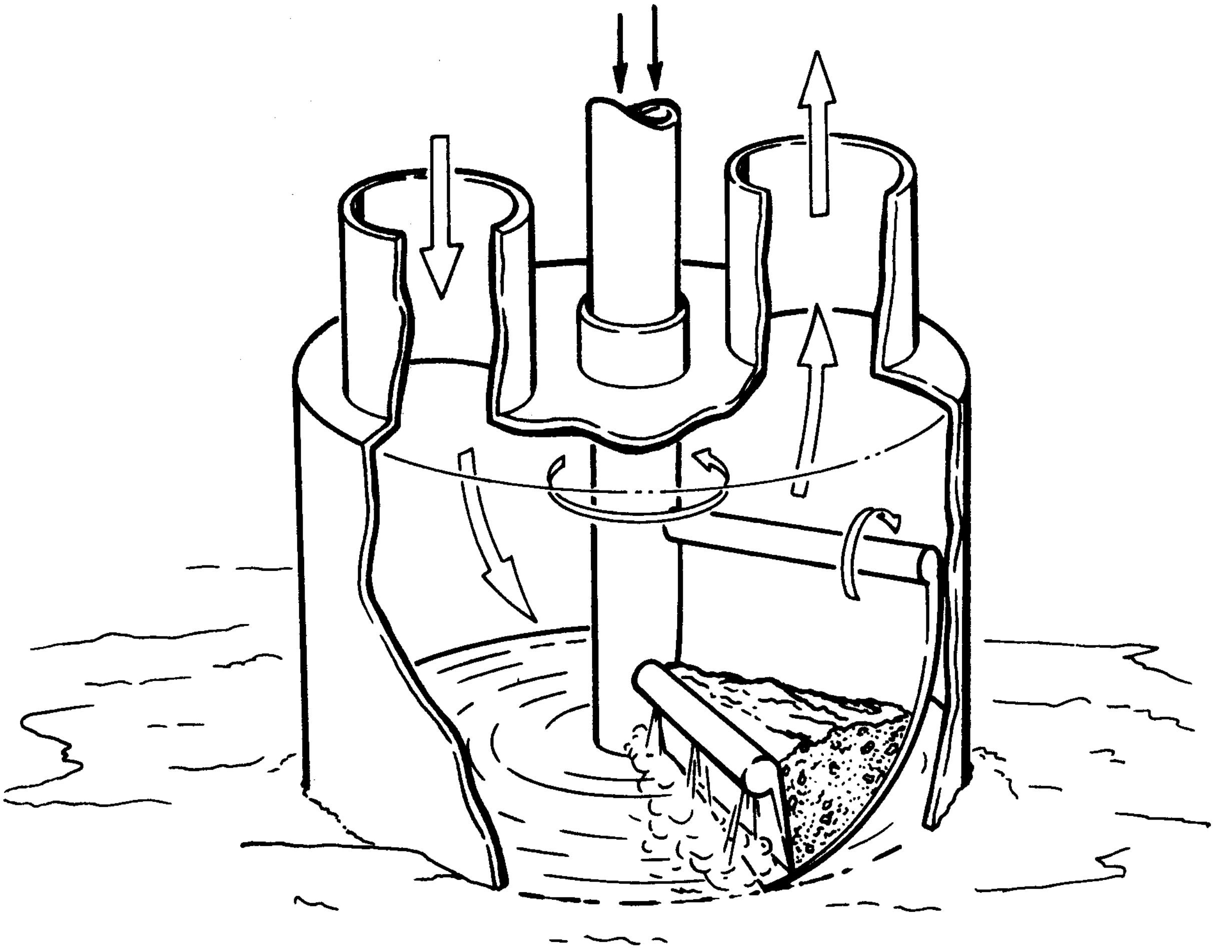

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FIGURE 4.5-11. SURFACE SOIL COLLECTION CONCEPT

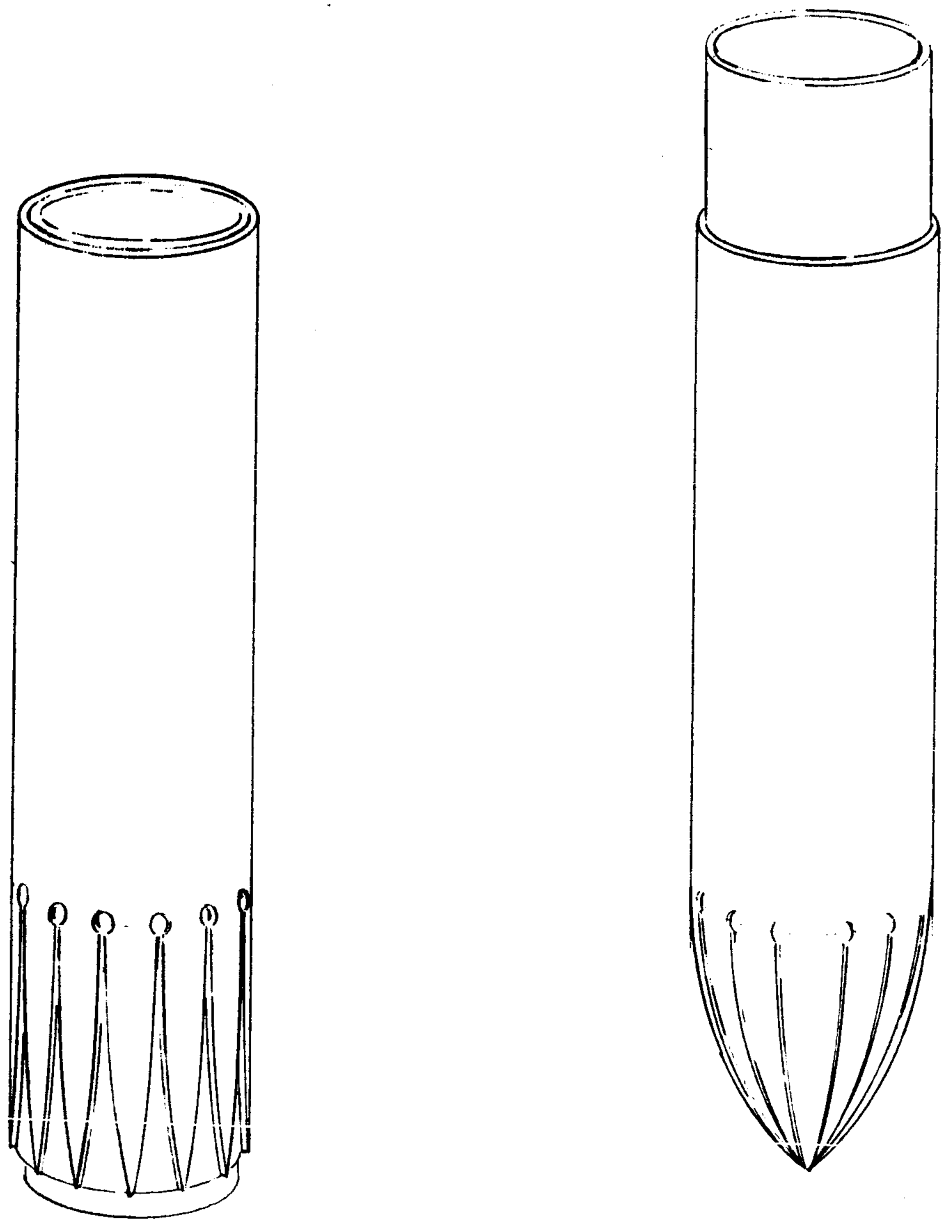

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FIGURE 4.5-12. PLUG SUBSOIL COLLECTOR CONCEPT

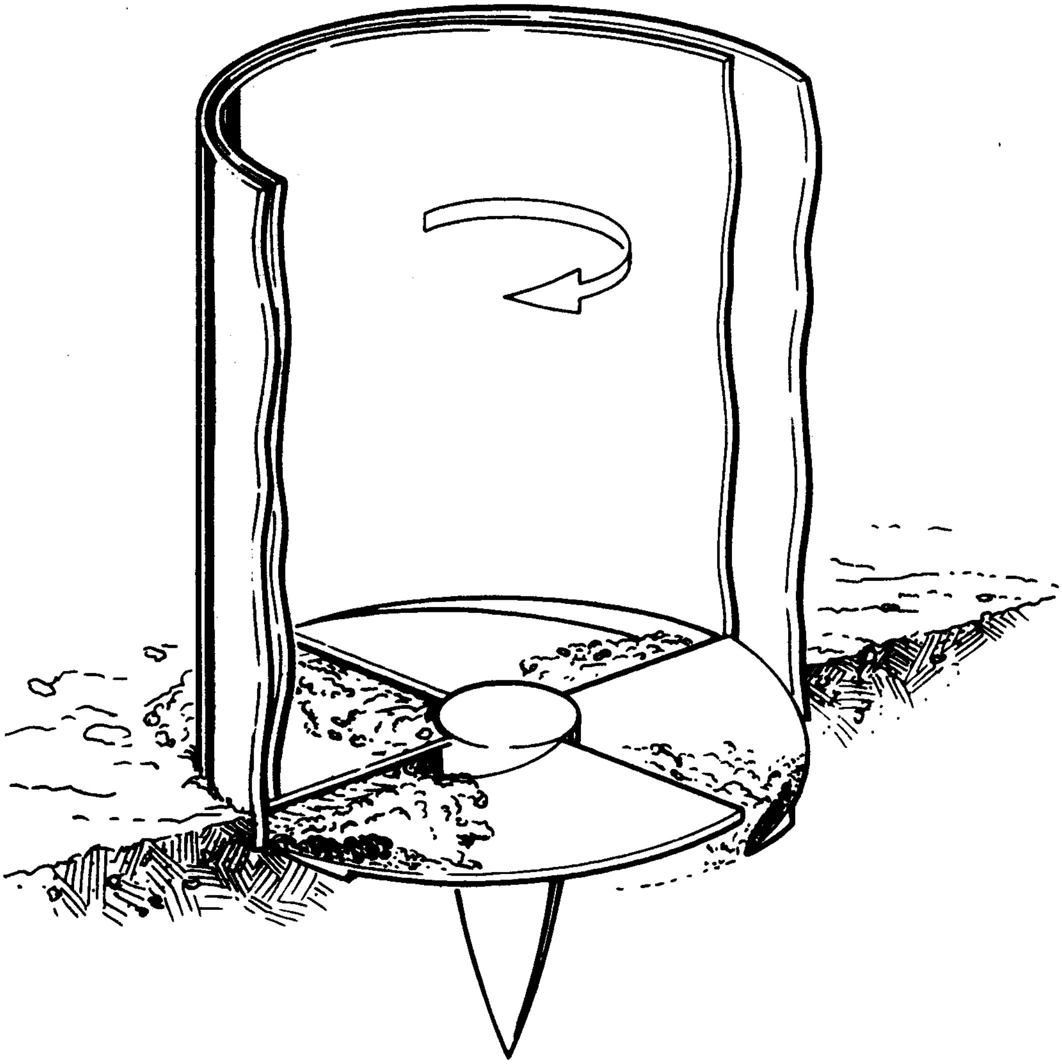

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FIGURE 4.5-13. LOOSE OR WEAK COHESIVE SOIL COLLECTION CONCEPT

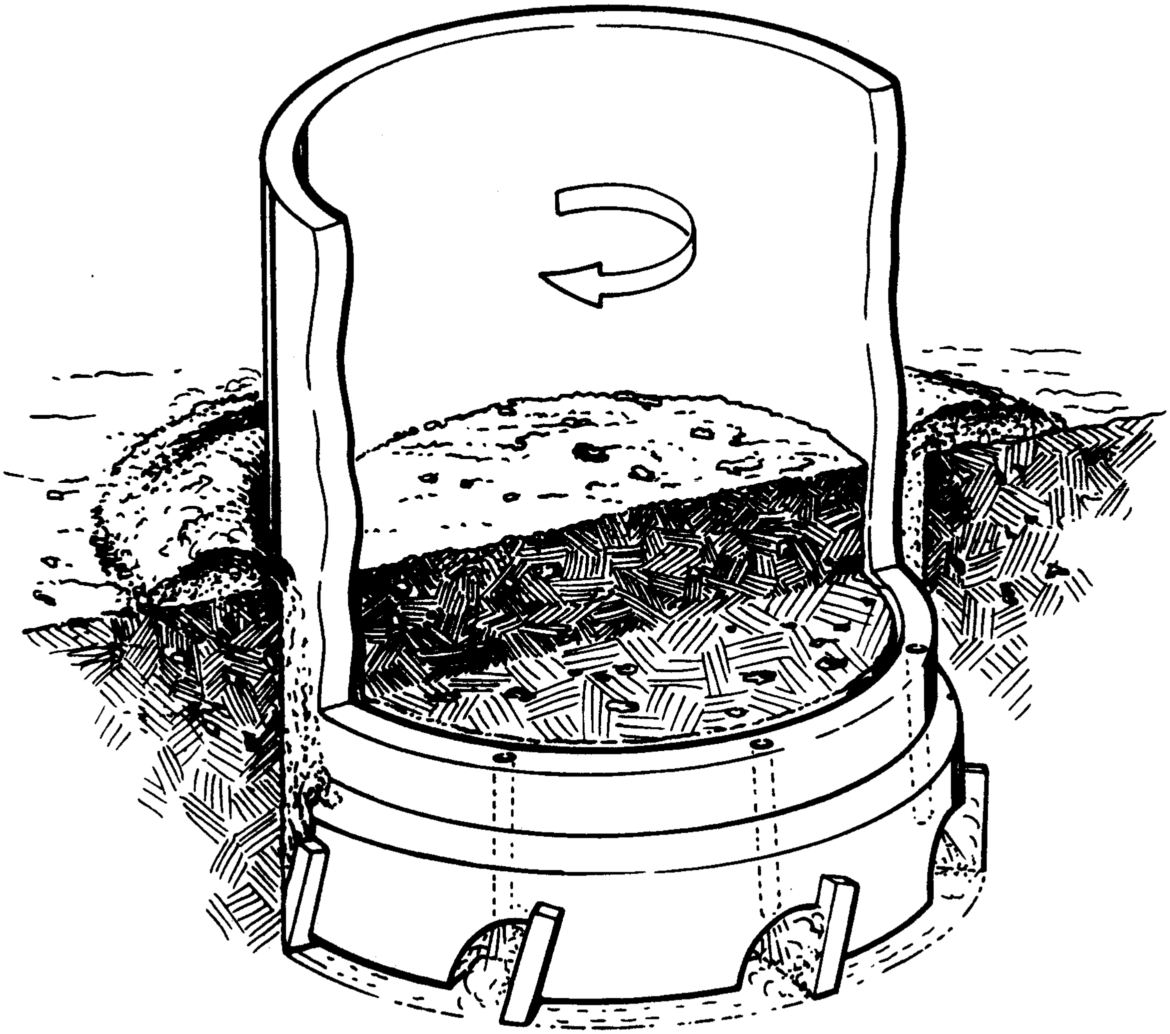

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FIGURE 4.5-14. SUBSOIL CORING TOOL CONCEPT

TABLE 4.5-XV

DEPLOYMENT CONCEPTS

Concept	Qualitative Evaluation	Estimated Reliability
1. Trench Hoe See Figure 4.5-15	This deployment method also combines a collection tool in the form of a shovel. Unless massive samples are collected, the weight of the system for a large reach will tend to be excessive. This deployment method should be confined to a miniature version used as an adjunct to the roving sampler. It will not provide selective sampling and presents a stowage problem.	Moderate for deployment. Moderate for retrieval.
2. Furlable Boom See Figure 4.5-16	For small weights a moderate reach of up to 20 feet should be reasonable. This deployment scheme is envisioned as being used with the aerosol dust and surface scraper tools and possibly the plug core tool. The stowage requirements are less severe than for the trench hoe.	Moderate for deployment. Moderate for retrieval.
3. Drag Line See Figure 4.5-17	In this concept the sample collector tools are deployed ballistically from the ABL. Greater range is available limited only by energy, line length, and tool weight. Deployment is independent of terrain; however, retrieval is not. Sample collection tools will be subjected to high impact loads.	High for deployment. Low for retrieval.

TABLE 4.5-XV (Continued)

Concept	Qualitative Evaluation	Estimated Reliability
4. Guy Wire and Trolley See Figure 4.5-18	This concept utilizes the deployment of a guy wire with an anchor on the end of the line. The sample collector is then deployed on the guy wire to the selected sample site. Thus deployment of both the guy wire and the sampler are independent of the local terrain as is the retrieval of the sampler. High impact loads on the sampler are eliminated. This system can be used either with or without guidance or observation.	Moderate for anchoring wire. High for deployment. High for retrieval.
5. Roving Sampler See Figure 4.5-19	This concept utilizes either a tracked, walking, or wheeled vehicle to give the sampler mobility. Roving range is limited only by energy requirements; however, sophisticated guidance and homing are required as well as complete visual observation of the terrain to be traversed. The possibility exists that even with visual observation, the vehicle may be immobilized by landslides, hidden crevasses, or mechanical failure.	Reliability will be a function of range traversed and type of terrain. It could range from high to low.
6. Roving ABL and/or Multiple Landers	These can be evaluated realistically only after the ABL has been more fully defined in terms of size, weight, and sensitivity.	Unknown

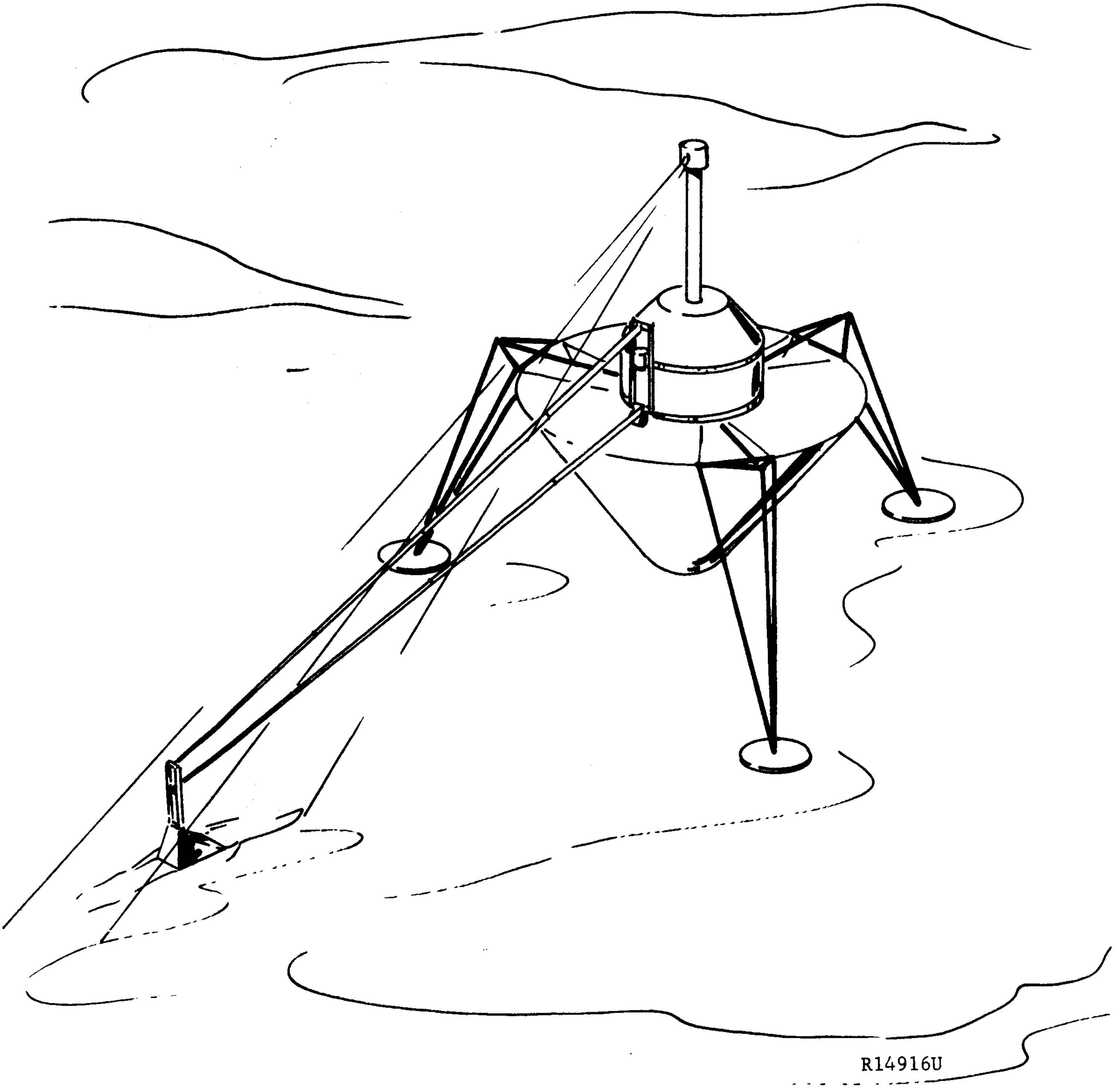

FIGURE 4.5-15. TRENCH HOE SOIL SAMPLER DEPLOYMENT CONCEPT

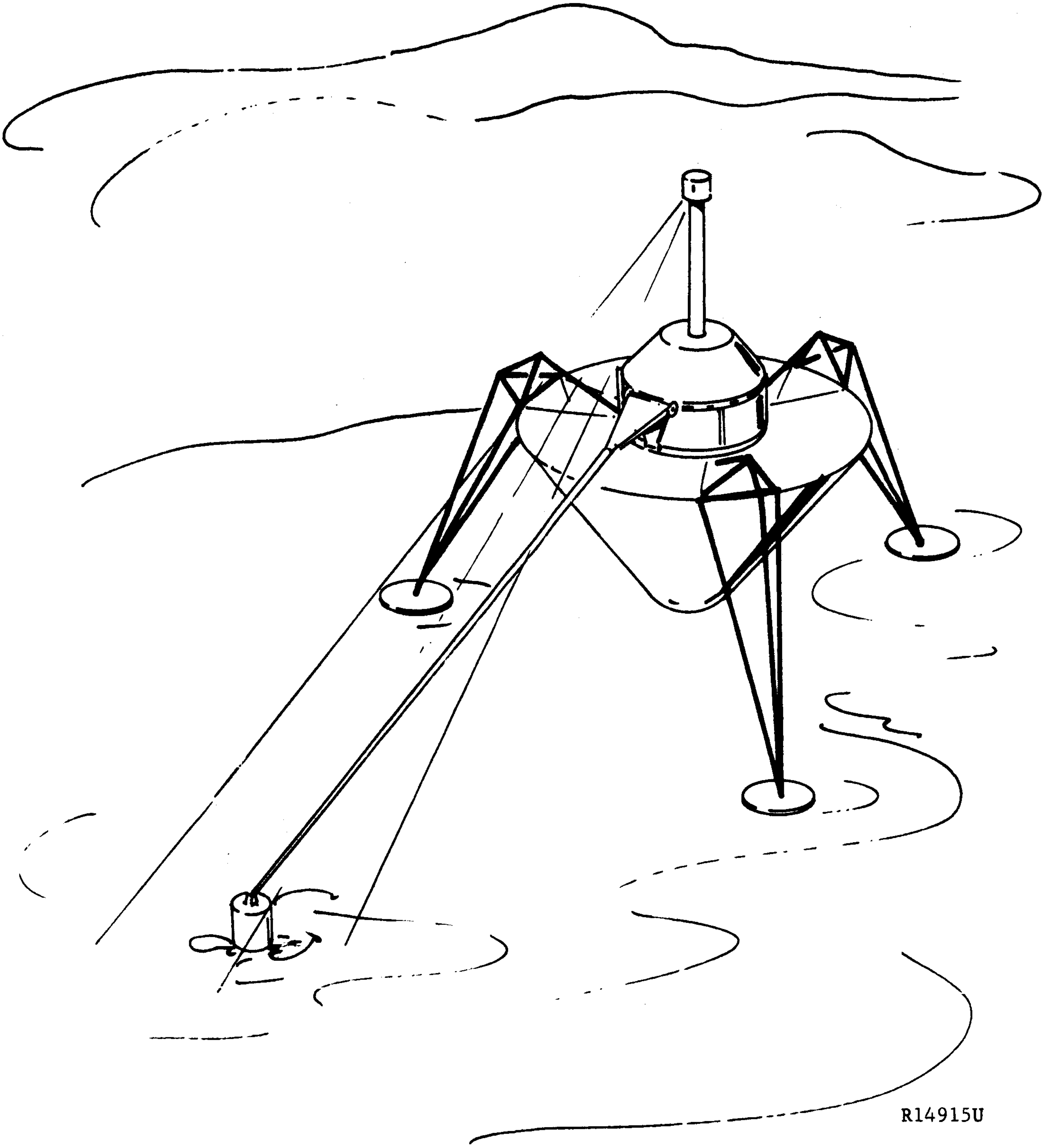

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FIGURE 4.5-16. FURLABLE BOOM SOIL SAMPLER CONCEPT

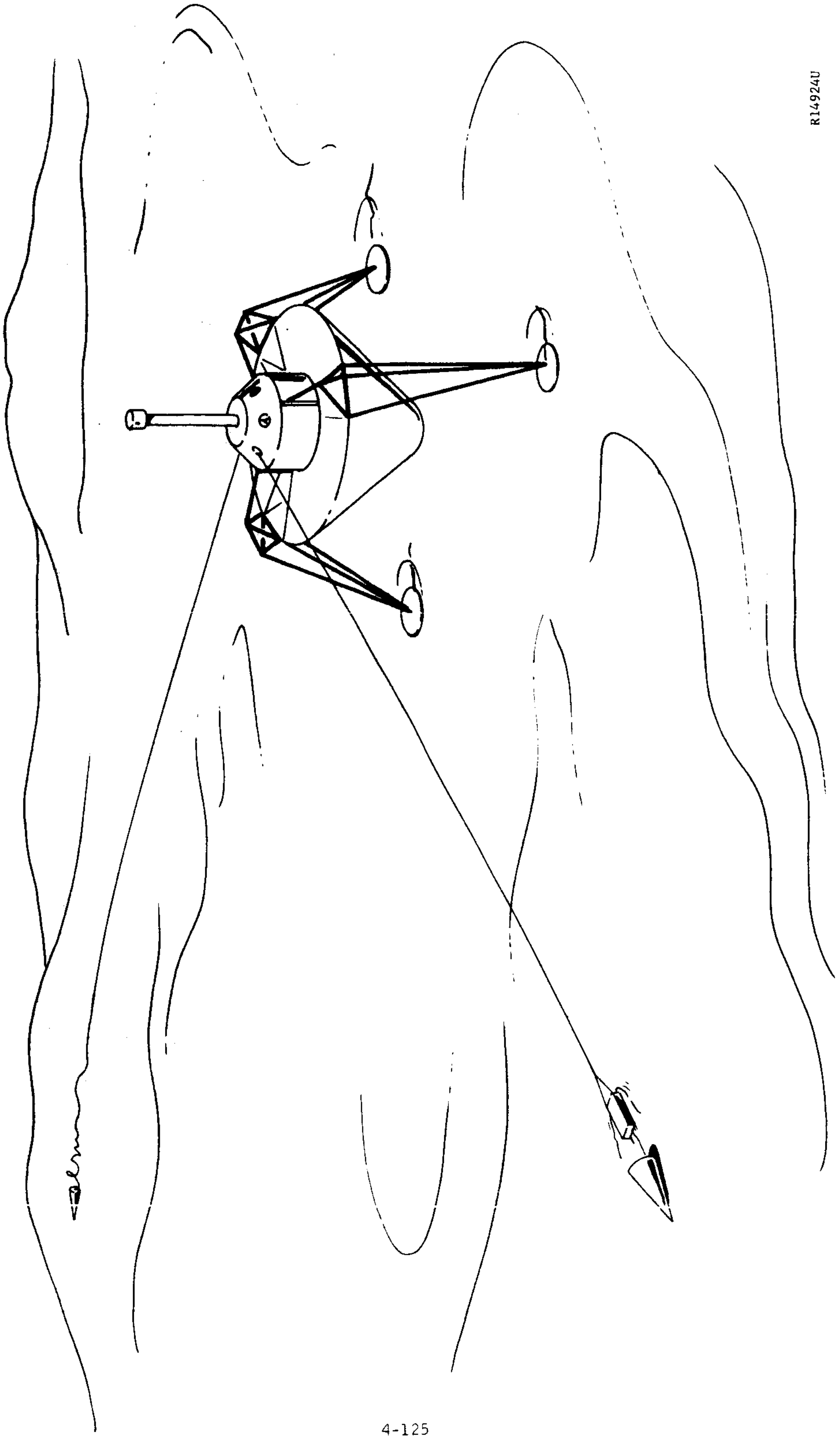

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FIGURE 4.5-17. DRAG LINE SOIL SAMPLER DEPLOYMENT CONCEPT

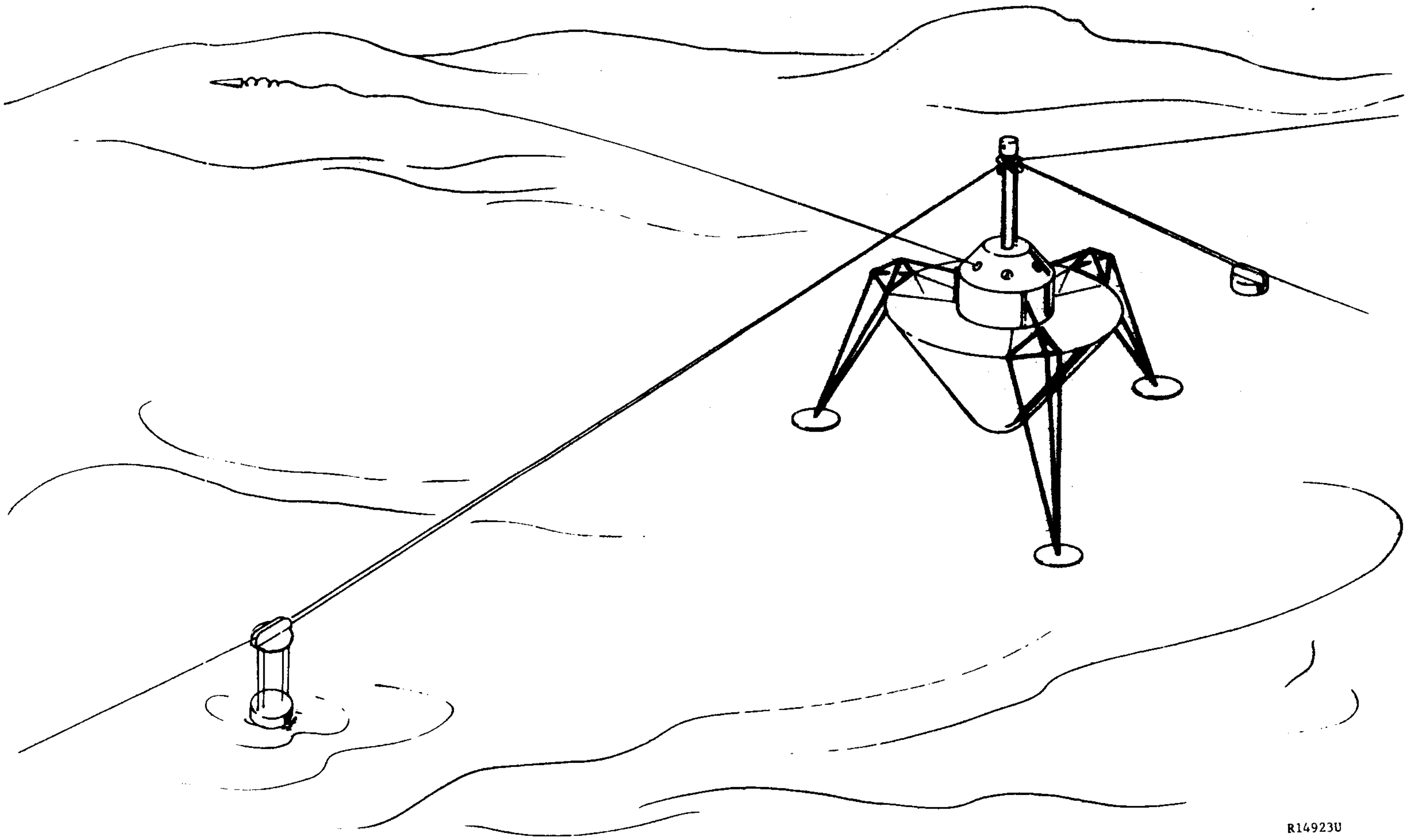

FIGURE 4.5-18. WIRE GUY AND TROLLEY SOIL SAMPLER DEPLOYMENT CONCEPT

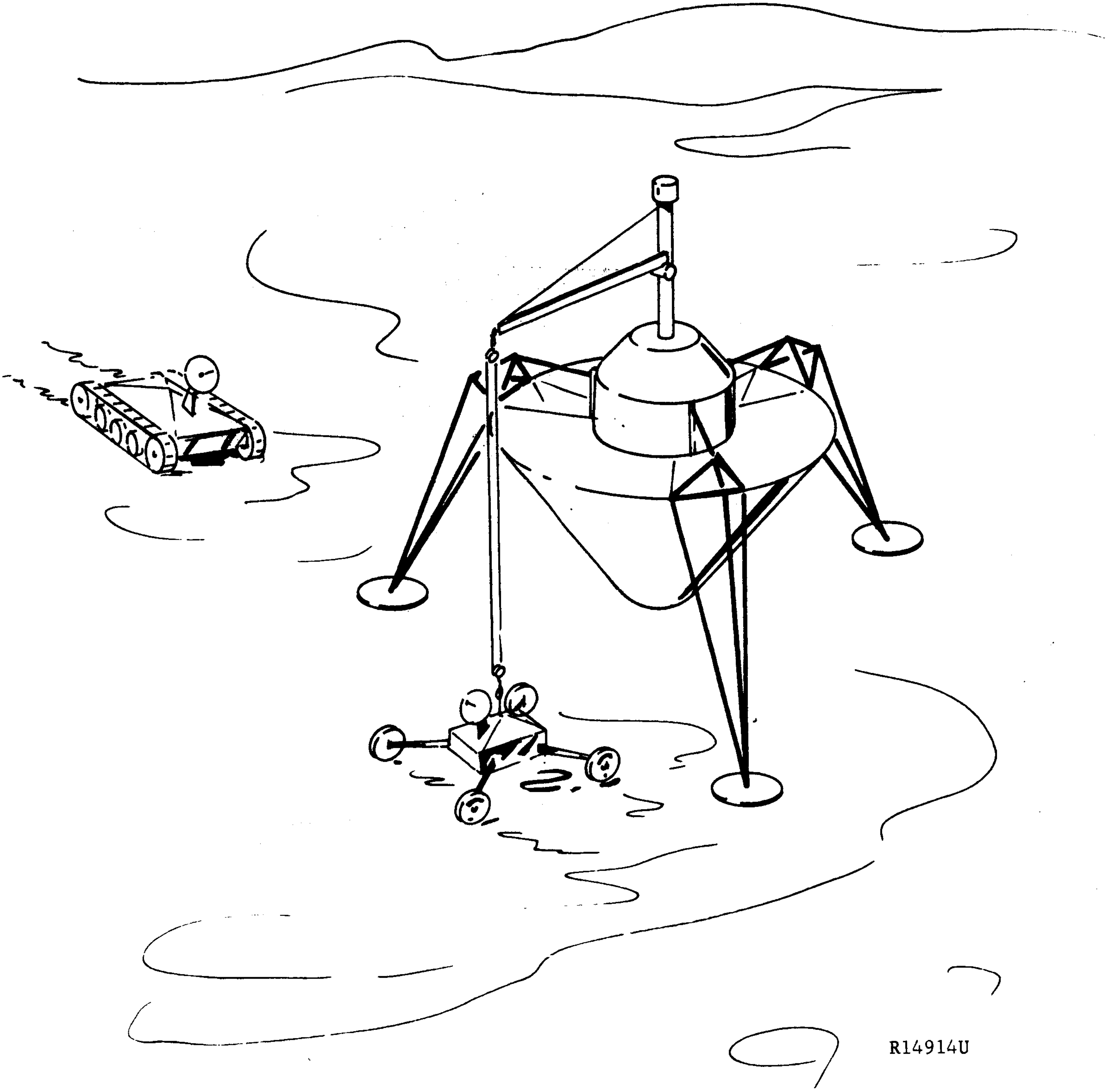

FIGURE 4.5-19. ROVING VEHICLE SOIL SAMPLER DEPLOYMENT CONCEPT

TABLE 4.5-XVI

SAMPLE GRADING CONCEPTS

Concept	Qualitative Evaluation	Estimated Reliability
1. Hammer Soil Pulverizer and Pebble Separator	This concept utilizes a pneumatic hammer to break cohesive soil into smaller particles against an agitated grating to separate pebbles from the sample. Forces generated are not large enough to crush solid stone. This concept can handle all forms of soil samples except plastic soils.	Moderate
2. Ball Mill	The residue from the pebble separator and the grading equipment is tumbled in a cylindrical container containing steel balls. This equipment is used to maximize the yield of usable sample from a given quantity of raw sample material. The process may be carried on either wet or dry. The expected ratio of biological material to inert material would be low. The primary purpose of this equipment would be to provide a more complete elemental analysis sample.	High

TABLE 4.5-XVI (Continued)

Concept	Qualitative Evaluation	Estimated Reliability
3. Pneumatic Grading See Figure 4.5-20	The pulverized sample is fed into a drop tube in discrete quantities at intervals. By falling through a fixed distance a particle size distribution is effected by virtue of drag differences. At predetermined time intervals pneumatic cross flows are generated to transport the particles into vortex collectors. The combination of cross flow velocity and timing will separate the sample into size ranges initially defined as $d < 50\mu$ and $50 < d < 300\mu$ for particles with a specific gravity of 2.6. The primary advantage of this system is its insensitivity to clogging and that less dense larger diameter material will be collected with the finer stony particles. Thus, this concept should also tend to concentrate biological material in the finer sample providing the highest attainable ratio of biological material to inert material.	High
4. Mechanical Screening See Figure 4.5-21	The soil is placed on a screen with a given mesh size which is agitated. Particles below a given size fall through. Successive mesh sizes of screens will produce the desired grading independent of particle density. Screen clogging can occur.	Low

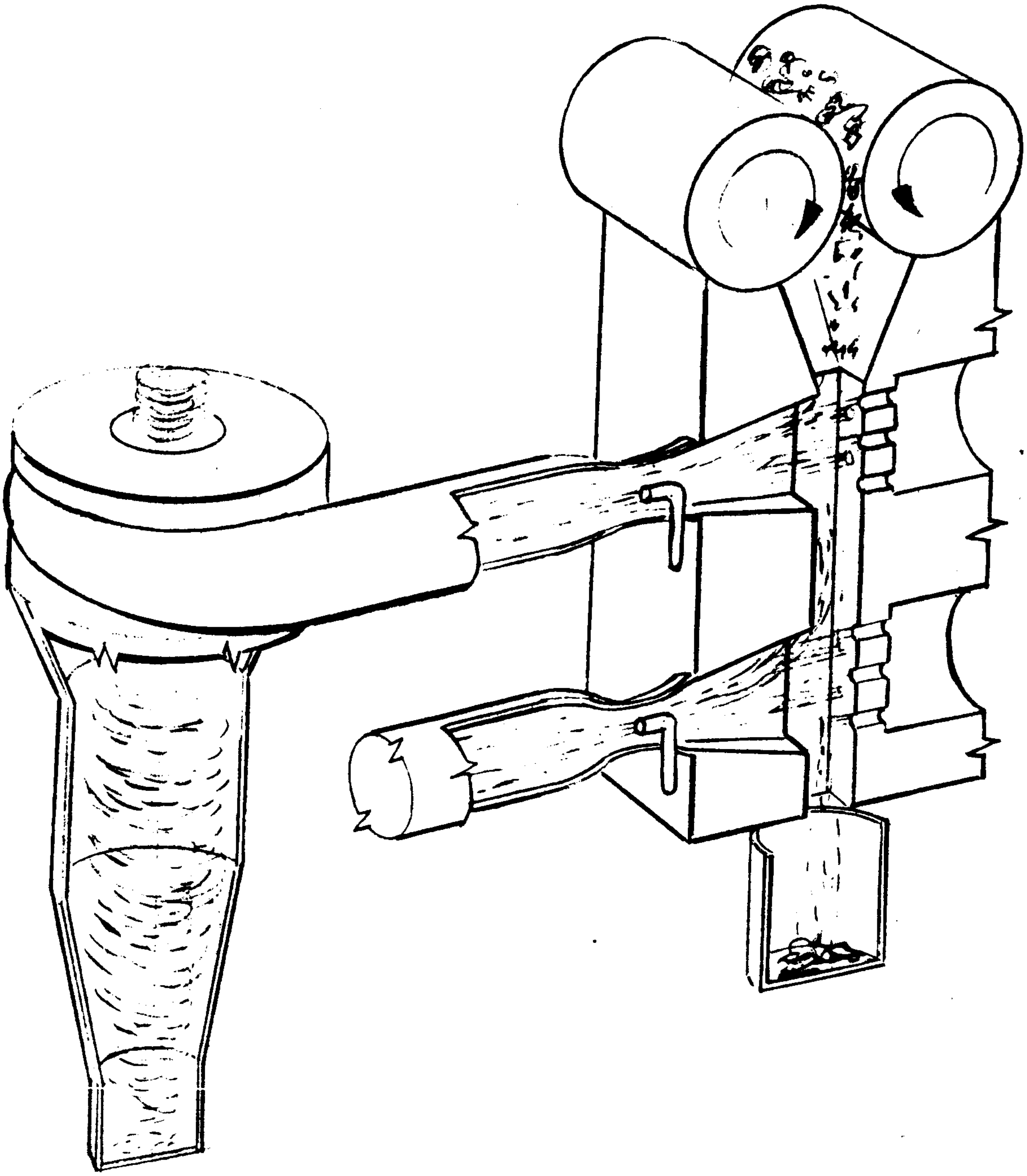

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FIGURE 4.5-20. PNEUMATIC SIEVING AND GRADING CONCEPT

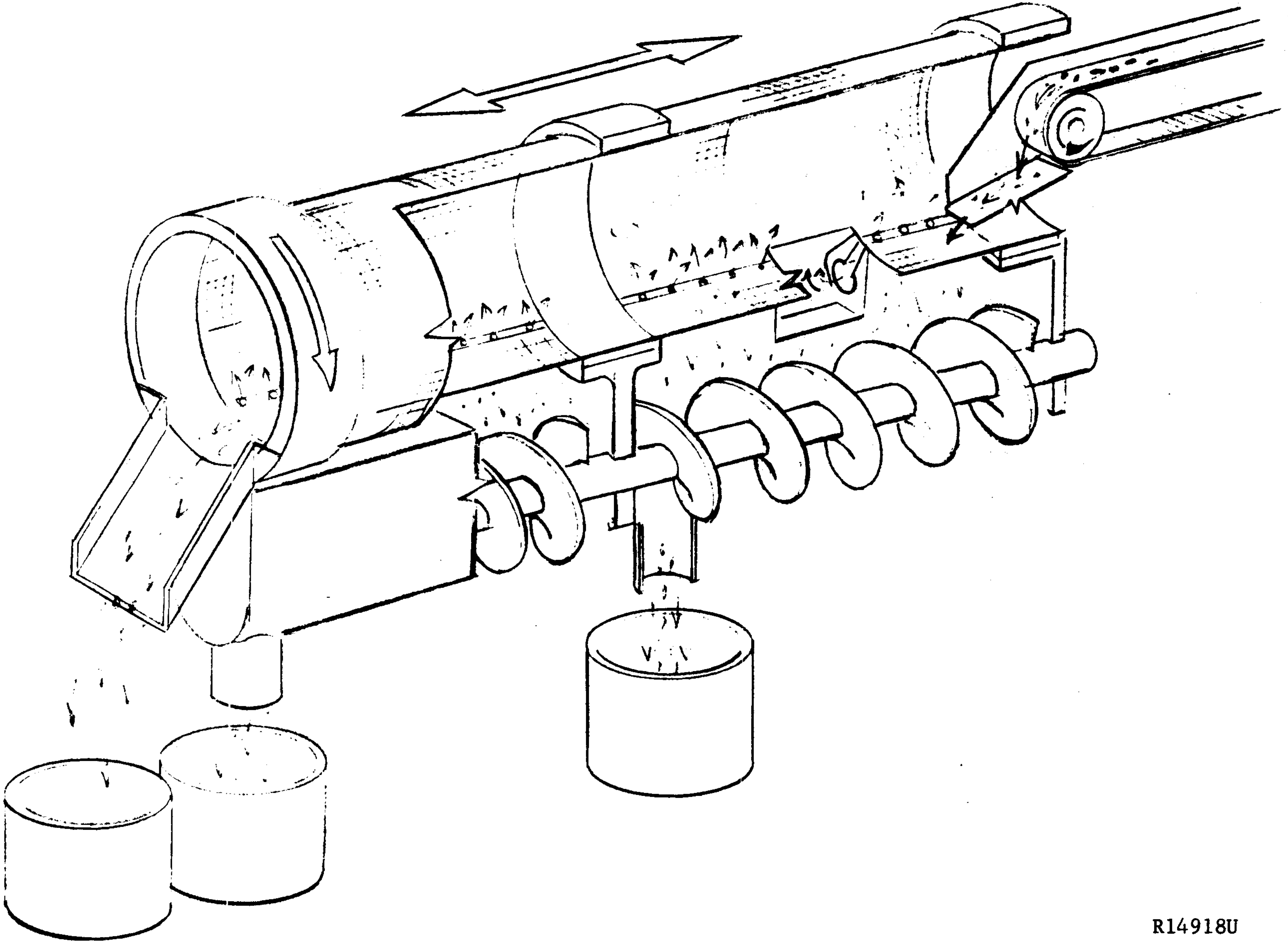

FIGURE 4.5-21. MECHANICAL SIEVING AND GRADING CONCEPT

4.5.6 FEASIBILITY AND PARAMETRIC ANALYSES

a. Impact Penetration of Soil Probes. This analysis was conducted principally to establish the feasibility of utilizing the kinetic energy of a ballistically deployed probe to achieve a desired penetration. Potential applications for this technique in the ABL design are the deployment of soil probes into the surface up to depths of 1 meter, the deployment of anchors to provide reactions for the soil sampling system, and possibly the deployment of soil sampling tubes.

Kornhauser(1) gives the relations for penetration in soils at low impact velocities in the form $y/D = k\gamma v$

where

y = the penetration distance in inches,

k = a constant determined by the soil type,

D = the diameter of the projectile in inches

v = the impact velocity in feet per second.

The variable γ is the effective ballistic density related to a steel sphere and is given by $\gamma = 6W/\pi \rho_s D^3$. For a cylindrical rod with an effective density ρ_c, the ballistic density is $\gamma = 3\ell \rho_c/2D \rho_s$ from which the penetration is $y = (3\ell/2)(\rho_c/\rho_s)(kv.)$ Thus, the penetration of a cylindrical rod is proportional to its length and the effective mass density of the rod. For the particular configuration chosen, penetration is independent of the diameter since the weight increases as the diameter increases.

In examining Figure 4.5-22, which gives the total penetration of a projectile, it is seen that penetration is not linear with velocity.

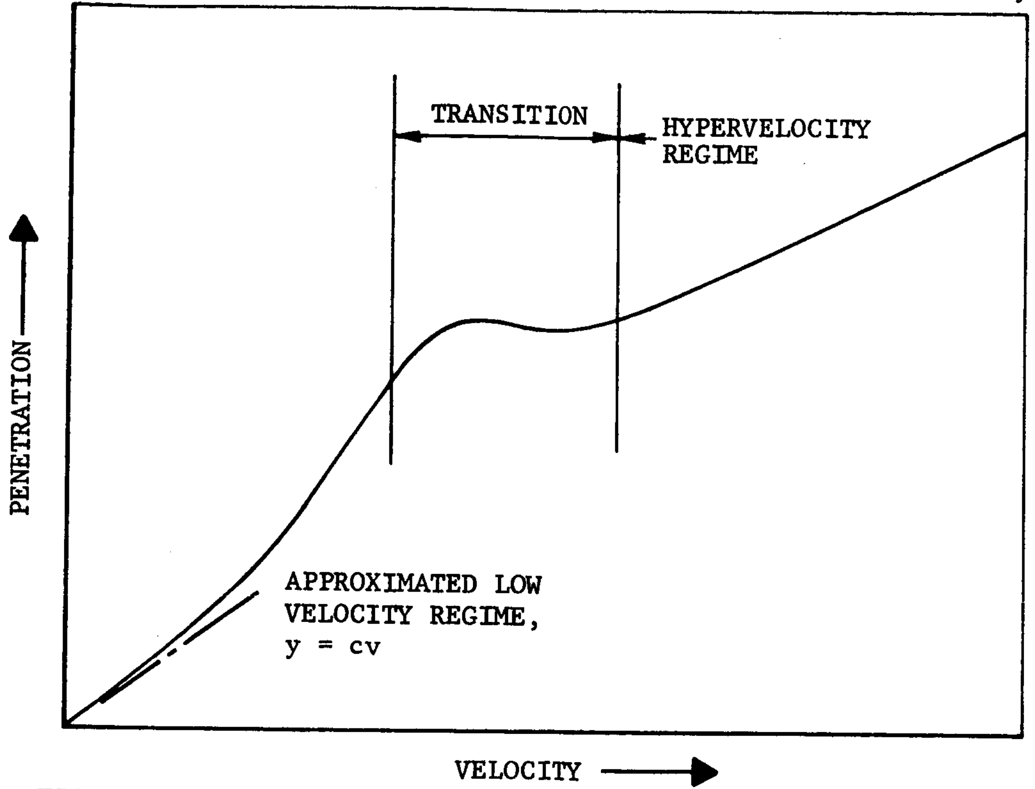

FIGURE 4.5-22. TOTAL PENETRATION OF PROJECTILES (REFERENCE 1)

For lower velocities, a reasonable approximation can be made with a linear relationship which should be useful in establishing the feasibility of implanting a probe to a depth of 1 meter.

The values for the penetration constant k given by Kornhauser(1) for sand, soft rock, and hard rock were plotted against compression modulus for the upper and lower limits of this value as defined in the published literature(10)(17) and is shown in Figure 4.5-23 by the broken lines. The values that were defined for the various models for Martian soil are shown by the solid line. By definition in the design criteria, only the sand and cohesive soil models shall be considered for the penetration of an instrumented soil probe. The rock models must be considered in the case of setting or implanting an anchor. In examining the equation for penetration in more detail, it is seen that for a given length and impact velocity, the penetration is determined by the penetration constant for the particular soil being penetrated. Thus, if a given length and diameter rod is to be implanted to its full length in sand, the same impact velocity will achieve only 70 percent of that penetration for the weak cohesive soil model, and 45 percent for the strong cohesive soil model since their

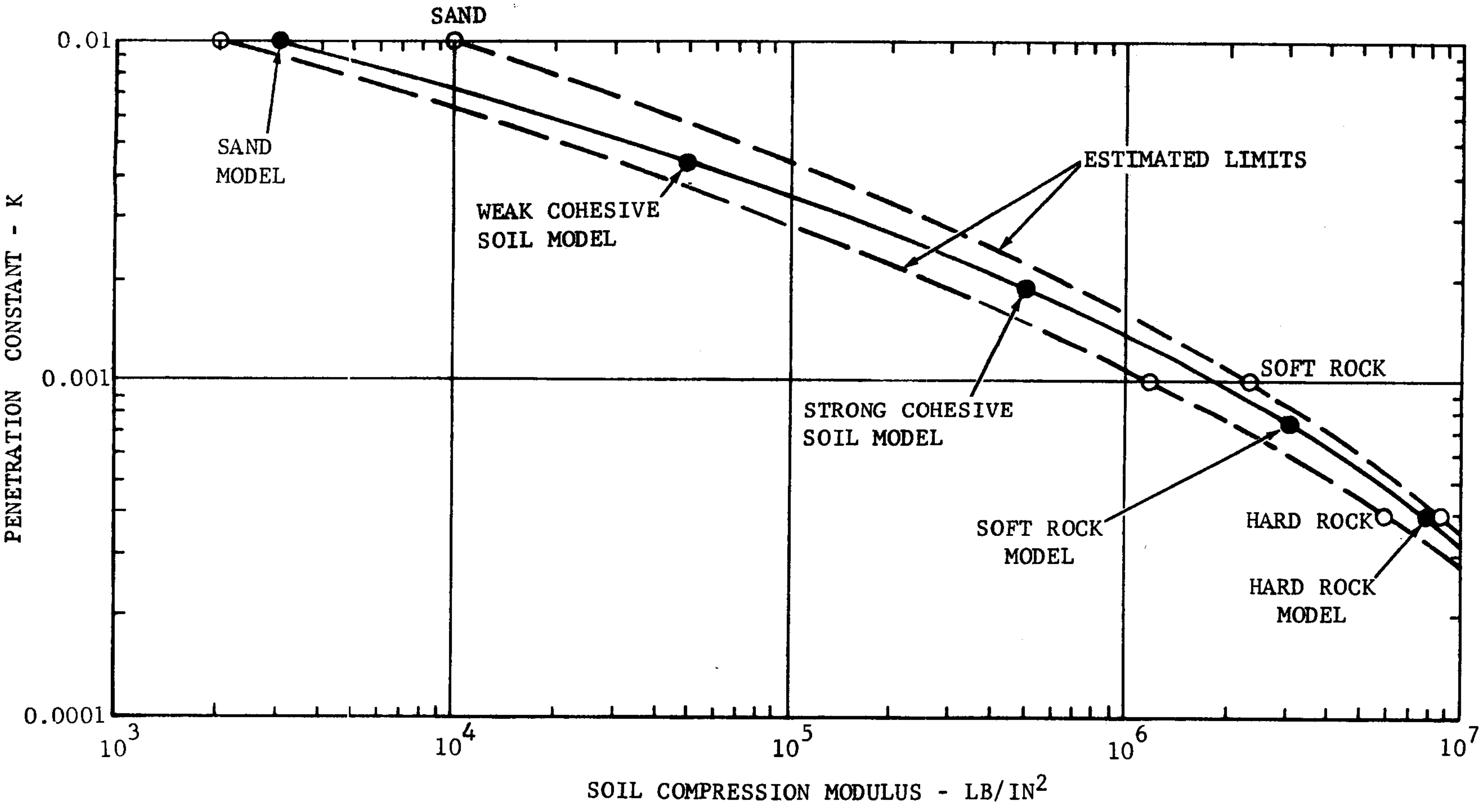

FIGURE 4.5-23. VARIATION OF PENETRATION CONSTANT WITH COMPRESSION MODULUS

penetration is in direct proportion to the constant k. This suggests that if more than one soil probe is deployed, the first should be accelerated to a velocity that will affect full penetration in sand. If less than full penetration is achieved as determined from depth sensors, the next probe can be deployed at a higher velocity to achieve greater penetration. Thus, unless the surface is solid rock, at least one probe should achieve the desired penetration. The velocities required to penetrate to a depth of 1 meter are given in Figure 4.5-24 for various ratios of effective mass densities. As would be expected, higher ratios of mass density require lower impact velocities. It will be shown later that velocities in the order 150 feet per second are achieved in ballistically deploying an anchor. This indicates that effective mass densities about equal that of steel or better is required. This can be achieved by adding the required mass on the end of the rod. It is estimated that an instrumented probe for the ABL will have an effective mass density of half that of steel for the portion of the probe embedded in the soil. This is shown in Figure 4.5-25 by the broken line. The solid lines give the trend in total weight required to achieve the effective mass densities of steel, one and one half times that of steel, and twice that of steel. From these curves, it is seen that the probe diameter should be kept small if weight is to be minimized. The range of probable diameters is estimated, based on preliminary configuration requirements in terms of providing the requisite sensors. It should be noted that a strength analysis must also be performed in the detail design of such a probe.

To evaluate the requirements for an anchor, penetration into rock must also be considered if a reliable deployment system is to be attained. The anchor does not require any sensors or internal cavities as is required for the instrumented probe. Thus, it can have a mass density equal to that of steel. If 1 meter of penetration into the soft cohesive soil model is set as a design criterion, then an effective mass density of 1.0 is required for an impact velocity of 150 feet per second. In this case, it is more desirable to use a denser material to increase the mass density rather than add weight to the end of the probe. This is based on the premise that the anchor will bury itself in soft sand and a larger mass located on the end of the anchor would reduce the depth of penetration achieved. By using tungsten, an effective mass density approximately 2.5 times that of steel can be attained in a solid rod. Thus, a shorter anchor for the same diameter is possible and will probably be desirable from a packaging viewpoint. The length can be reduced by the ratio of the effective densities of steel and tungsten, resulting in an anchor length of 16 inches. This anchor will achieve 15 to 16 inches of penetration into the hard cohesive soil model. Since the angle of penetration can be made very nearly vertical by using a high looping trajectory, the tension on the cable will produce only a small component tending to withdraw the probe axially along its path of entry. In order to investigate the penetration in the soft and hard rock models, the

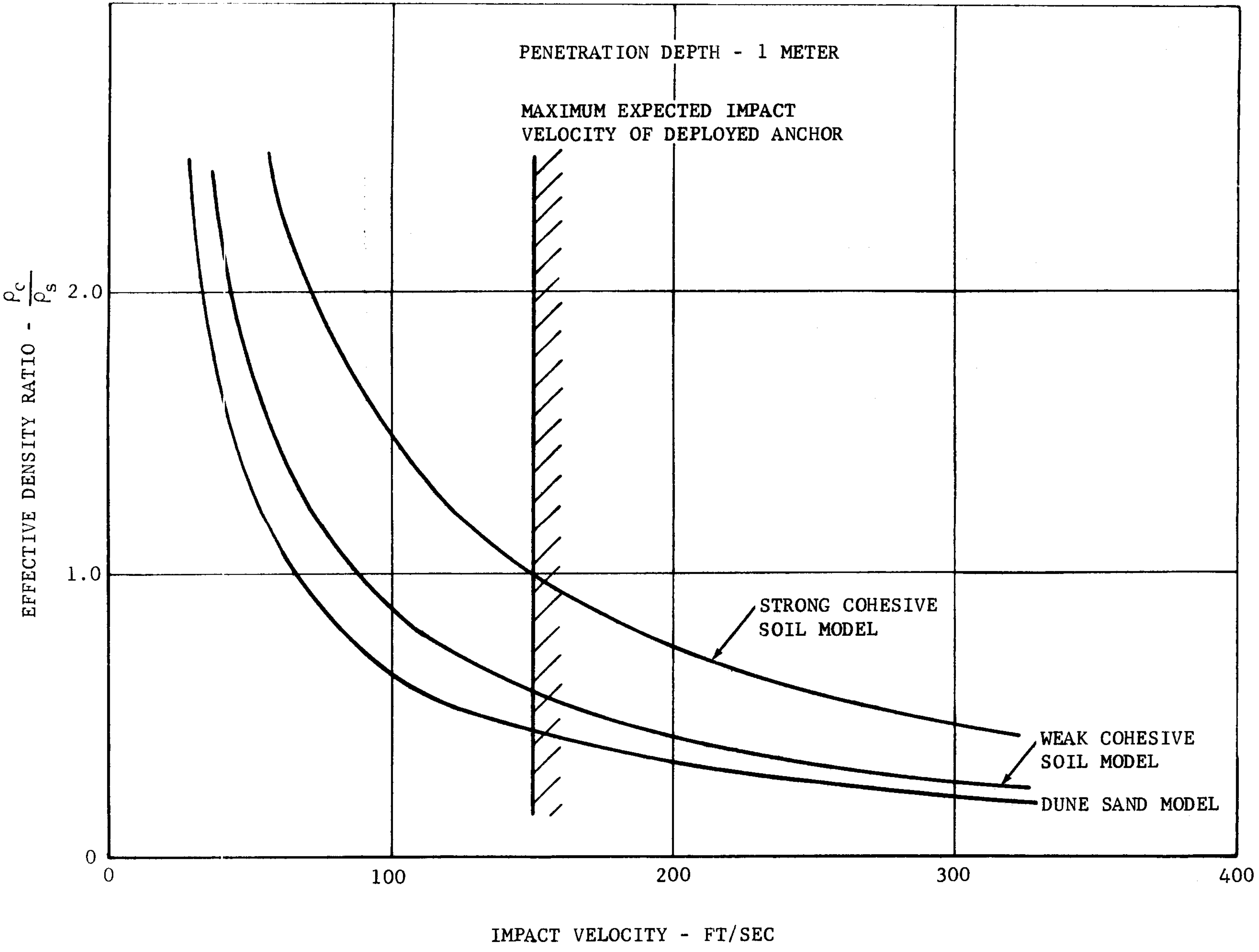

FIGURE 4.5-24. REQUIRED IMPACT VELOCITY TO PENETRATE SOIL

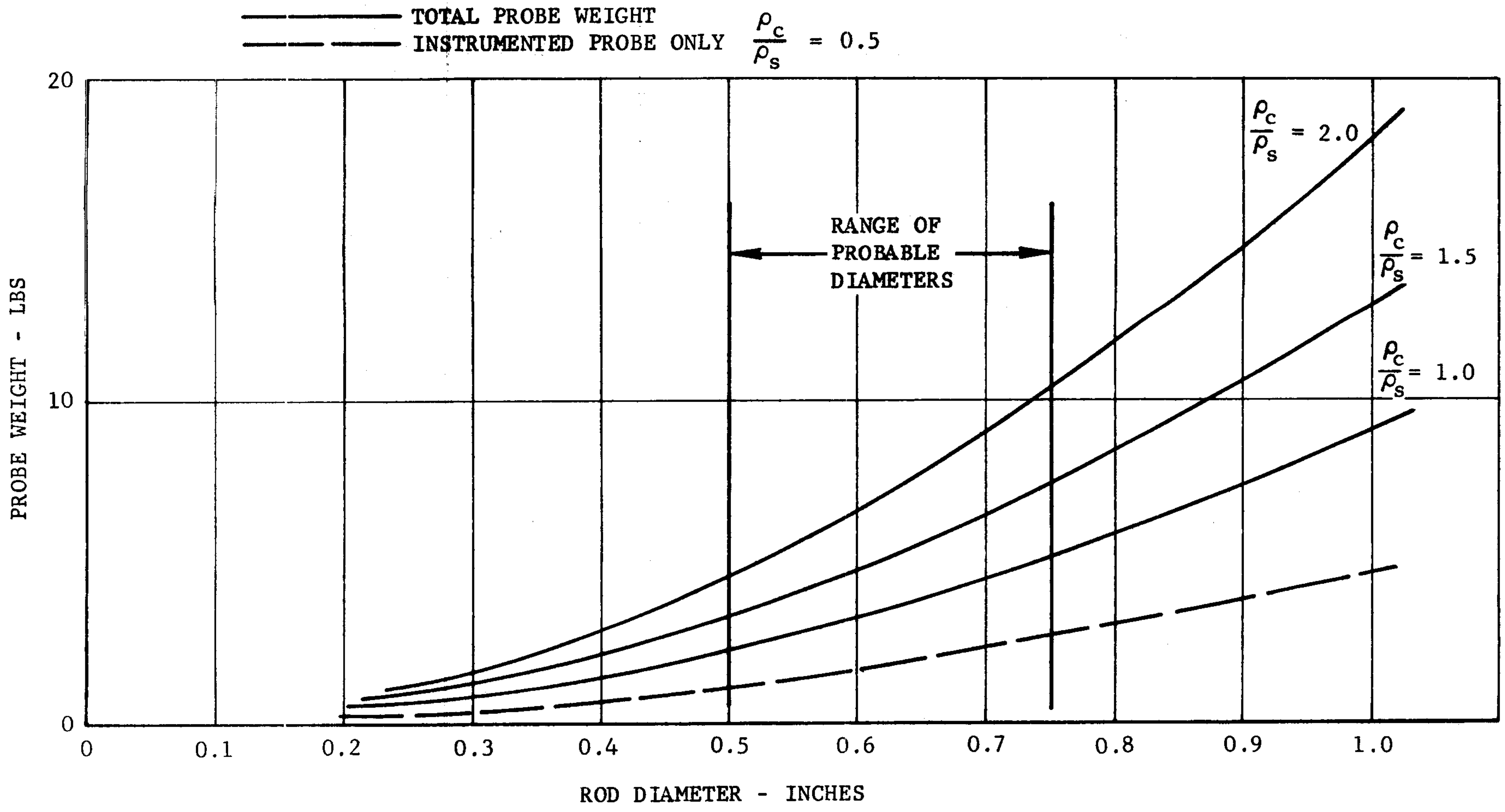

FIGURE 4.5-25. PROBE WEIGHT VARIATION WITH DIAMETER

penetration achieved as a function of impact velocity is shown in Figure 4.5-26. While the values shown are expected to be somewhat unconservative, they are sufficiently accurate to establish feasibility. Since tungsten is relatively brittle and may fracture on impact, it is proposed to tip the anchor with a case hardened steel stud which is attached to the deployed line. Thus, reliable anchoring to solid rock can also be achieved with anchors weighing from 2 to 10 pounds as determined from Figure 4.5-27.

b. Ballistic Deployment of Sample Collection Systems. To develop the feasibility of ballistically deploying a sample collector or a line on which to transport a collector, the ballistic deployment was investigated in terms of cable size and length, launch energy requirements, and deployed geometry with respect to the local terrain. The detailed analysis for deployment methods discussed here are given in Appendix 9.

A first order approximation of launch energy requirements as a function of launch angle and desired range were made by considering vacuum trajectories. Since the Martian atmosphere is several orders of magnitude more tenuous than is Earth's, this is not considered to represent a large error in the analysis. In developing the range equation, it is immediately noted that range is inversely proportional to the acceleration of gravity. Thus, for a given launch energy, the range on Mars is increased over that for Earth by the ratio of their gravitational accelerations. This results in an increase of 2.62 times that achieved on Earth. Required launch velocities as a function of range are plotted for several launch angles in Figure 4.5-27. It is seen that for ranges up to one or two thousand feet, the required velocities are not particularly high. To serve as guides for reasonable velocity limits, two conditions were considered. The wire deployment limit is based upon wire guided missile technology and is governed by wire breakage. The compressibility limit was somewhat arbitrarily taken at a Mach number of 0.75 for a reasonably cold day. This avoids any problems that could be introduced by entering the transonic region of flight. It is seen that low flat trajectories or high looping trajectories require higher launch velocities than the optimum at a launch angle of 45 degrees; however, the increase is not rapid until 30 and 60 degrees are exceeded. The choice of trajectory used depends on the end result that is desired. A high trajectory is desired for implanting line anchors to make the anchor more difficult to pull out and to achieve the greatest depth of penetration. The low flat trajectory would be used to deploy a sampler which must be retrieved to reduce the chances for burial on impact. There are several advantages accruing to deploying a line anchored at its end for the transport of a soil sampler to some remote location. These are that both deployment and retrieval of the sample collector is independent of the local features of the terrain as well as possible lower energy requirements of a simple anchor. To evaluate the latter requirement, the theoretical launch energy as a function of range was plotted for various launch weights as shown in Figure 4.5-28 by the

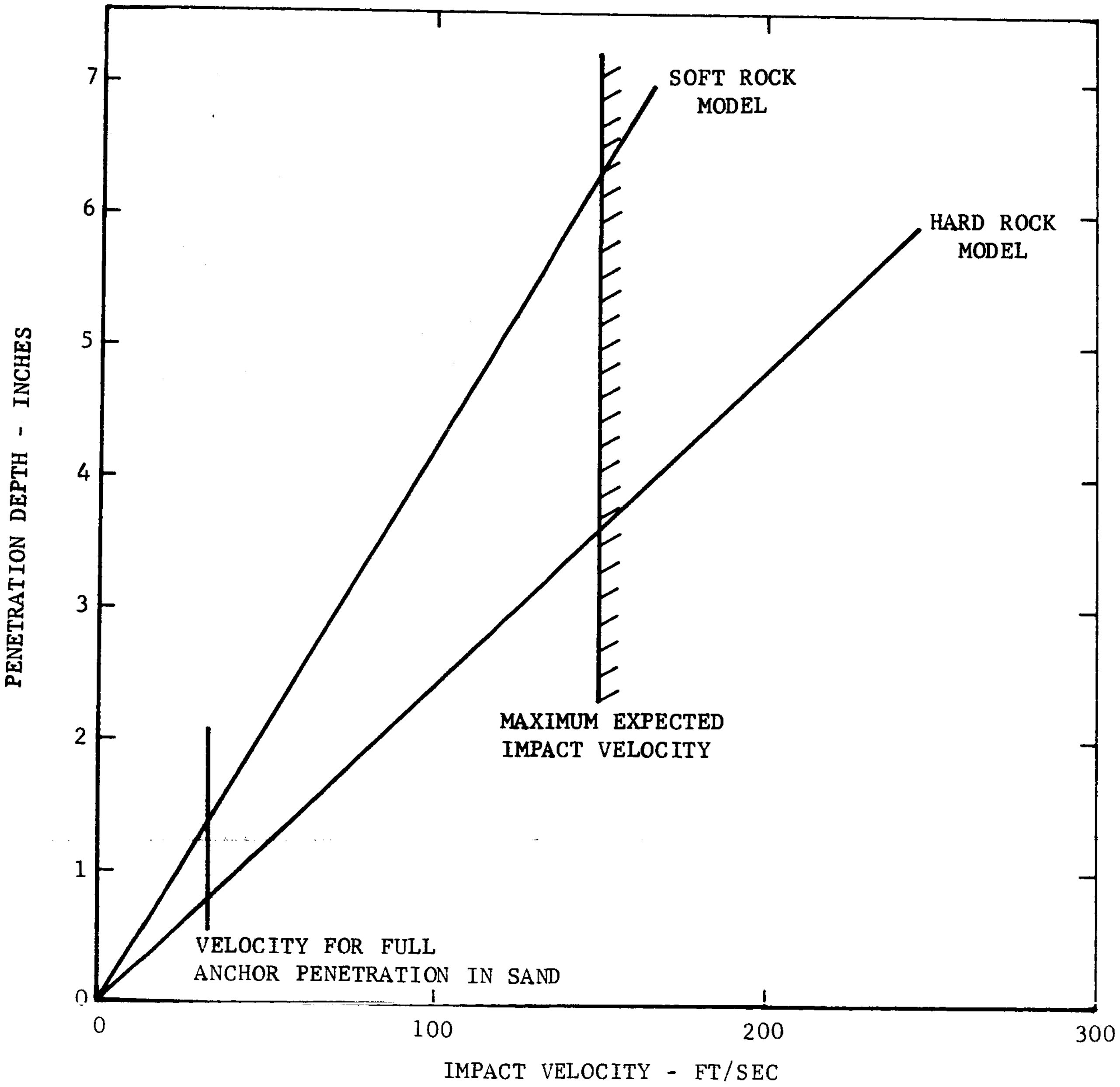

FIGURE 4.5-26. ANCHOR PENETRATION IN ROCK

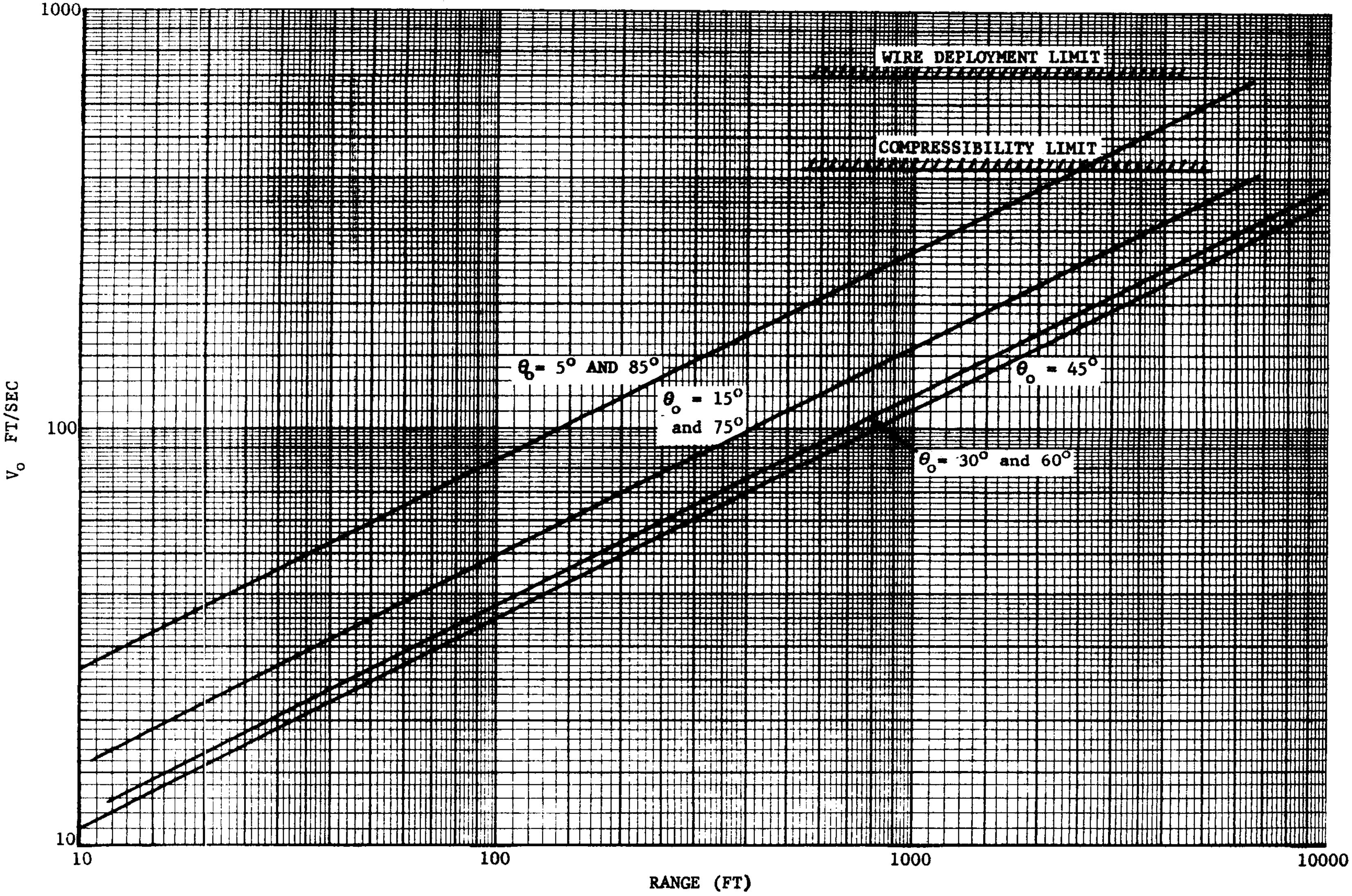

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FIGURE 4.5-27. RANGE VERSUS LAUNCH VELOCITY FOR VACUUM TRAJECTORY

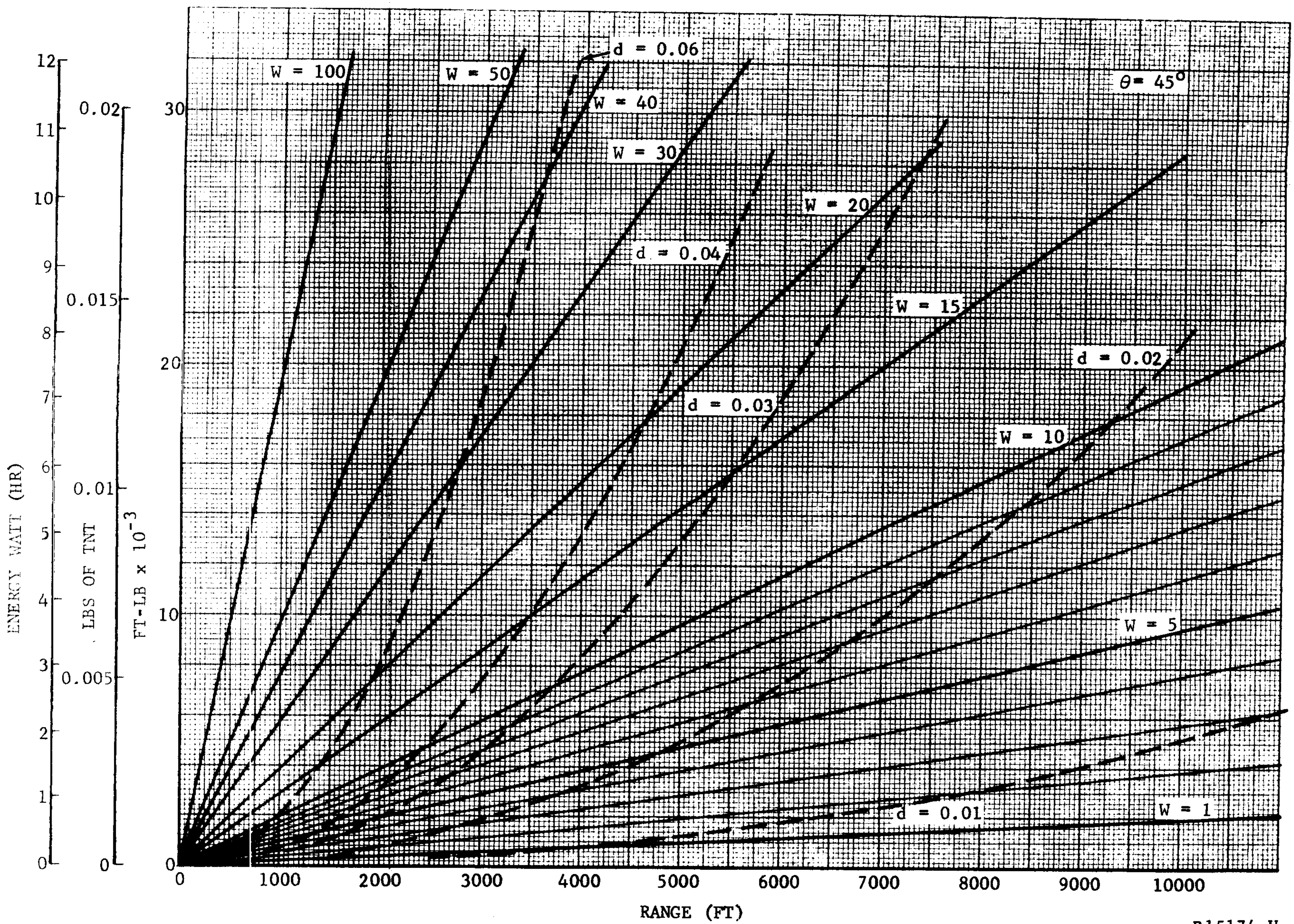

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FIGURE 4.5-28. LAUNCH ENERGY REQUIREMENTS AND WIRE RANGE LIMITS solid curves. The dashed curves are theoretical limits imposed by the total length of a given wire size. These represent the point at which the weight of wire equals the launch weight. This limit cannot, of course, be achieved in a real system. It is seen that ranges up to 10,000 feet could be achieved with small wire sizes; however, practical considerations dictated by wire strength and deflection geometry, in general, limit the useful range to essentially 1500 feet. Thus, a 5 pound anchor can be deployed 1500 feet for an initial launch weight of 20 pounds and requires a theoretical launch energy of 6000 foot pounds. This has been expressed in the equivalent weight of TNT or electrical energy in watt hours. If utilization efficiencies as low as 10 percent are assumed, the 20 pound anchor and line will require 6.5 ounces of TNT or 20 watt hours to deploy it to a range of 1500 feet. Electrical power is considered since it may be utilized to compress Martian atmosphere as a launch propellant.

To evaluate the effect of atmospheric drag and wire drag, estimates of the relative magnitudes of each of these were made and compared to Earth conditions. Using the Model 1 or 40 millibar atmosphere, it is seen that the ratio of drag on a body in Earth's atmosphere to that in Mars is given by the ratio of the atmospheric densities. This ratio is given by

$$\frac{D_{\oplus}}{D_{\text{♂}}} = \frac{1/2\,\rho_{\oplus} C_D v^2}{1/2\,\rho_{\text{♂}} C_D v^2} = \frac{2.38 \times 10^{-3}}{8.97 \times 10^{-5}} \approx 27$$

The wire drag is a function of coiling geometry, wire stiffness, and inertia forces and would therefore be essentially independent of atmospheric effects. The magnitude of this drag was calculated and compared to the atmospheric drag in the Model 1 atmosphere and was determined to be from 12 to 25 percent of the total drag. In an Earth atmosphere, the wire drag is estimated to from 1/2 to 1 percent of the total drag. Thus, it is seen that under Martian conditions, the wire drag becomes more dominant requiring more consideration. It is emphasized that this analysis represents only a first order approximation of the parameters in a ballistic deployment system and must be analyzed in greater detail to fully develop all parameters affecting the design. It is considered sufficiently accurate to establish not only the feasibility of this approach but also to ascertain that severe weight penalties are not necessarily very large.

The final consideration in developing the useable range for a wire transported sampling system, the relative geometry of the deployed wire, the sample collector, and the local terrain were evaluated. To limit the scope of the calculations involved, a system as schematically portrayed in Figure 4.5-29 was assumed.

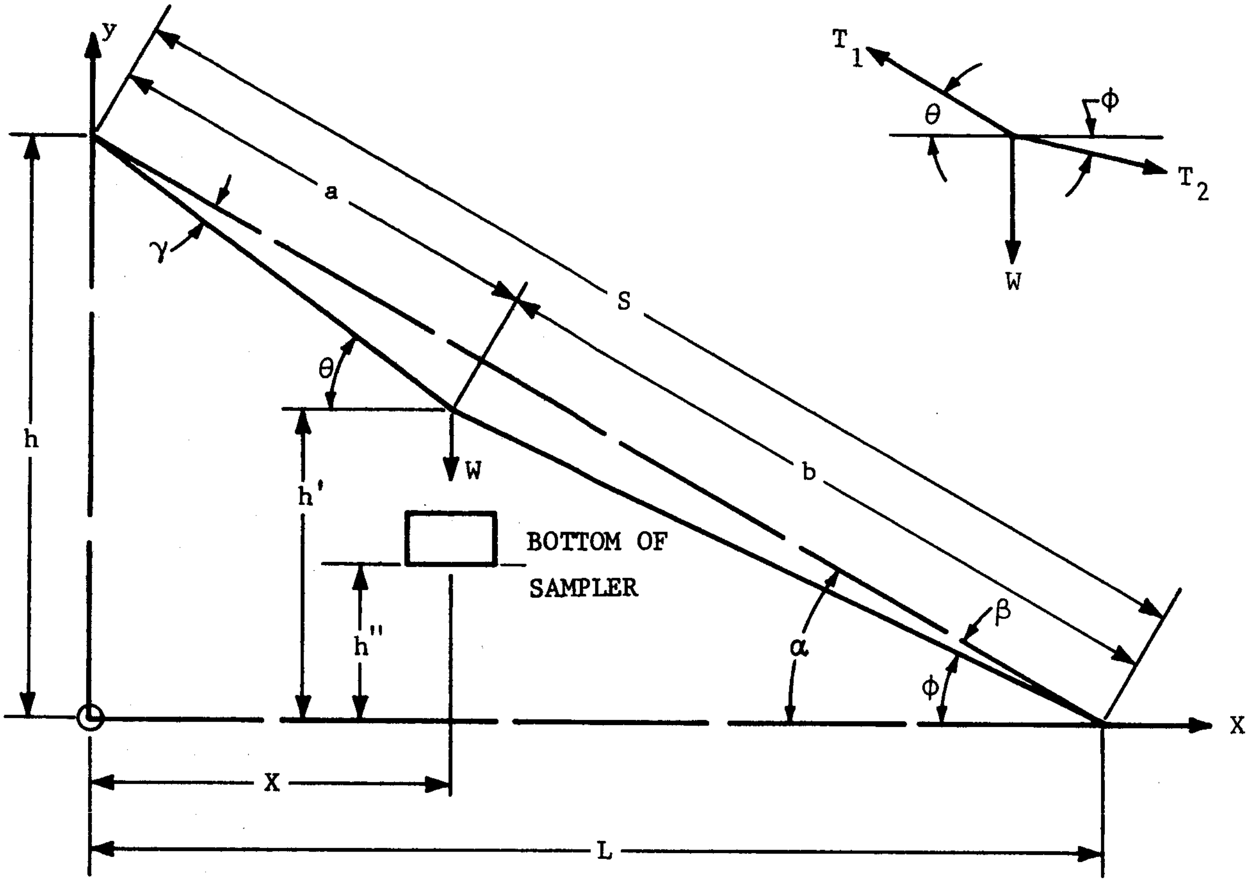


FIGURE 4.5-29. GUY WIRE TRANSPORT GEOMETRY

It was assumed that the line is deployed over level ground and that the height of the line above the ground at the ABL is 15 feet with a suspended sampler length of 2 feet. A sample collection system weight of 10 pounds was also assumed. The parameters which were considered important in this geometry were cable length, cable tension, and useable range. Useable range was defined as that point at which the lower edge of the sample collector first contacts a level surface without reducing tension in the cable. The change in tension in the cable caused by the addition of the sample collector weight was found to be insignificantly small. For a 0.062 diameter cable it amounts to a maximum increase of 2 percent of the cable stress. It should be noted here that under the assumptions of the analysis, the stretch in the cable can be neglected since a winch is assumed to take up the elongation of the cable in establishing the tension. Catenary effects have been neglected however, and should be considered in a more sophisticated analysis. The useful range as a function of deployed cable length is shown in Figure 4.5-30 for three values of cable tension. It is seen that as deployed length increases, the useful range is an increasingly smaller proportion of the total line length. Thus at 100 pounds tension, the sampler can be deployed to about 400 feet for a cable length of 1500 feet or slightly less than a third of the deployed

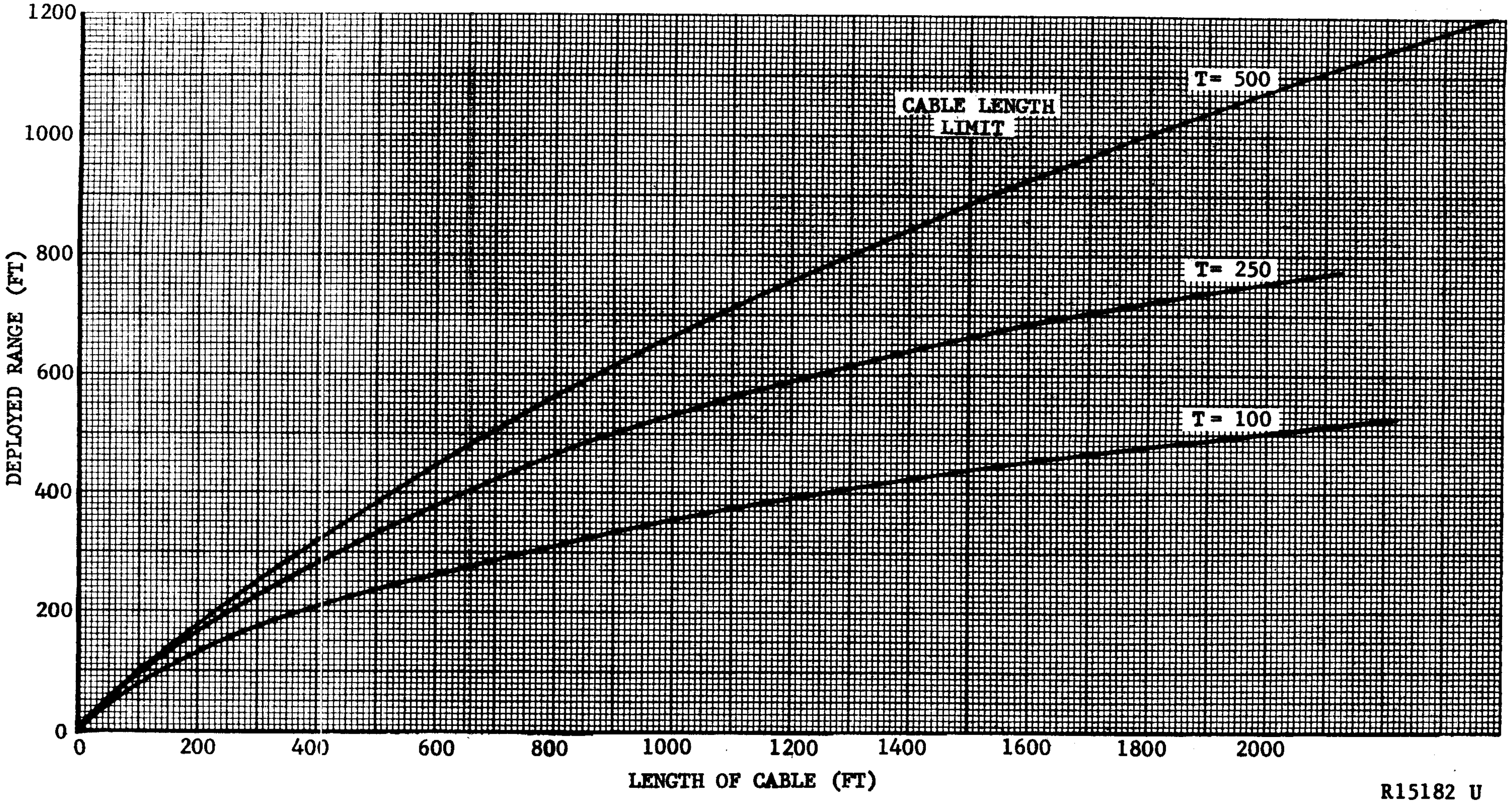


FIGURE 4.5-30. DEPLOYED RANGE AS A FUNCTION OF CABLE LENGTH

cable is useable. If the cable tension is increased to 500 pounds, the useful range is extended to 800 feet or about one-half the total deployed length. To more fully illustrate the influence of cable tension or useable range, the data presented in Figure 4.5-30 are cross plotted in Figure 4.5-31 with cable tension as a function of deployed cable length. Each labeled curve is the useful range that can be achieved by the sample collection system which relates the required cable tension and deployed length. It is seen that for relatively short ranges, the amount of useful range is a large percentage of the deployed cable length and is also relatively insensitive to the tension in the cable. As useful range increases, the amount of excess deployed cable also increases and cable tension becomes increasingly critical. A practical limit on achieable range by this technique is thus encountered between 800 and 900 feet. This range should be adequate for all practical purposes. If greater ranges are desired, then either a roving sample collector or a roving laboratory should be employed.

c. Pneumatic Transport of Soil Samples. There are certain appealing aspects in considering soil transport with a fluid flow using atmospheric gases in terms of simplicity of implementation. However, the very tenuous nature of the atmosphere on Mars immediately poses the question as to the feasibility of such a method. To analytically develop the parameters of this approach, a particle model must be established. This is conventionally chosen as a sphere since the drag does not change with the aspect the particle presents to the flow and is also more easily determined as a function of Reynolds number. In addition, a vertical flow is assumed so that the velocity to just suspend a particle in the flow can be determined. Under this condition, the drag is equal to the weight of the particle. Litton Industries(7) have reported that the volocities required for horizontal transport of particles in a tube is higher than for vertical transport. This is because of the fact that gravitational acceleration will cause particles to settle in the tube. The effect is further aggravated by the fact that, as the wall of the tube is approached, the boundary effects reduce the flow velocity. Thus, the flow velocity must be large enough so that the heavier particles will also progress along the tube by saltation, as described by Bagnold(40).

Again, it is felt instructive to compare the parametric results with those that pertain to an Earth atmosphere. In order to do this, velocities were calculated as a function of the particle size which would be just suspended in the flow. A specific gravity of 2.6 was assumed in the calculations since this is typical of silica sand and is the most likely density to be encountered on the basis of relative abundance. The

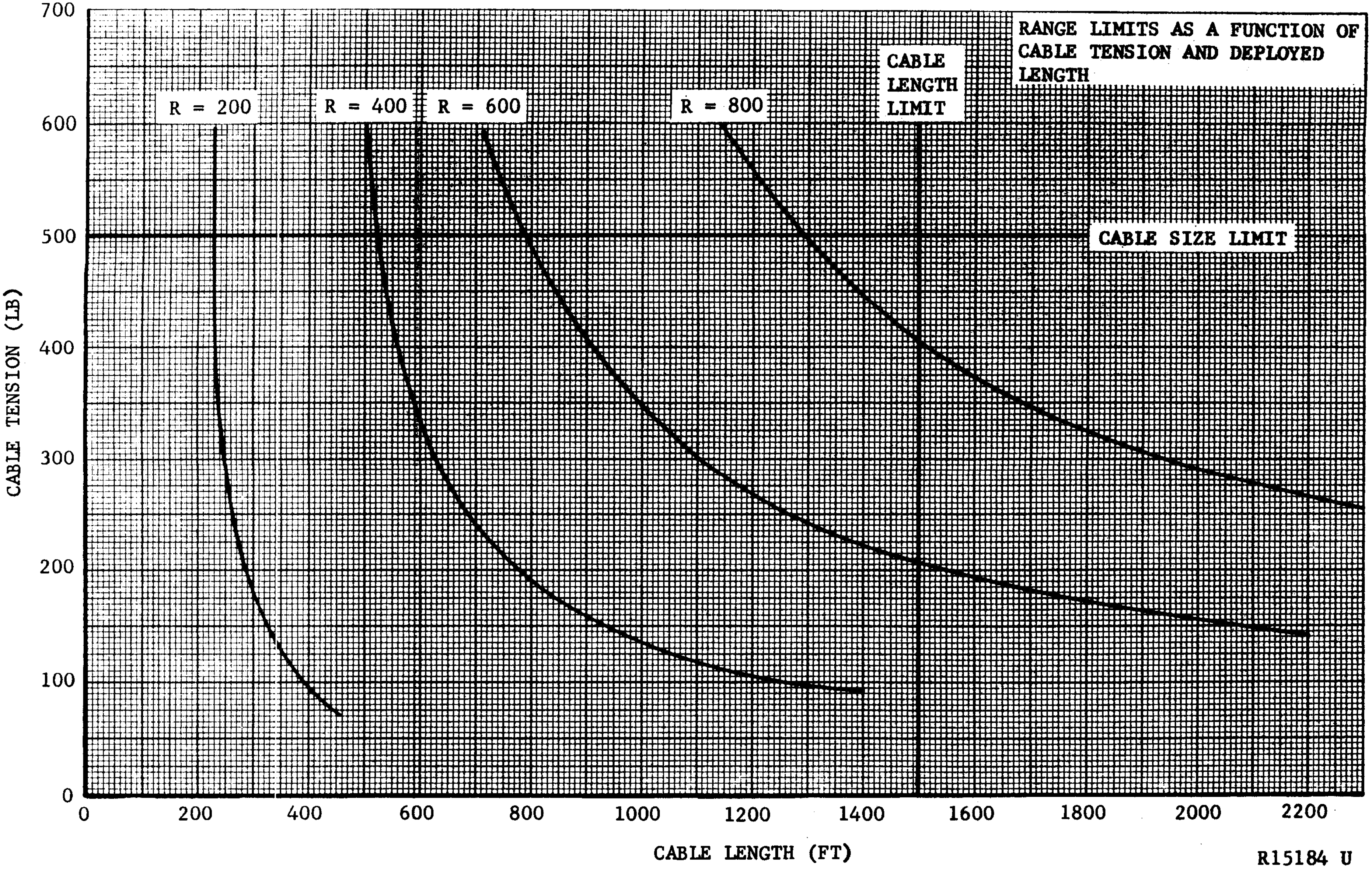


FIGURE 4.5-31. RANGE LIMITS AS A FUNCTION OF CABLE TENSION AND DEPLOYED LENGTH

variation in drag coefficient is shown in Figure 4.5-32 for a sphere as a function of Reynolds number, $R_N = \rho vd/\mu$

where

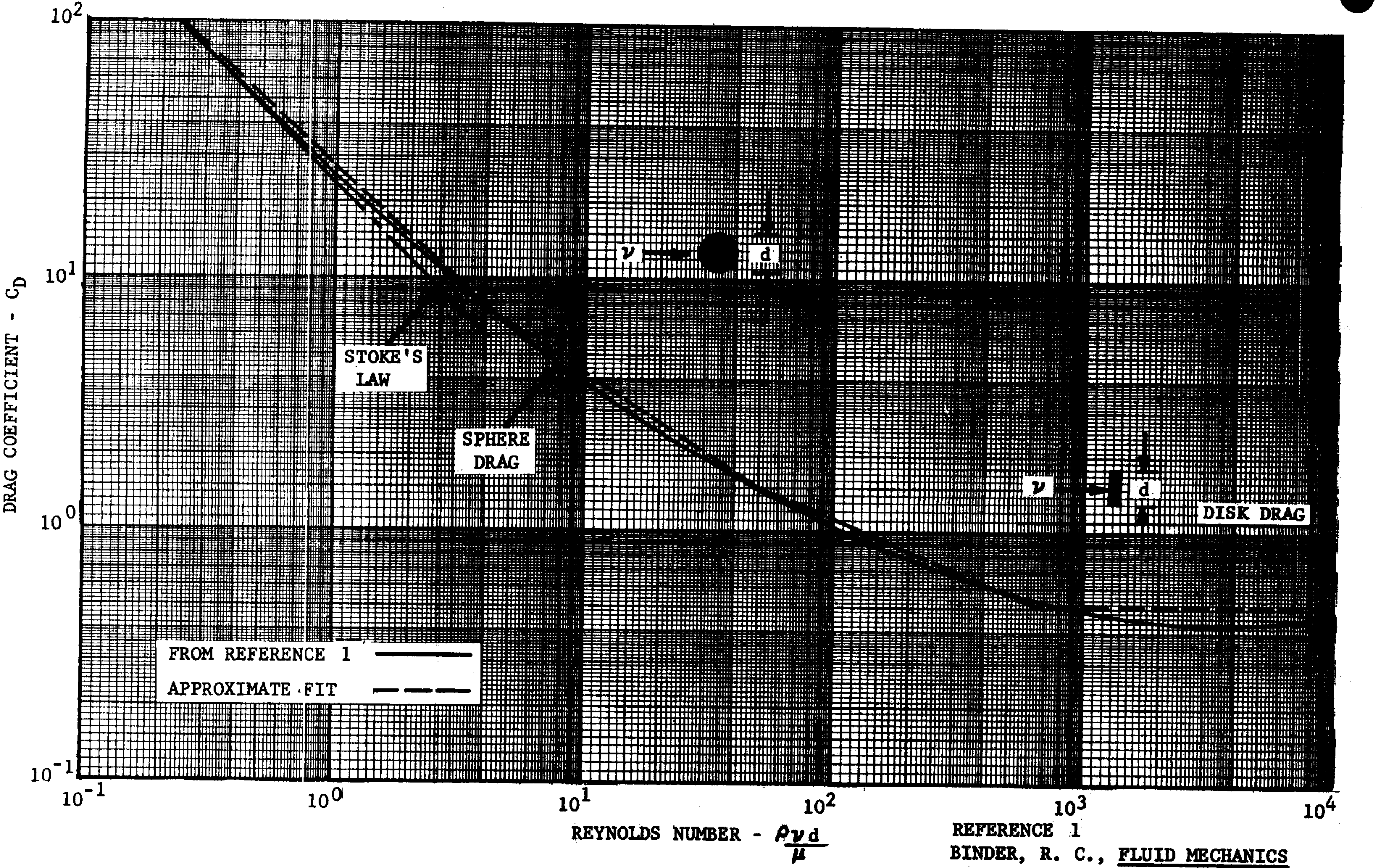
ρ = the fluid density in slug/ft^3,

v = the flow velocity in ft/sec,

d = the particle diameter in feet,

μ = the absolute viscosity in slug/ft sec

The drag of a particle is given by $D = 1/2 \rho C_D v^2$ where C_D is the drag coefficient. Since the drag coefficient is also a function of Reynclds number, an explicit solution cannot be obtained simply unless some simplifying approach is taken. The details of this analysis are given in Appendix 9. For this purpose, the drag curve was fitted with a series of straight line segments as indicated by the dashed or broken lines in Figure 4.5-32. By doing this, each segment of the drag coefficient curve can be expressed in the form $C_D = (\frac{k}{R_N})^n$ where k is constant and n is an exponent determined by the slope of the drag curve for the range of Reynolds numbers over which the curve has been fitted. Thus, the threshold velocity to transport a given size particle can be determined. The variation of threshold velocity for particle transport is shown in Figure 4.5-33. At the very low Reynolds numbers, i.e., less than 0.5, the particles obey Stoke's Law which fits the drag coefficient curve with a relation of the form $C_D = 24/Rn$. In this range of Reynolds numbers, the velocity is given by $v = g(\rho_p - \rho)d^2/18\mu$ where ρ_p is the particle density and ρ is the fluid density. Since the density of the fluid is small compared with the particle density, the bouyant forces can be neglected and the equation reduces to the form $v = g\rho_p d^2/18\mu$. It is seen from the curve, that particles in either the 40 or 10 millibar atmosphere on Mars obey Stoke's Law to larger particle sizes than on Earth - 200 microns rather than 40 microns. It is also seen that the threshold velocity over this range is lower than for particles in an Earth atmosphere, up to 150 microns. This is essentially because of the differences in gravitational fields as is illustrated by calculating the threshold velocity for an Earth atmosphere with the gravitational acceleration of Mars shown in the dashed curve of Figure 4.5-33. Above 150 microns, the threshold velocity on Mars is higher than on Earth. This is because the atmospheric density becomes the predominant factor in determining the drag rather than the absolute viscosity which is dominant in the Stoke's Law range. The range of variables investigated by Litton Industries(7) for vertical transport are superimposed on this curve to obtain a correlation with some experimental data. It is seen that, in general, the experimental data indicate velocities that are a factor of one-and-a-half to three times higher than the theoretical value. This can be explained in two ways.



REFERENCE 1
BINDER, R. C., FLUID MECHANICS
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FIGURE 4.5-32. VARIATION OF DRAG COEFFICIENT WITH REYNOLDS NUMBER

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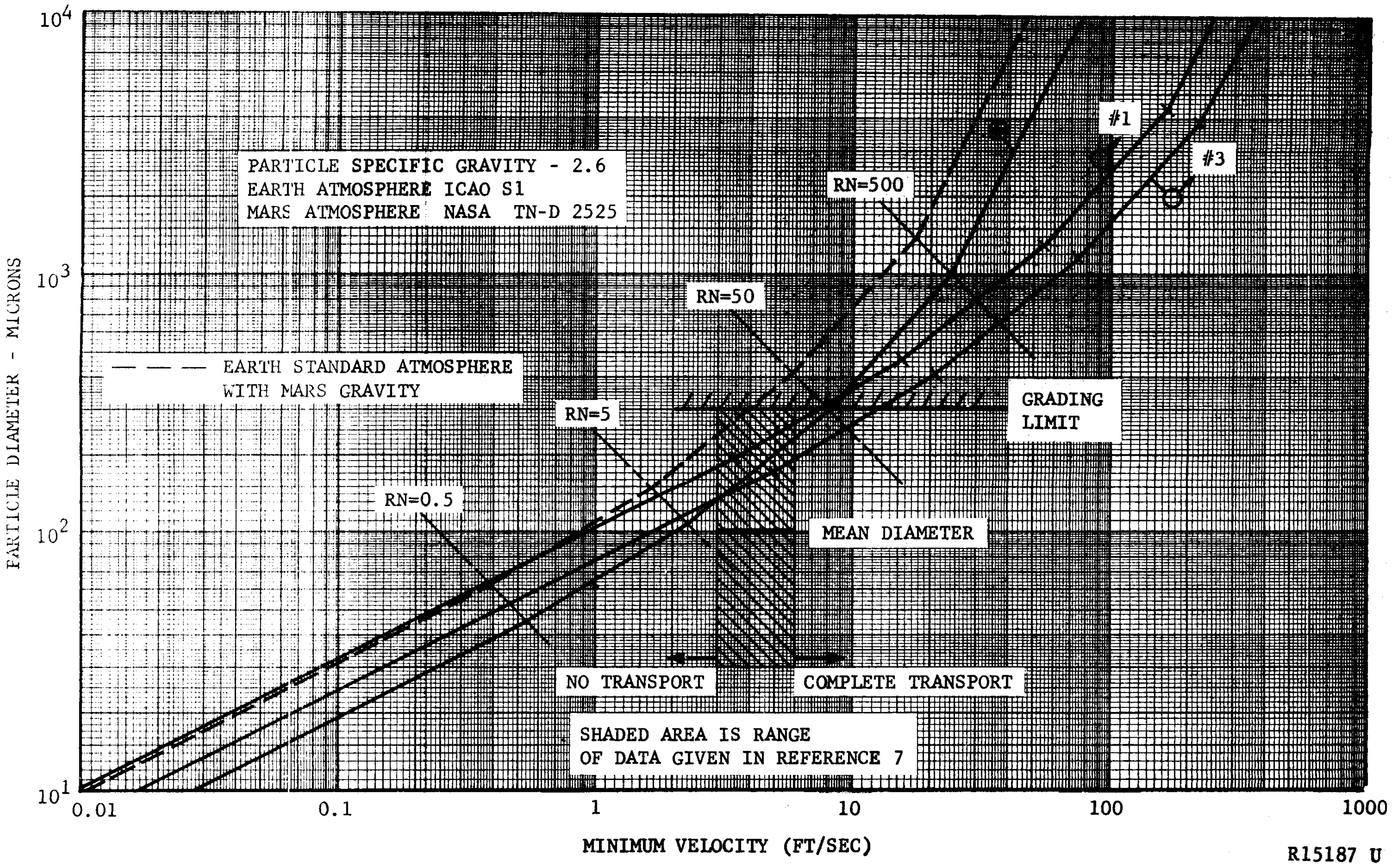

FIGURE 4.5-33. VELOCITY THRESHOLD TO TRANSPORT SOIL PARTICLES

The drag coefficient for real particles tends to be lower than for spheres in this velocity range. The other is that the Litton data were obtained by a flow in a tube. As mentioned previously, the flow in a tube has a velocity gradient which varies from a maximum at the center to zero at the tube wall. To compensate, the average velocity must be increased to carry the particles along that drift over to the side into lower velocity regions. Thus, reasonably good correlation is achieved and the feasibility of using this mode of soil particle transport is established for even the 10 millibar atmosphere on Mars. This is particularly important since more of the experimental sequences that have been defined for ABL stipulate soil samples that have been graded to particle sizes of 300 microns or less.

At this point, it is suggested that more success is to be expected from a pneumatic sample collection system which utilizes an aerosolizing jet of compressed atmosphere to lift particles from the surface than an induction system. This is particularly true since the mass flow of atmosphere required to produce the high velocity aerosolizing jet can also be utilized to provide the lower velocity flow required for transport of the particles in suspension so long as the flow is contained in a closed system.

It has been shown in Figure 4.5-33 that most of the particles from 300 microns and less in size obey Stoke's Law on Mars. From the equation for Stoke's Law, previously given in this analysis, it can be deduced that the threshold velocity, or conversely, the terminal velocity of fall for a particle is not only a function of absolute viscosity but also of the particle diameter and the particle mass density. This then suggests a scheme for pneumatically grading the soil which is not only highly reliable but seems to be ideally suited to refining and grading a soil sample by mechanical processing for a biological experiment. It would be intuitively logical to presume that less dense material than silica sand would be more likely to be of organic origin. Thus, it is not reasonable to exclude a larger particle from the sample on the basis of size alone, which is the result of mechanical screening through a wire mesh. By utilizing a pneumatic grading concept, soil particles can be selected on the basis of density as well as size. The pneumatic grading scheme proposed is that the soil sample be pulverized to reduce agglomerations of soil particles but not to crush the solid stony matter. From the pulverizer, the soil sample is dropped down an open tube in a thin dispersed stream. As the particles fall, the more dense and larger particles will fall at higher velocities and will also be less susceptible to cross flows at low velocities. Thus, cross flows can be initiated at an appropriate point in the drop tube to draw off the small particles. The particle size is determined by the velocity of the cross flow and the relative dimensions of the tube at this point as well as the time required to fall a given distance. The time of fall in the 10 millibar atmosphere is shown in Figure 4.5-34. In the ABL design point soil grading system, a continuous flow is established at some point below the drop point since the only

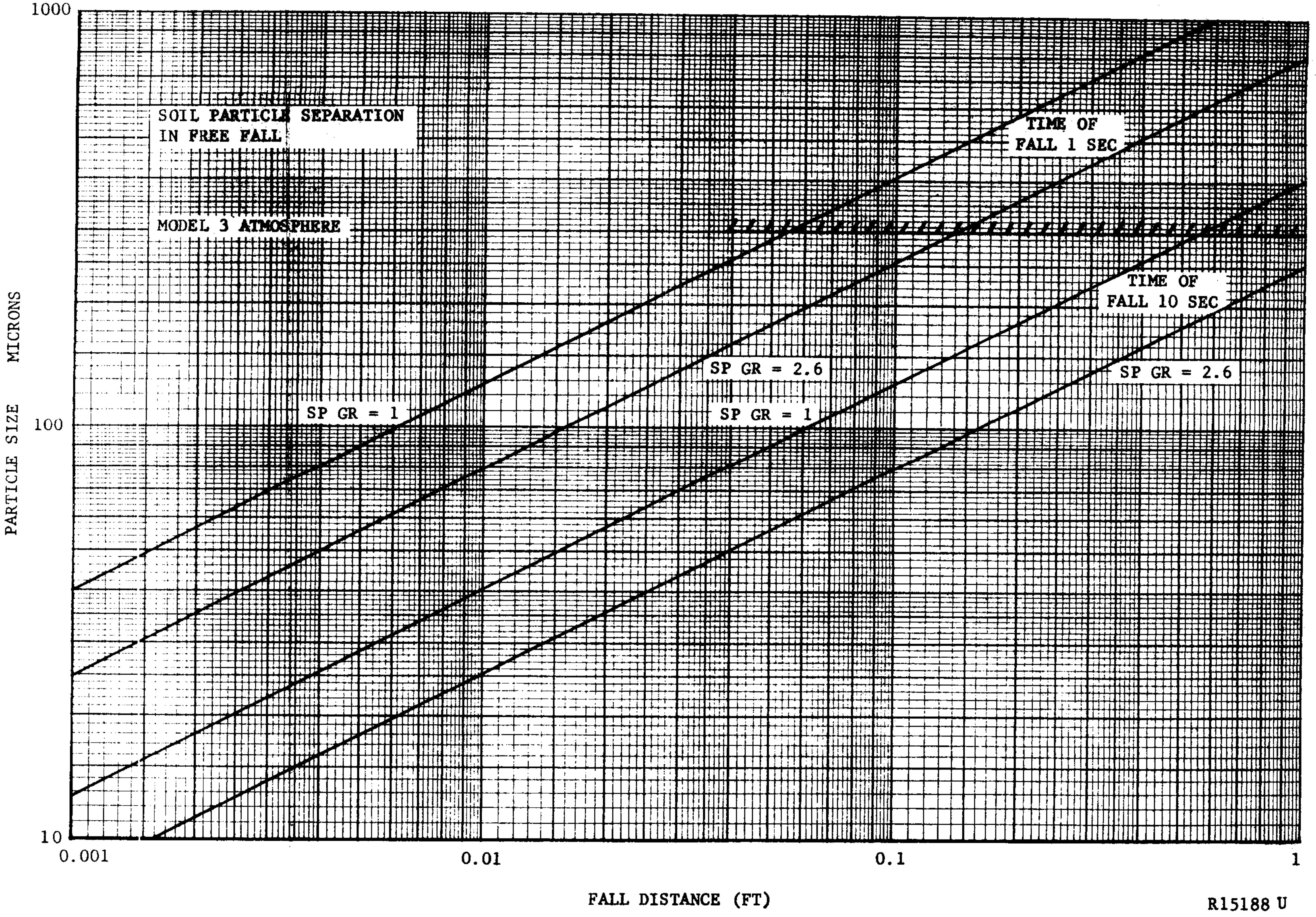

FIGURE 4.5-34. SOIL PARTICLE SEPARATION IN FREE FALL

particle size separation desired is 300 microns or less. If several ranges of sizes were desired, the pulverized soil sample should be dropped in finite quantities at predetermined intervals. The cross flow would then gather samples at a predetermined time based on the fall time for the particle size range desired. At appropriately timed intervals, the flow could be diverted to a different collector to collect the next size range of particles. A similar method of soil particle separation has been reported by Puri(21) for determining soil particle sizes for terrestrial soils except that the working fluid he used is water rather than atmospheric gases. The technique as suggested is not as applicable to gathering the larger particle sizes although it could be extended to particle sizes up to a millimeter for reasonable cross flow velocities as indicated in Figure 4.5-33.

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SECTION 5

LABORATORY PRELIMINARY DESIGN

5.1 PRELIMINARY DESIGN ANALYSIS-OBJECTIVES AND CONSTRAINTS

5.1.1 OBJECTIVES

The principal objectives of the preliminary design study were the following:

a. ABL Preliminary Design Studies. The execution of a first order preliminary design of an automated laboratory meeting the requirements defined as a result of the studies reported in Volume II of this report was a primary objective of this study. The results of the preliminary design study were utilized to determine representative payload and subsystem sizes, weights, power requirement, data loads, data processing and control requirements and to identify major problem areas related to payload mechanization, component developments and attainment of operational objectives. These objectives were attained by selecting a representative near-optimum configuration for the preliminary design analysis. A rigorous optimization was beyond the scope of the present study. The results of preliminary design studies are reported in this Section (5) of this report.

b. Vehicle Interface Studies. A second important objective for the preliminary design studies was the identification and definition of the important interfaces between the ABL payload and its entry vehicle delivery system. The ABL preliminary design configuration developed in the studies described above were used to study these interfaces with the principal vehicle subsystems (electrical power, thermal control, data processing and communications) and with a wide range of feasible entry vehicle configurations. The results of these studies are reported in Section 6 of this report.

5.1.2 DISCUSSION

The principal steps in achieving the objectives set forth in the previous discussion included the following.

(1) The review of existing instrumentation and equipment suitable for achieving the objectives of the ABL, and the identification of required hardware developments necessary to make such items available in the appropriate time period. The results of these studies coverning laboratory instrumentation are found in Volume II, Paragraph 5.3. Discussions of requirements for equipment related to other specific subsystems are found in sections on these subsystems (e.g., Communications, Paragraph 6.2; Data Processing, Paragraph 6.3; Electrical Power, Paragraph 6.4; and, Thermal Control, Paragraph 6.5 of this Volume (III)). All of these studies were integrated into, and formed the basis for, the preliminary design study.

(2) Development of schematic diagrams, configuration drawings and physical and functional characteristics of new or combined prices of equipment required to satisfy unique requirements of the ABL and to determine their feasibility. Laboratory instruments falling in this category are discussed in Paragraph 5.3 of Volume II. Processing, sampling and other equipment peculiar to the ABL System are discussed in Paragraph 5.5, Principal Laboratory Subsystems, in this Volume.

(3) Development of operational sequence event diagrams and charts demonstrating experiment phasing and power, data load and command control time histories, and to identify the principal vehicle, payload and subsystems operational sequences. The former have been discussed in Paragraph 4.2 of this Volume in connection with Automation. The latter are covered in Paragraph 5.6 of this Volume, Laboratory Assembly and Functional Operation.

(4) Design analysis of representative payload and subsystem configurations by means of configuration studies and the determination of sizes, weights, power requirements, and functional suitability. This task included trade-off analyses of critical alternative approaches to internal laboratory mechanization as reported in Paragraphs 4.4 and 4.5 of this Volume. The results of the preliminary design studies are covered in Paragraph 5.3 below.

(5) The evaluation of various ABL components and systems, as well as the composite laboratory, for compliance with sterilization requirement. These studies are described in Paragraphs 5.3 and 5.7 of this Volume.

Extensive parametric trade-off studies involving the comparative analysis of widely different means of accomplishing the same functions within the ABL were not conducted as a part of this study for two reasons:

(1) It was necessary to restrict the study within reasonable bounds in this way in order to accomplish an analysis of the design point case in sufficient depth to reveal the important interactions within such a complex payload as ABL.

(2) Efforts originally scheduled for investigations of alternative approaches were employed, at NASA's direction, in the special studies reported in Section 3 of this Volume.

While near-optimum approaches were used based on certain detailed subsystem tradeoffs, previous design studies of similar systems and logical choice of design alternatives, and which were adequate for purposes of achieving the stated objectives of the preliminary design analysis, rigorous optimization of the payload remains as a necessary objective of a subsequent and more detailed study.

5.1.3 STUDY CONSTRAINTS

The principal study constraints imposed by NASA for purposes of the preliminary design study were:

(1) Mission Time: 1975*

(2) Mission Duration: Two Earth years.

(3) Payload Size: 500 - 1000 pounds.

(4) Mission Philosophy: The mission is to be a comprehensive biological and related environmental mission, probably following orbital and possible single entry or landing, missions in 1969, 1971 and 1973.

Some of the principal conclusions resulting from other parts of the study which provided criteria or constraints on the ABL preliminary analysis included the following:

(1) Primary power source will employ an RTG** with rechargable batteries to carry peak loads.

(2) Primary communication mode will be direct to Earth and will employ a fan beam, oriented antenna.

(3) Multiple sampling sites are required with five samples collected at each site over the two year period.

(4) Separable roving sampler or roving ABL will not be employed because it does not represent a significant enough improvement over other methods for inclusion in the first ABL.

(5) Internal laboratory organization will employ a form of batch processing and will be mechanized and controlled on a flexible format to permit reorganization or direction, either internally as a result of experimental output, or externally by Earth command, to take advantage of preceding experimental results and bypass failed components.

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* Selected studies were performed, however, in certain areas where time period was critical, such as communications, to evaluate the effects on system performance within the 1970-1980 time period.

** Radioisotope Thermoelectric Generator

5.2 DESIGN CRITERIA

5.2.1 GENERAL

The design criteria employed in the preliminary design study are composed of operational and performance requirements, major interfaces, natural and induced environmental constraints and reliability goals. This section presents a broad general discussion of these areas. Operation, performance, maintenance, and induced environments are discussed according to mission phase. The space and Mars surface environment and reliability considerations are presented separately. More detailed design requirements and constraints are discussed as appropriate, in each of the design and interface study sections.

5.2.2 PRELAUNCH PHASE

a. Sterilization Procedure. The fundamental consideration in design is dictated by terminal sterilization requirements. Tentative requirements established by NASA are:

(1) Qualification. 145°C for 36 hours, 3 cycles dry heat bake.

(2) Operational. 135°C for 24 hours, 1 cycle dry heat bake.

The sterilization procedure is accomplished on an encapsulated ABL which remains sealed until some point prior to entry and after injection into the transfer trajectory. Additional surface sterilization treatments which may be used prior to baking are:

(1) 121°C for 15 minutes in saturated steam autoclave

(2) Ethylene oxide decontamination

(3) Ozone decontamination

In addition to sterilization, residual materials from other sources such as chips, dust, oils, solvents, and acids which will affect reliability shall be controlled. The design will allow thorough mechanical and chemical cleaning and final subassembly and assembly operations will be accomplished in a clean room.

b. Maintenance and Checkout. In a preliminary design study this area must remain somewhat qualitative. However, the following basic philosophies and concepts will be considered in the design.

(1) Instruments will be calibrated and checked individually prior to assembly and caged where required for handling and transport. Instrumentation that will indicate a premature release of the caging mechanism is assumed.

(2) The final assembly consists of checking for operation, except for analysis instruments, prior to encapsulation and then stowing or caging as necessary.

(3) After encapsulation and terminal sterilization parts will not be replaced. Checkout from this point will consist of monitoring caging mechanisms for premature release, monitoring and controlling the internal thermal environment (which will be maintained at $0^\circ C < T < 75^\circ C$) and monitoring the encapsulated atmosphere for leaks. Leak detection will be monitored by pressurizing and noting the pressure change. The internal pressure shall not vary by more than ±0.01 percent after corrections for temperature have been applied. This system can also be used to detect leaks in gaseous containers or gases evolved by spontaneous chemical reactions. A drop in pressure will indicate a leak in the encapsulation shield and an increase in pressure, an internal leak or reaction. Any absorption or outgassing by internal components will be stabilized 100 hours after terminal sterilization. Individual pressures of each gaseous storage will be monitored to assist in determining spontaneous chemical reactions.

Other items to be monitored or checked consist of power supply output, programmer operation, and operation of passive elements such as light sources, heating elements, and detectors where these do not entail operation of an instrument requiring it to be uncaged.

c. Handling Loads. The encapsulation shield shall provide attach points for a ground handling fixture as well as the necessary hermetically sealed umbilical connection. It is assumed that the encapsulated ABL will endure loads not to exceed ±3 g along any axis. It is assumed that any mode of handling that exceeds these values will be avoided. Although the ABL will be designed to sustain much higher load factors in other conditions, this limit is set on ground handling to minimize abuse. As a control check, it is also assumed that recording accelerometers will be installed in the ABL package and the maximum value that these indicate will be part of the prelaunch check.

5.2.3 LAUNCH AND BOOST PHASE

The booster system assumed for the Voyager/ABL payloads is the Saturn IB using a S-I first stage, S-IVB second stage, and the S-V "Centaur" third stage. Configuration and performance data as given in Reference 1 were used as required by the study.

a. Operational Mode. The operational mode in this phase is defined as an engineering standby mode in which certain functions are performed as required to prevent breakdown of equipment. Indications are that some pieces of equipment will be started up prior to terminal sterilization and will operate for the lifetime of the laboratory. Two specific examples are a radioisotope thermoelectric generator and an ionization vacuum pump. Continuous monitoring and control of such equipment will be required to maintain allowable temperatures and to preclude inadvertent shut down.

b. Environmental Control. During launch and boost any additional environmental loads such as increased thermal input will be controlled and limited by boost system components so that no additional design requirements are imposed on the laboratory. The temperature limits will be the same as stipulated for the prelaunch phase ($0^oC < T < 75^oC$). Load factors, of course, must be tolerated by the ABL; however, these are less severe for launch and boost than entry and landing. The acoustic environment as indicated in Reference 1 is a peak at launch and is approximately 146 db at the payload. Attenuation through the exit heatshield and the sterilization encapsulation envelope can probably be controlled to provide an acceptable level at the ABL components. For this study it is assumed that acoustic noise will not influence the design of the ABL.

5.2.4 INTERPLANETARY TRANSIT PHASE

a. Operational Mode. The operational mode in this phase is essentially a continuation of the engineering standby phase.

b. Environmental Control. The environmental control in this phase is likewise essentially a continuation of the prelaunch and launch phases. The ABL provides the necessary components integrated into the sterilized package to maintain the temperature between 0^oC and 75^oC. It is also assumed that the Voyager bus will provide any additional meteorite protection required to achieve a given low level of probability of penetration which cannot be afforded by the sterilization encapsulation shield. A probability of no penetration in 8 months of 99.9 percent is considered to be a reasonable goal.

5.2.5 ENTRY AND LANDING PHASE

a. Operational Mode. The engineering standby mode is continued with the addition of operations associated with entry and landing. Since the sterilization encapsulation shield will probably contain both the entry vehicle and the ABL, it is assumed that this shield is separated sometime prior to initiation of the entry sequence by command from the Voyager bus system. It is also assumed that the ABL and entry vehicle would share the command and control center functions during entry and landing. Thus, on receipt of Earth command to initiate the entry sequence, the control computer and programmer would be activated. A typical entry and landing sequence is outlined as follows:

t_o	Separate entry vehicle from Voyager bus.
t_{EC}	Receipt of Earth command to initiate entry mode.
(t_o + several days)	Turn on central computer and programmer and perform check on entry components.
t_{EC} + 15 min	Orient and fire retro rockets.
t_{EC} + 16 min	Orient for entry and activate attitude control. Atmospheric entry begins. During entry, attitude control is maintained. Entry accelerations, heat flux, total heat, and dynamic pressure are recorded. ABL sampling is initiated in this phase by obtaining and storing atmospheric samples at periodic intervals for subsequent analysis.
t_p	Sense g level to initiate drogue chute deployment.
t_{PMR}	Activate altimeter and deploy main chute in reefed condition.
t_{PM}	Sense minimum g level and/or altitude to activate disreefing.
t_{PS}	Sense minimum altitude and velocity for parachute separation. If velocity is sufficiently low, entry will be completed without a rocket retro boost and the parachute will be separated at or just prior to impact. If velocity demands retrorocket boost, separate parachute and begin free fall.

$t_I - t_p$	Sense altitude and velocity at which retrorocket boost is initiated. A fixed impulse retro boost is assumed. At end of burnout sense and record altitude and velocity, both vertical and horizontal components.
t_I	ABL and/or entry vehicle impact. This initiates the surface operations for the ABL.

b. Environmental Control. The same philosophy is employed as before in that the entry vehicle will control and limit the heat input into the ABL. Maximum allowable temperature for the ABL and components is 120°C. This is approximately 10 percent less than the terminal sterilization. The ABL temperature at the beginning of entry is between 0°C and 75°C which is maintained during the transit phase. The 120°C temperature is assumed to be either the maximum achieved during entry or the post landing heat soak which occurs before the ABL is rigged for surface operations.

c. Loads. The maximum acceleration during entry for a $\beta = W/(C_D A) = 5$ lb/ft^2 using the Model 3 atmosphere is 167 Earth g. This is an estimated upper limit which is used as a basis for defining the entry loads encountered by the ABL. The major load conditions are therefore defined as follows:

(1) Steady state loads:

  (a) 180 g axial

  (b) ±20 g lateral

(2) Dynamic loads:

  (a) Vibration (undetermined)

  (b) Shock 500 g maximum resultant

The shock load is applied in such a manner that the vertical and horizontal components will not produce a resultant greater than the specified maximum.

Load factors to provide a margin of safety are:

(1)	Basic structure	n = 1.05 applied to yield n = 1.25 applied to ultimate
(2)	Instruments and processing equipment	n = 2.0 applied to yield

Note that the load factor for the instruments is to be applied in the caged configuration.

5.2.6 MARS SURFACE OPERATIONS

There are two modes of surface operations, the engineering mode and the scientific mode. These operations will be conducted concurrently on a continuous basis; the phasing of power demands will, in general, give preference to the scientific mode.

a. Engineering Operations. The operations consist of the following major functions.

(1) Power Generation and Control. This includes a primary power source and a secondary power supply which may include batteries, chemical fuel, and a pressurized gas supply.

(2) Sequencing and Control. This function is performed by a central computer and programmer through which all decision making and control commands are issued.

(3) Communications. This function includes the Earth to Mars command link and the ABL-to-Earth telecommunications link. S-band will be used for the Earth to Mars link. The 210 foot diameter antennas in the Deep Space Instrumentation Facility are assumed. Both the direct link and relay links will be considered in terms of reliability and suitability.

(4) Environmental Control. These functions are those associated with maintaining a suitable operating environment within the ABL. Specifically these include temperature control, internal atmospheric quality and pressure, and external effects such as wind and dust.

The laboratory is assumed to have an inert atmosphere of dry nitrogen at time of arrival on Mars. After arrival this atmosphere will be maintained until environmental analysis indicates the safe use of Martian atmospheric gases. For estimating gaseous N_2 supply requirements the most severe assumption that Martian atmospheric gases cannot be used will be made. Where experimental requirements dictate the use of a Martian atmosphere, such as in a growth experiment, this will constitute a subenvironment confined to a specific piece of apparatus.

The temperature of the laboratory will be controlled at 4°C ± 3°C. This is defined to be as low as possible without freezing water. If water is allowed to freeze the laboratory functions, particularly chemical processing, cannot be accomplished.

The effect of wind and dust on the operational mode of the ABL will be evaluated in terms of surface degradation of optical or thermal control surfaces and physical threats such as damage, turn over, and burying. The engineering operations mode will sense critical conditions and perform the necessary preventative or corrective actions.

(5) Mobility. This function involves the actions of transfer and transport required to collect samples, and move and process samples within the ABL. Detailed specifications and assumptions pertaining to sample collecting are given in Paragraph 4.5, Conceptual Sampling Studies. Batch processing is assumed for the initial preliminary design of the transport mechanism.

From the standpoint of developing a mapping an orientation system to be employed by either the sample collection subsystem or the transport mechanism within the ABL, a polar coordinate system for identifying sample sites or equipment locations is the simplest to implement and control. Thus, a radius vector which identifies a distance of an angle, using the ABL as the origin, is proposed. Such a coordinate system is compatible with both optical and radio ranging techniques and provides the simplest set of guidance and transport requirements. When a three dimensional system is required, a spherical coordinate system external to the ABL is assumed. Within the laboratory a cylindrical coordinate system is assumed as being most compatible with probable structural arrangements.

(6) Checkout and Repair. These engineering functions are identified as detecting equipment or component failures and initiating remedial action. They are different from the scientific function of calibration, which is described later, by the fact that only equipment component failures or malfunctions are involved rather than instrument drift or procedural errors. Examples of typical failures are lamp burnout, bearings seizure, atmospheric contamination, etc. Repairs or corrective action will be taken either by replacing a component, using alternate equipment, or by initiating a corrective routine. The philosophy of design will be that these checks and repairs will be accomplished automatically and failure information stored. This information will not be transmitted except on demand from Earth or when the failure incidence is sufficiently high to put a major experimental sequence at the point of incipient breakdown. Incipient breakdown is assumed to occur when only one more failure of any element or component that cannot be repaired remains in a particular experimental sequence.

b. Scientific Operations

(1) Sample Collection and Grading. The specific details of these functions of the ABL are defined in Paragraph 4.5.

(2) Sample Processing. These operational functions are those concerned with converting the raw or graded samples into the form required for a specific analytical instrument which will obtain the quantitative results of a given experiment; the bulk of the sample processing occurs as chemical reactions and growth cultures.

(3) Waste Control and Recycling to Initial Conditions. Those operational functions required to dispose of waste products and used samples, and to prepare the equipment for re-use. For design purposes, the following levels of cleanliness are defined.

(a) Sterile. This is defined as recycling the equipment to its original state achieved in terminal sterilization. As such, it implies a repetition of the original dry heat bake cycle.

(b) Biologically Clean. Biologically clean is defined as recycling to a condition that is stated as acceptable by the experimental technique. This implies that any microorganisms or organic matter that remains will not produce a positive result when the procedure is repeated with a blank or sterile sample.

(c) Chemically Clean. This is defined as recycling to condition equivalent to that defined in biologically clean for processes involving only chemical reactions. As before, this implies that any chemical residue that remains will not produce a positive or erroneous result when the procedure is repeated with a blank or chemically inert sample.

(d) Mechanically Clean. Mechanically clean is defined as a condition in which 99 percent of the solid particles left on a surface are less than 10μ in diameter. Ten microns is the lower limit of visual observation by the unaided human eye and also is roughly the line of demarcation between virus, bacteria, and chemical fumes and ashes, dust plant spores, or pollen.

In order to minimize contamination of the laboratory, all waste solids and disposable components will be transferred to a sealed compartment in the laboratory. Solutions will be evaporated to dryness and the residue disposed of as solids. Evaporated gases and vapors as well as waste gaseous samples will be dumped into the external atmosphere after being filtered through a one micron filter. Passing the gaseous waste through a flame to provide sterilization and combustion of inflammable products will be considered.

(4) Calibration and Analysis. These functions are operations which need to be performed to ensure that the analytical data are reliable and quantitatively accurate. Calibration will consist of uncaging the instrument from the standby condition and performing an analysis using a known standard or reference sample. A calibration run will be performed before and after each experimental analysis is performed.

(5) Data Sampling and Processing. This operational function is concerned with conditioning the data output of the analytical instruments and sensors to put it in a form suitable for transmission to Earth. All data will be digested in digit form for transmission. Where possible, the design philosophy will be that instrument output will be digital; however, this should not penalize the quality of the data output.

5.2.7 ENVIRONMENTAL CONSTRAINTS

This section considers the natural criteria not induced criteria such as vibration, acoustic noise, etc. The latter are discussed as pertinent in the appropriate design section. The natural criteria are discussed as a function of mission phase. These criteria fall into two principal categories, the space environment and Mars surface environment.

a. Earth-Mars Transit. The ABL will be in the space environment for 8 to 9 months. There are no scientific operational requirements, however there will be equipment operating to perform engineering functions such as thermal control. Such equipment must be designed to operate in the space environment which include:

(1) Zero gravity

(2) Zero pressure

(3) Solar constant, 442 Btu/hr-ft^2 at Earth orbit decreasing to a minimum of 157 Btu/hr-ft^2 at Mars orbit (aphelion).

(4) Heat sink of outer space 4°K.

(5) Meteoroids - As previously mentioned, it is assumed that the Voyager bus provides any protection needed beyond that provided by the sterilization shield.

(6) Van Allen Belt - The spacecraft will pass through the Van Allen Belt; however, for this study it is assumed that the shielding provided by the entry vehicle and the sterilization shield will protect the ABL.

b. Mars Surface Operation. The Mars surface environment is discussed in detail in two other sections of the report. The soil and terrain models are presented in Paragraph 4.5, Conceptual Sampling Studies. Atmosphere, temperatures, wind velocities, etc., are discussed in Paragraph 6.5, Thermal Design Studies.

5.2.8 RELIABILITY CONSIDERATIONS

The ultimate success of an automated biological laboratory can be expressed in terms of a probability of nonfailure of the various components for a given lifetime. The total lifetime of the ABL system consists of two years' operation, 8 to 9 months in transit from Earth to Mars, and an undefined period of shelf time before launch. Thus, a total system lifetime of approximately three years minimum is required. The event sequences described in Paragraph 5.6 define the operational life requirements for various components. Thus, all components will have lifetimes which consist of two parts which are defined as down time and operational time. Ultimately, the reliability of the data obtained must be evaluated in order to assess the total mission reliability. For purposes of evaluating the reliability of the design, however, it will be considered that the data reliability can be equated to the probability of successfully completing an experimental sequence, assuming all other necessary support functions are performed. (See Paragraph 4.4)

Two fundamental philosophies are listed below:

(1) Design simplicity and the use of passive components; i.e., probability of failure will be assumed to be directly proportional to the increase in the number of moving parts and the type of motion.

(2) Parallel redundancy will be employed wherever failure prone elements can be identified and some measure of their failure rate assessed.

The reliability analysis will assume that the laboratory shall achieve a probability of approximately 95 percent of obtaining one set of pictorial data and 80 percent of all other data during the first 43-day complete experiment cycle, and that the overall laboratory shall have a probability of 50 percent of successfully obtaining the same data in the full two-year lifetime. Although this definition of reliability is somewhat arbitrary, it will serve as a useful index to obtain an estimate of the critical elements and/or critical sequences, and is used in the reliability analysis, (see Paragraph 4.4).

5.2.9 REFERENCES

1. NASA paper presented to American Astronautical Society, Denver, Colorado, "Description and Status of Saturn IB," April, 1963.

5.3 PRELIMINARY DESIGN ANALYSIS AND SYSTEM DESCRIPTION

5.3.1 SYSTEM DESIGN

The preceding paragraphs have delineated the criteria and constraints which control the ABL system design. The scientific mission objectives which must be attained within these limitations are clearly set forth in Volume II of this report. Some of the more important considerations relating to the automation aspects of the ABL design have been discussed in Section 4. The preliminary design analysis of a representative design point ABL was accomplished while working within the boundaries of these various criteria and constraints. A very large number of additional broad system design considerations were evaluated during the development of the analysis and the more important of these will be discussed briefly here to serve as a background for the detailed results of the study which will follow.

a. Type of Investigation. An initial study of a new system such as the ABL can take two basic directions: a broad parametric approach and a more specific design analysis approach. The reasons for placing a great deal of emphasis on the design analysis in this phase of the study have been discussed in Section 2. The implications for this portion of the study are that certain mechanical and subsystems details could be examined sufficiently to demonstrate feasibility of the concept and to make valid assumptions regarding weight, power, volume, reliability, and other operational characteristics of many of the principal ABL subsystems. These results are far more realistic than those that would have resulted from a broad parametric study that had to consider a wide range of system concepts and performance. For optimizing system performance, parametric evaluations over relatively broad ranges are mandatory and must follow the studies performed here. Optimization, however, was not the primary goal at this early stage. Demonstration of feasibility and identification of principal system and hardware development problem areas was the principal, and most appropriate, objective at this time. To satisfy this objective, enough depth of detail must be achieved in the analysis to bring to light the fundamental problems inherent in the system concept. Optimization of the ABL, in any case, must await a more detailed definition of certain scientific objectives and approaches by NASA and the scientific community. The solution of the engineering problems need not be so delayed, however, since they have been identified by this study and can be efficiently attacked on a reasonable development schedule, as demonstrated in Volume IV of this report.

At the same time, the detail demonstrated in this design should not be taken to indicate exhaustive mechanical design analysis or optimization of indicated subsystems. In general, such analyses were taken far enough to demonstrate a feasible mechanization. Other feasible mechanizations undoubtedly exist and subsequent optimizations are required to identify the proper choice among the alternatives. The present design point example was intended, and should prove, to be a useful starting point for such future system evaluations.

b. ABL System Definition and Entry Vehicle Interface. The fundamental factors defining the ABL concept, as laid down by the NASA work statement for this study, have been discussed in Section 2. The interpretation of these definitions for purposes of the preliminary design analysis require some elaboration. For example, data processing and laboratory control are intimately ABL-related functions. And yet these functions and the communications aspects and the electrical power requirements (communications considerations representing the single largest power requirement) are inseparable, from a system sense, and nearly so from a functional sense. While laboratory internal environmental control is clearly an ABL concern, its solution is so intimately related to the thermal characteristics of the electrical power system and other electronic components that the problems are systematically and functionally inseparable. Many more examples could be sited. Therefore, while the various subsystems can be considered as "interfaces" from a conceptual point of view, they must be considered integrally from a system design point of view, and were so considered in this analysis.

While such considerations pertain between the ABL and the various subsystems the same does not hold true between these entities and the entry vehicle employed for their delivery to the Mars surface. No strong interfaces were identified in this area as a result of this study. (See Paragraph 6.6.5, "Summary of Principal Payload/Entry Vehicle Interfaces".) These factors lead to consideration of conceptually very clean interfaces between the landed payload and the entry vehicle. For purposes of this study, at least the following reasons supported this approach.

(1) Entry Vehicle Interface. A defined task for this study was an evaluation of the effects of an ABL payload on the entry vehicle, i.e., the payload/entry vehicle interface. The entry vehicle concept to be employed for 1975-class Voyager missions is not yet defined. If the ABL components were individually integrated into each of the various entry vehicle structures, this fact would have required that a detailed design analysis of many different entry vehicle concepts be performed in order to develop the internal packaging arrangements for each. This would have been a sizable task, defeating the objective previously stated of attaining a detailed understanding of the subsystems (since any one concept could not have been pursued in adequate depth). A more satisfactory solution was to consider the landed payload (a term used hereafter to designate the science payload or ABL plus its necessary supporting subsystems landed on Mars) as an integrated unit having a clean interface with the entry vehicle. By this approach, a comprehensive effort could be pursued on one packaging arrangement to achieve the desired detailed evaluation, and this one payload evaluated on a consistent basis with each of the entry vehicle

concepts. This approach was further justified by the results of the analysis (Paragraph 6.6, "Entry Vehicle Technology and Conceptual Design Studies") which revealed that, with the present low density estimates of the Mars atmosphere, the sizes of the entry vehicles required to achieve the necessary low values of β are such that the size of payloads having the weight and density of the ABL are not a controlling factor.

(2) Landed Payload System Analysis. The consideration of the intimate relationship existing between many of the subsystems and the ABL also could be much more effectively studied on this basis. In addition to the interfaces already mentioned were such additional factors as antenna erection and pointing requirements and their relationship to the laboratory erection and deployment functions, the utilization of the laboratory water supply as a passive nonconsumable element in the thermal control system, and many more.

(3) Terminal Deceleration and Landing Concept. The study reported in Paragraph 6.6.3 indicated the probable performance advantage (improvement in payload ratio) that can be expected if the payload is separated from the entry vehicle during descent on parachute and landed separately. Even if this advantage should prove to be small, a functional advantage accruing to this same approach is the greater confidence in the landed conditions and orientation of the payload; that is, the elimination of the requirement for deploying various payload functions, such as sampling devices, from a large lightweight structure which may have been deformed in unpredictable ways as a result of the landing impact. In comparison to very low β entry vehicle structures, the ABL landed payload structure is extremely compact and rugged, and can readily be designed to survive tumbling on landing. These several considerations, of course, support the concept of a separable landed payload which lends itself ideally to parachute extraction from the entry vehicle.

The above arguments, as well as others, appear to be so favorable that this approach was adapted for the study. Within the resulting landed payload, as defined, there remains the essential interfaces between the ABL and its supporting subsystems, and these have been defined by the analyses reported in Section 6. However, by adopting this systems approach, the entire payload has been considered as a functional entity, permitting a far more thorough analysis of the interactions of system functions than could otherwise have been possible.

c. ABL Landed Payload Conceptual Arrangement. After the above considerations relating to the separable payload concept were adopted, the next question to be assessed was that of the conceptual arrangement of the laboratory that would best satisfy the many functional demands. The selected basic cylindrical layout of the processing functions of the laboratory, housed in an overall spherical configuration, was influenced by the following factors.

(1) Terminal Deceleration and Landing. Consistent with the consideration of extraction of the payload from the entry vehicle, a compact nearly symmetrical shape is desirable. The sphere is eminently suited to this requirement. Furthermore, it is probable that the actual landing may be hard or semi-hard, and that the orientation of the final velocity vector with respect to the surface may not be well controlled. If this landing technique should prevail, an omni-directional (orthotropic) impact deceleration structure around the payload is called for. Such orthotropic protection is most easily provided on a basic spherical shape. Even if a soft or semi-soft landing is anticipated, a high margin of safety against subsequent tumbling after initial contact, due to either poor control of the orientation of the contact velocity vector or terrain unknowns, is a desirable feature in contrast to the rather marginal performance of the Surveyor concept in this respect. The spherical concept, as developed in this study, is eminently suited to this requirement.

(2) Structural Efficiency. A basic spherical shape is well suited to resisting the loads associated with the landing functions described above, as well as internal pressure loads created by the laboratory controlled atmosphere. While the spherical shape is geometrically the most efficient for enclosing a given volume, this advantage frequently disappears when employed as a packaging shape due to the reduced packing efficiency (waste space) resulting from enclosing "square" boxes in the spherical volume. This effect is very dependent upon the ratio of the sphere diameter to the average "box" dimensions, however. In the case of the ABL, this ratio is very large (~10 to 100) and is not a limiting factor in achieving high packing density.

d. Operational Orientation. In general, any final orientation of the laboratory can be considered, from random to alignment to the local vertical. Aeronutronic had previously designed landing payloads (Ranger hard landing capsule) that would function properly with any terminal orientation of the payload capsule. This was accomplished by floating the equipment inside the outer shell and allowing it to erect internally after landing. A similar action could also be accomplished functionally by internal gimballing of the payload elements. These techniques are most applicable to small, high density packages, however. When landing loads must be taken out at discrete gimbal attachments to a heavy but relatively low density package, or the package completely enclosed in a flotation fluid, the weight penalty is severe. A further complication for a payload as complex as the ABL is the subsequent deployment, after landing, of the many auxiliary functions, such as sampling systems.

Aeronutronic had also previously investigated lander payloads having one principal plane of symmetry (a flat disk) and which would function satisfactorily regardless of which face of the disk was down. This concept is attractive for certain types of payloads, generally with fairly simple functions. Mechanization of the concept for a payload as complex as ABL appeared to present unnecessary problems.

The need to erect the laboratory quite accurately to the local vertical seemed clear for several reasons. Chemical processing equipment could be made much simpler and lighter in weight if the location of such things as fluid-gas interfaces and gravity gradients could be known in advance. In addition, such functions as deployment of sophisticated sampling and boring devices are highly dependent on a knowledge of the laboratory orientation. Experiments involving imaging and spectral scans of the sky and surface are also orientation dependent as is the pointing of efficient high gain communication antennas. It also seemed reasonable that such an orientation capability was consistent with the general level of sophistication of the ABL, and further, that its implementation was not a major design problem. The resulting spherical concept previously discussed was adaptable to an oriented final operational configuration by the simple addition of legs which could provide the dual function of a turn-over structure and leveling mechanism. This concept was therefore adapted.

e. Internal Environment. A further major consideration in the preliminary design is the harsh Martian environment. With the tenuous atmosphere and low water content on Mars, the daily temperature variations will be high and the atmosphere will be, at least periodically, extremely dusty. The extremely low atmospheric pressure, humidity, and unknown atmospheric composition, coupled with the large daily temperature variations, would defeat any attempt to perform wet chemical processing based on Earth conditions. This then sets a fundamental requirement that the basic laboratory be pressurized to some value near one Earth atmosphere and that the temperature be maintained at least above the freezing point of water. Some components, such as the secondary storage batteries, will require even higher operating temperatures to perform efficiently. Some equipment items such as high resolution optical equipment also demand that the temperature variations be minimized if calibration and alignment errors are to be avoided. Sealing and pressurizing the laboratory also enhances the reliability of the various mechanisms and drives by providing a boundary through which surface dust cannot penetrate, thereby reducing wear and failure rate. The automated biological laboratory, then, should employ a complete internal environmental control system employing a sealed atmosphere at a positive pressure with respect to the ambient to exclude dust and other unwanted material and to permit conventional processing to be performed.

f. Internal Laboratory Organization. The studies reported in Section 4 of this volume relate to several aspects of internal laboratory functions, and these will be reviewed here with respect to their effect on the conceptual internal organization of the laboratory.

The first consideration was the selection of the proper processing concepts which would be compatible with automation of the laboratory. The continuous flow process was seen to be incompatible with the flexibility of operational sequences required for the ABL. In addition, this approach suffers by virtue of the fact that it is not conservative in the consumption of processing supplies and the means for reliably preventing cross-contamination between sequential experiments are not apparent. The batch processing approach on the other hand is ideally suited to precise quantitative control since displacement measuring techniques are more easily mechanized than flow rate measurements. The batch process also permits the use of individually prepackaged reagents in hermetically sealed ampules. Thus, the contents of each ampule are not as vulnerable to contamination before they are ultimately used. Within the batch processing concept, a further subdivision between fluid transport and mechanical transport was considered as discussed in Paragraph 4.4.2. The fluid transport concept has several problems associated with the continuous flow processing and does not lend itself readily to the transport of dry or solid reagents except in a finely divided form using pneumatic transport. The final decision on the use of fluid transport or mechanical transport ultimately must be related to the characteristics of the material being transported and the total quantity required. Thus, gaseous storage and bulk reagents, such as water and wash solvents are more efficiently stored in single containers and most easily transported through piping, whereas small quantities of reagents, dry reagents, and throw-away units, such as filters, lend themselves to individual packaging and mechanical transport. Thus, the laboratory design ultilized both methods of transport selected on the basis of the specific requirements.

A second consideration was that of the overall organization of the laboratory. Again, to satisfy the concept of automation for the ABL, which demands flexibility of interconnection between processing components and the analysis instruments, the questions of accessibility and transport are raised. Even before knowing the detail mechanization of each piece of equipment, it was necessary to develop the concept to be used for an address system to locate a particular component or reagent. This necessitated the development of some suitable coordinate system which could be defined in either rectangular, cylindrical, or spherical coordinates. To select the most appropriate system, the constraints imposed by the structure, storage columes, and the transport method to be employed were evaluated. From a qualitative viewpoint, the following generalizations can be made with regard to reliability and mechanical complexity. Rotational joints utilizing rolling elements, such as ball bearings, are less susceptible to siezing that sliding elements in translation. Actuation between physical limits can be repeated more precisely than with positional feedback control. If the degrees of freedom of motion that are involved are minimized, the failure modes for the mechanism are also minimized. With these considerations in mind, the simplest coordinate system would be a two dimensional polar coordinate system such as is shown in Figure 5.3-1. It should be noted that the arm sweeps out the entire volume from the axis of rotation eliminating the space for other uses. Thus, this approach can only be used to go to a given angular and radial address and transport from it to another at some point between the innermost radial position and

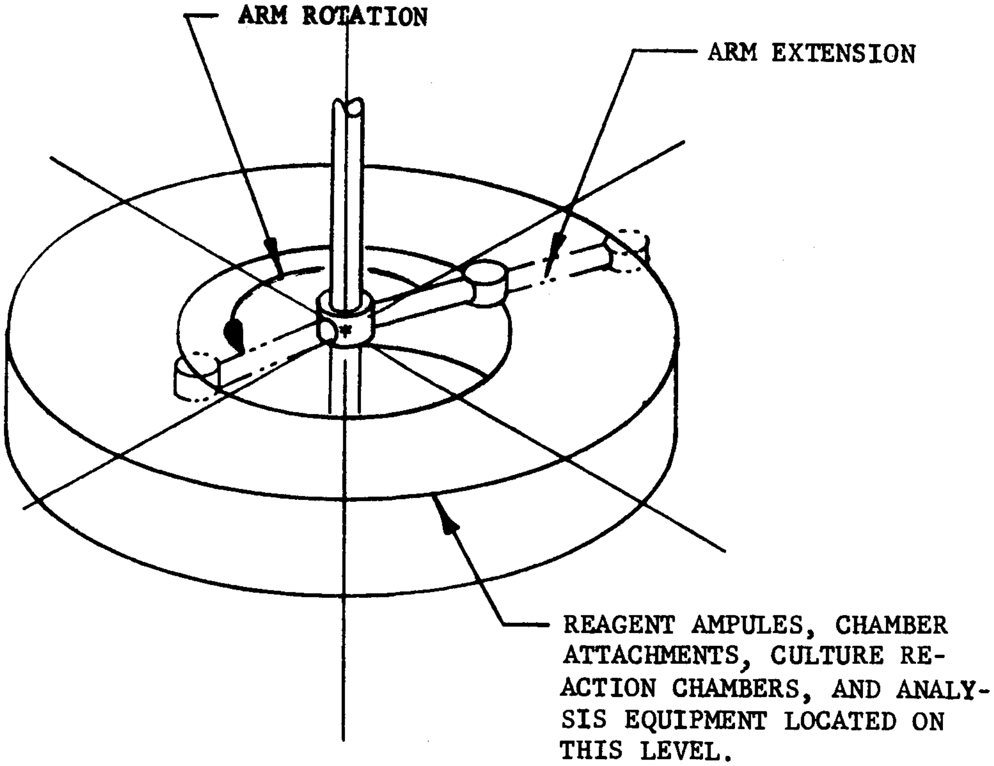

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FIGURE 5.3-1 TWO DIMENSIONAL POLAR COORDINATE INTERNAL TRANSPORT the outermost. This results in an inefficient system from a volumetric utilization viewpoint. The additional consideration that most chemical processing requires the introduction of various types of components at different levels, such as filters, at some level below the reagent ampules, would require this system to employ multiple transport units. Similar reasoning can be applied to a spherical coordinate address system as for the two dimensional polar system since the volume swept out by the transport system is unavailable for other uses, resulting in a spherical empty space at the heart of the laboratory. The mechanization of such a system is also more complex, because the angular elevation of the arm must be provided at essentially the same point as the angular azimuth. Thus, the cylindrical coordinate system as shown in Figure 5.3-2 was selected as the most suitable one for the initial preliminary design for the ABL. The volume swept out by this system is a cylindrical annulus with a disk at either end, allowing the central portion of the laboratory to be utilized as well as the outer portion. To provide a volume of space through which fixed interconnecting structure from the central to outer portions of the laboratory could pass, the angular address in azimuth is restricted to a sector of less than 360 degrees. In the selected design point case, the internal transport mechanism sweeps through 347 degrees.

After considering the coordinate system to be used for addressing and control, the functional components as they affect the laboratory organization are considered. The major functional items to consider, besides the internal transport mechanism, are chemical processing and culturing, soil sampling and grading, reagent and supply storage, and analysis and data collection. By the nature of their functional requirements, the reagent and supply storage should be located near the chemical processing and analysis system. Since the bulk gaseous supply occupied less volume than the reagent ampule and supply storage and were also adaptable to being wrapped around the central support structure by using toroidal tanks, these were located at the center of the laboratory. The chemical processing units were arranged around these since the required number utilized the full volume over the range of azimuth for the internal transport system. This also provided the simplest plumbing from the bulk supply storage to the chemical processing units. The reagent ampules and supply storage was then fitted around the central laboratory unit allowing a space for the transport mechanism between the storage and the chemical processors. The analytical instruments, power supply, and data processing and control computer were then arranged above and below this basic structure in terms of accessibility requirements to the internal transport system and available space. The function of sampling and sampler deployment requires that it be largely external to the basic laboratory functions. Thus the functional group is mounted above the laboratory, with the exception of the core drill, to provide ready access to the surrounding terrain.

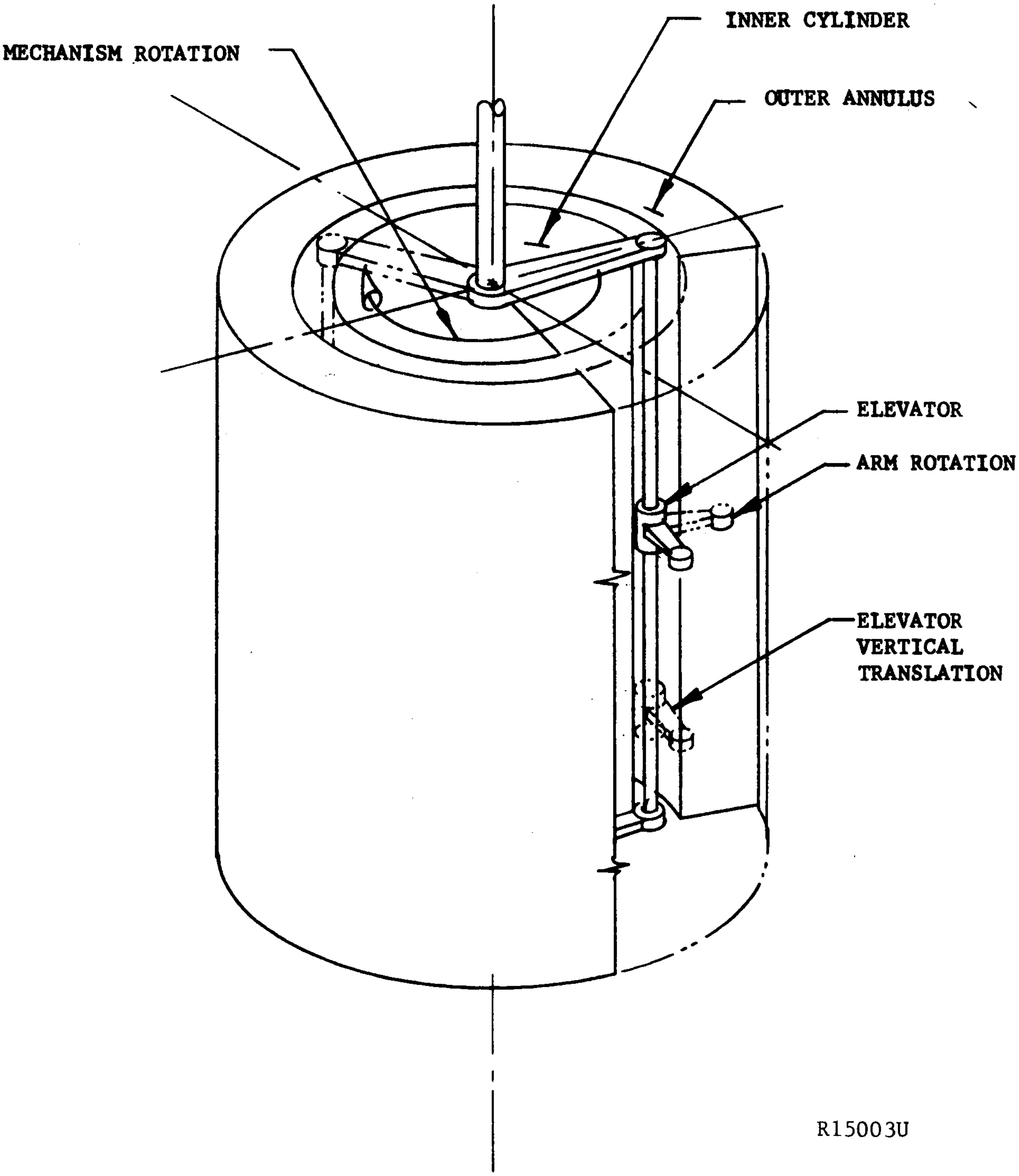


FIGURE 5.3-2 CYLINDRICAL COORDINATE INTERNAL TRANSPORT

Figure 5.3-3 shows these three basic laboratory zones and the basic structural elements consisting of the central tubular spine and structural bulkheads. Only the central zone in this concept is pressurized and temperature controlled.

5.3.2 SYSTEM DESCRIPTION

Based on the approaches presented in the foregoing discussion, a preliminary design configuration for the ABL was developed as shown in Figures 5.3-4 and 5.3-5. The configuration shown is packaged into essentially a sperical shape before deployment with a nominal diameter of 68 inches. The spine of the ABL is a 6-inch-diameter thin-wall tube, which stores the collapsed mast above the core drill. The mast consists of telescoping tubing supported by a ring at its base. Located at the head of the mast area are the pitot system, hot wire anemometer, humidity detector, motion detector, and macroimaging system. The mast also mounts the trolley cable support pulleys and remote sampler recovery mechanism. The mast is deployed by pressurizing the storage cavity and telescoping the cylinders and interlock at their extreme position to form a rigid unit. The core drill is stowed beneath and partially within the collapsed mast. The drill stem is made up of five hollow hexagon cylinders. The rotary table is motor-gearhead driven, and the drill stem interlocks during the drilling operation. A multiple blade core saw, mounted off the center spine cuts four core wafers at determined intervals and positions them for subsequent transfer. The drill stem is advanced and withdrawn with canted rollers bearing on the flat of the hexagonal stem. After the core hole is completed, the stem is withdrawn, broken into five segments and stored in its original position. The core hole sonde, stored in parallel with the stem segments is stepped into position and lowered into the core hole.

The upper level is depicted in plan view Section A-A of Figure 5.3-5. Two motor driven cable winches are mounted alongside the mast. The winches are used to control cable tension in the overhead trolley cables. Relaxing the cable tension when the remote sample collector is deployed lowers the sampler to the ground level. This permits complete flexibility of sample site selection within the limits of the cable length. Soil encapsulation chambers are mounted on a motor driven, bearing mounted table. Twelve chambers, four for proximity samples and eight for remote samples, are used to receive soil collected by the samplers. The stepper motor indexes the open chamber into the receiver position and soil from the sampler is fed into the chamber. Stepping the chamber table into the next position passes the loaded chamber by a proximity switch which releases the spring loaded cover plate. A delay system initiates firing of a pyrotechnic cover sheet that hermetically seals the sample within the chamber. Two soil samplers are stored on the upper bulkhead. The remote sampler is linked with the elevator so that the remote sampler can be deployed without secondary indexing. The proximity sampler is deployed by the upper arm which is rotated by the harmonic drive system mounted in the elbow. The sampler is lowered to

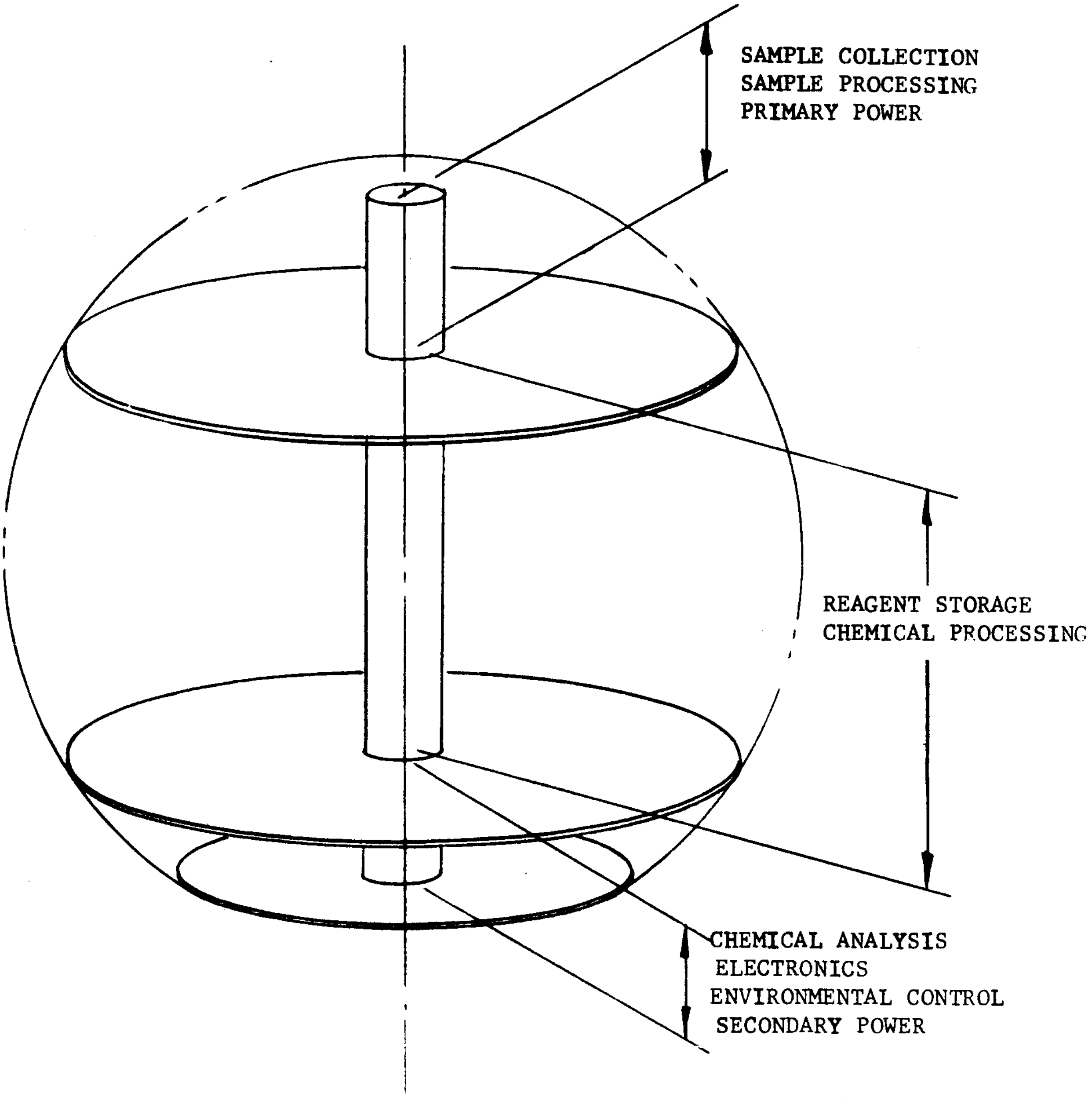
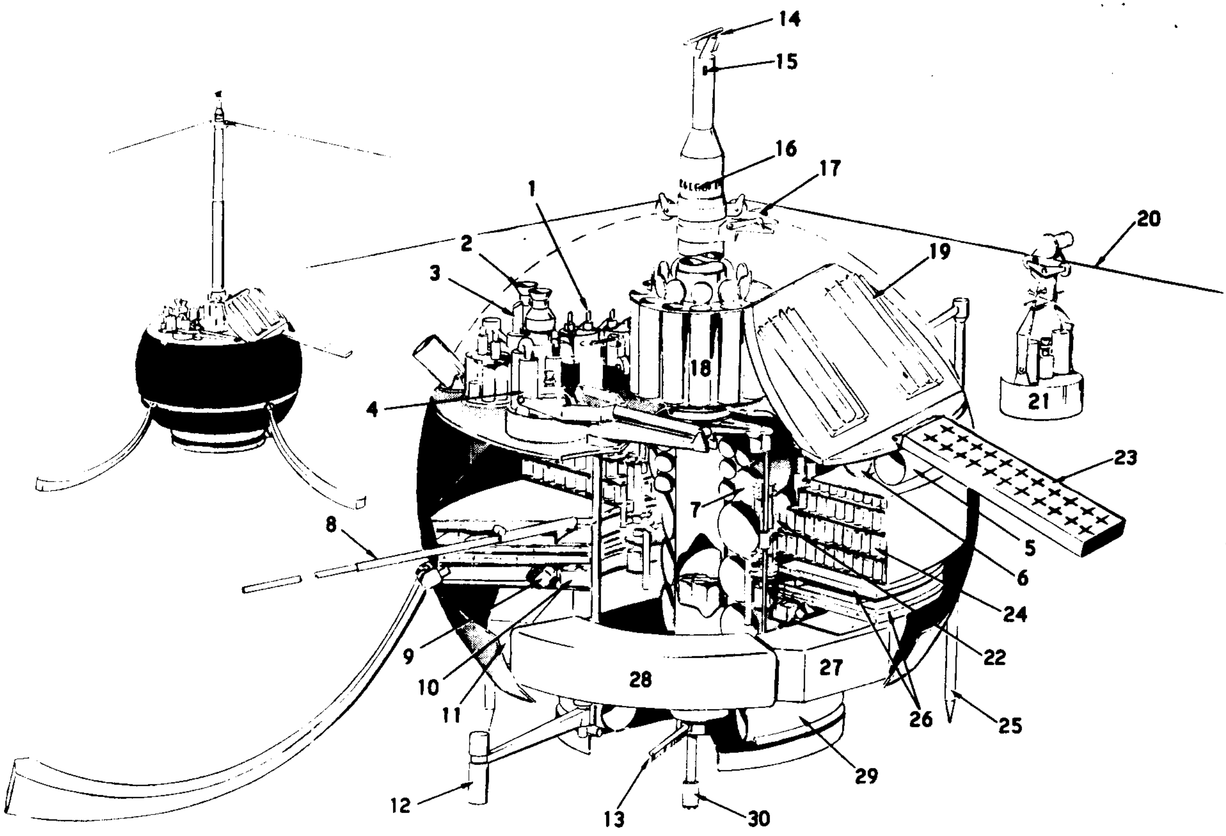


FIGURE 5.3-3 PRINCIPAL LABORATORY ZONES



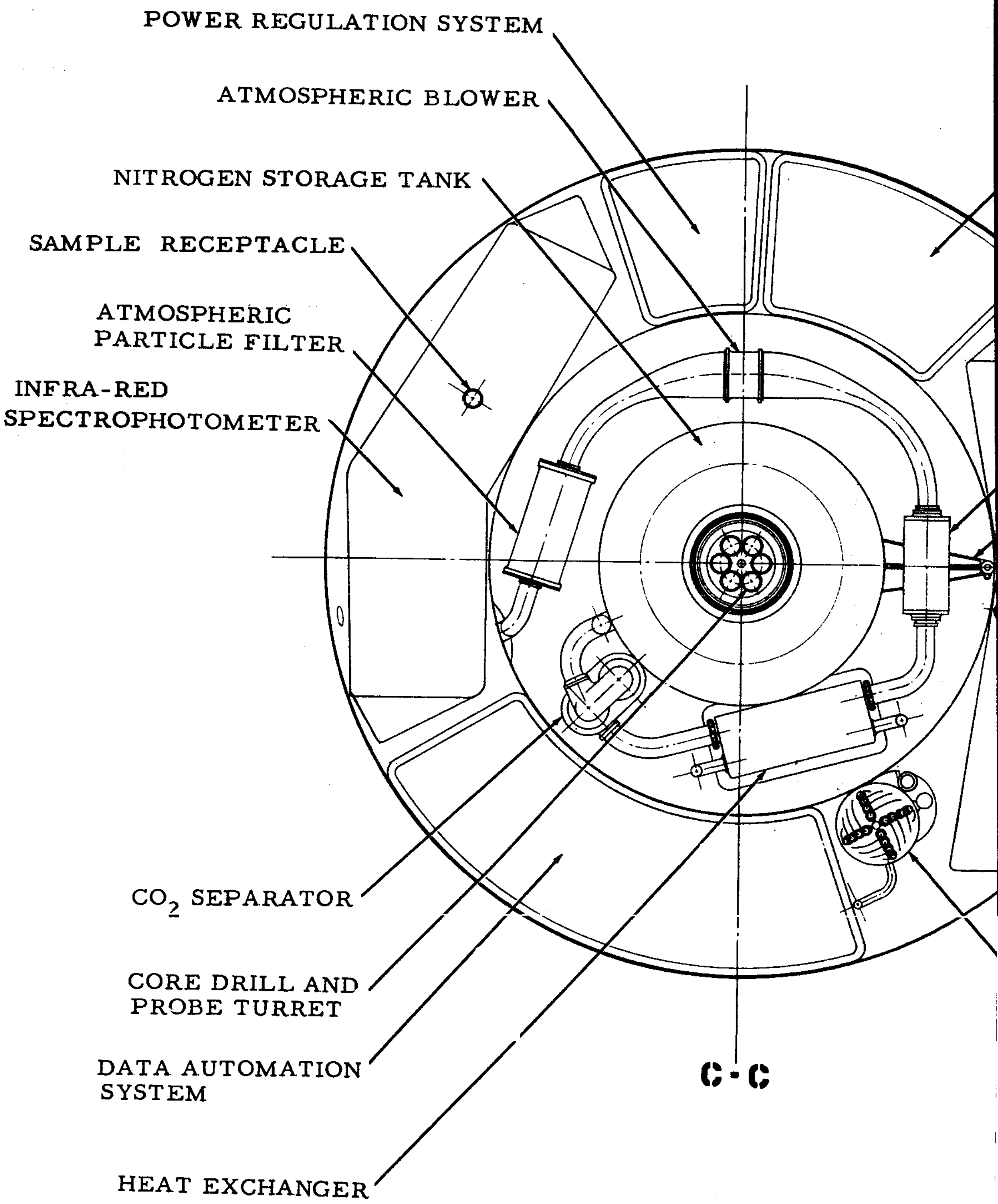
1 ATMOSPHERIC GAS CHROMATOGRAPH
2 SOIL PULVERIZER
3 SEPARATOR SCALE
4 SURFACE SAMPLER
5 WATER STORAGE
6 CLEANING SOLVENT STORAGE
7 BULK STORAGE FOR GASES
8 PROBE FOR WIND TRANSPORTED PARTICLES
9 LEG SUPPORT TRACK
10 BATTERY
11 IR SPECTROPHOTOMETER
12 IN-SITU CHAMBER
13 SURFACE SAMPLER
14 ATMOSPHERIC PROPERTY DETECTORS
15 MACROIMAGING PORT
16 MOTION DETECTOR
17 REMOTE SAMPLER HOIST
18 SOIL PRESERVATION CAPSULES
19 RTG
20 STAY WIRE
21 REMOTE SAMPLER
22 CULTURE-REACTION CHAMBER
23 DIRECTIONAL ANTENNA
24 REAGENT STORAGE (AMPULE)
25 SUBSURFACE PROBE
26 CHAMBER ATTACHMENT STORAGE
27 SPECTRAL ANALYZER
28 DATA AUTOMATION SYSTEM
29 WASTE STORAGE
30 CORE DRILL

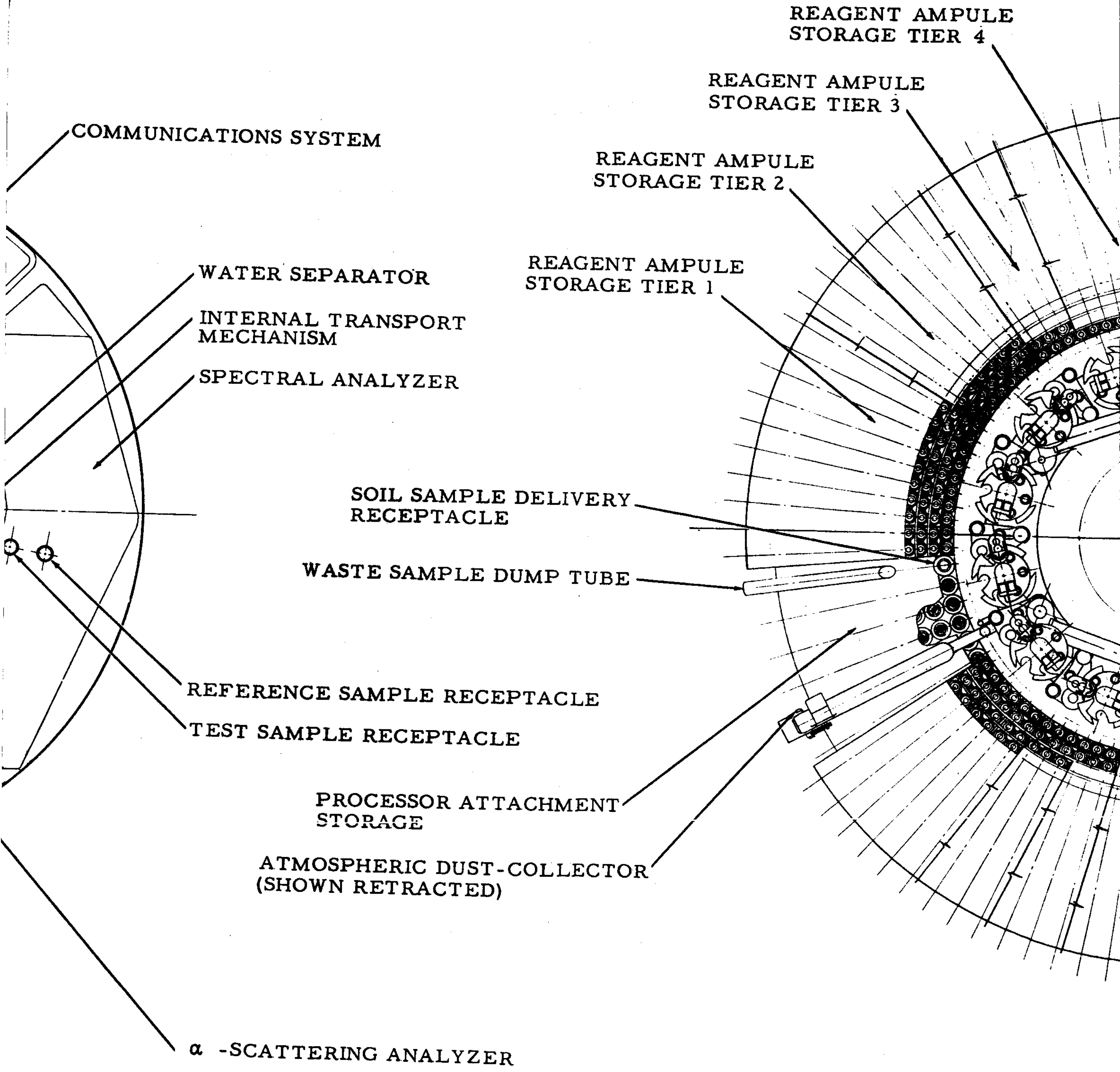
FIGURE 5.3-4. ABL DESIGN POINT CONFIGURATION - GENERAL ARRANGEMENT ground level by extension of the upper arm through a lead screw drive system. Multiple sites may be sampled by elevating the sampler and rotating the entire sampler arm system about its support base. The samplers are described in detail in Paragraph 5.5.

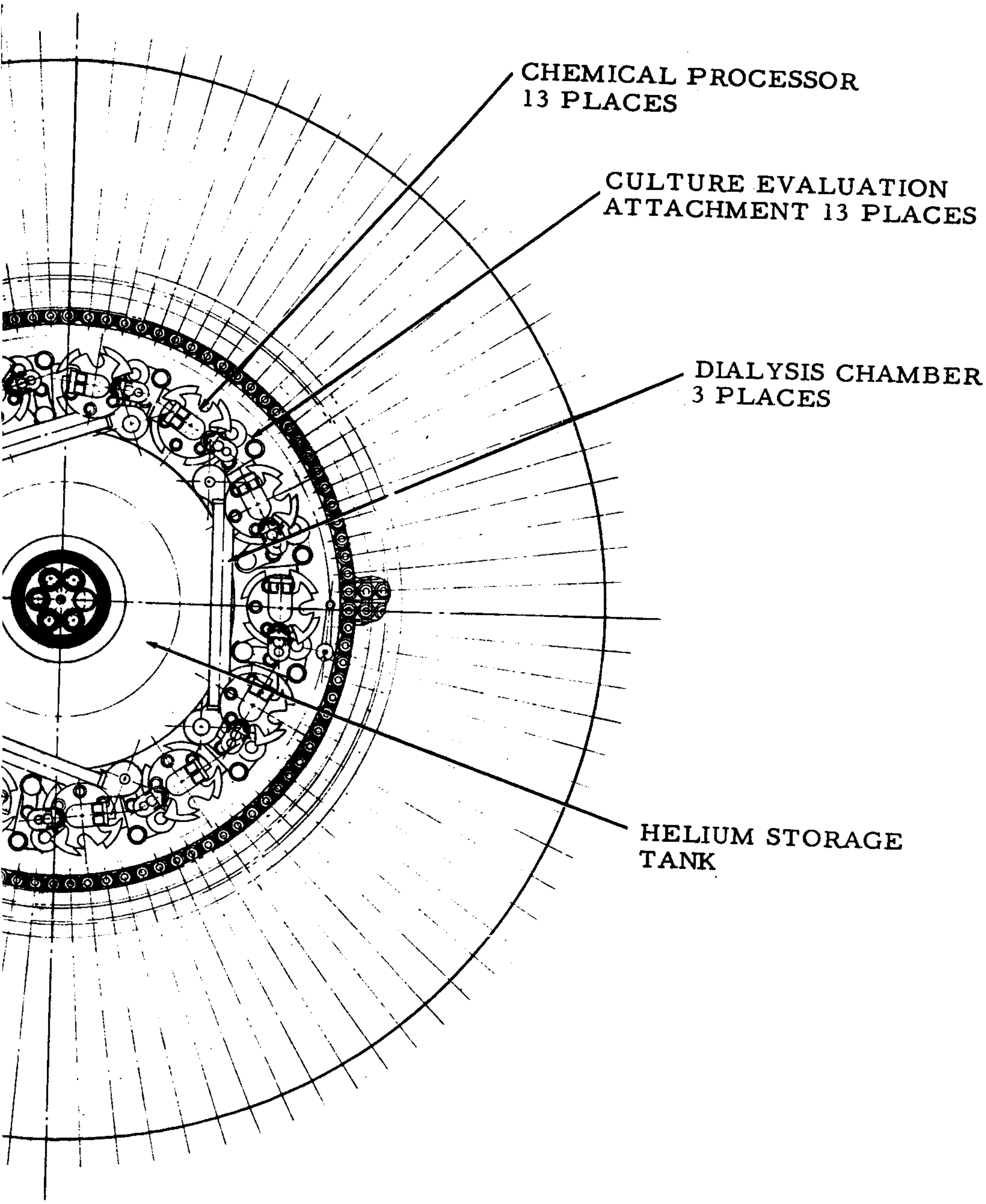
Two soil probes are mounted in parallel on the upper bulkhead. They are affixed to the structure through a double canted hinge that permits the probe to translate from its horizontal storage position to a vertical deployment position. The probe is spring loaded into the stored position and locked in place by a pyrotechnic locking ring. Separation of the locking ring permits probe deployment into a locked vertical position. The probe is forced into the surface by ignition of a self-contained explosive charge. Soil gas lines and electrical leads are deployed from the aft end of the probe.

Trolley cable anchors are stored in two positions. They are locked into horizontal storage. Release of the locking mechanisms permits erection of the launcher through a spring loaded actuator. The launcher is erected to an angle of 30 degrees from the vertical. An azimuth motor gearhead drive rotates the launcher until it is positioned to deploy the cable in the direction that appears to offer the most productive samples. The anchors are rocket launched and follow a ballistic trajectory to impact. Upon impact with soil, a second charge is ignited, driving the anchor further below the surface.

Two soil pulverizing chambers are used to provide reliability through redundant installation. The pulverizer is essentially a hammermill that uses three rotating blade segments mounted within the pulverizer barrel. Armature and field windings are incorporated within the pulverizer shell, eliminating any requirement for a secondary drive system. Solenoid actuated flapper doors are integrally mounted in each pulverizer to deflect a small ungraded soil sample into the gas chromatograph. The two pulverizers are interconnected by a "Y" discharge tube and a delivery tube from the terminal of the Y delivers pulverized soil to the separator scale by pneumatic transport. Oversize soil elements are carried overboard through a dump tube. The separator scale, mounted alongside the pulverizers,consists of a cyclone separator to settle out soil particles smaller than 300 microns and a weight scale to weigh these particles within each soil sample. The scale is a torsion balance using a null drive system to center a light source deflected through an optical path to a deflection detector. Incorporated in the weight pan is a dispensing shaft which delivers soil samples to the chamber filters in approximately one gram quantities. Five gas chromatographs, a mass spectrometer, and their vacuum system are located alongside the pulverizers and separator-scale. The pyrolysis gas chromatograph (Gas Chromatograph No. 2) pyrolyses the soil samples fed by a pulverizer and analyses the gases evolved for amino acids. Gas Chromatograph No. 1 performs soil and


POWER REGULATION SYSTEM
ATMOSPHERIC BLOWER
NITROGEN STORAGE TANK
SAMPLE RECEPTACLE
ATMOSPHERIC PARTICLE FILTER
INFRA-RED SPECTROPHOTOMETER
CO_2 SEPARATOR
CORE DRILL AND PROBE TURRET
DATA AUTOMATION SYSTEM
HEAT EXCHANGER
C - C


REAGENT AMPULE STORAGE TIER 4
REAGENT AMPULE STORAGE TIER 3
COMMUNICATIONS SYSTEM
REAGENT AMPULE STORAGE TIER 2
REAGENT AMPULE STORAGE TIER 1
WATER SEPARATOR
INTERNAL TRANSPORT MECHANISM
SPECTRAL ANALYZER
SOIL SAMPLE DELIVERY RECEPTACLE
WASTE SAMPLE DUMP TUBE
REFERENCE SAMPLE RECEPTACLE
TEST SAMPLE RECEPTACLE
PROCESSOR ATTACHMENT STORAGE
ATMOSPHERIC DUST-COLLECTOR (SHOWN RETRACTED)
α -SCATTERING ANALYZER



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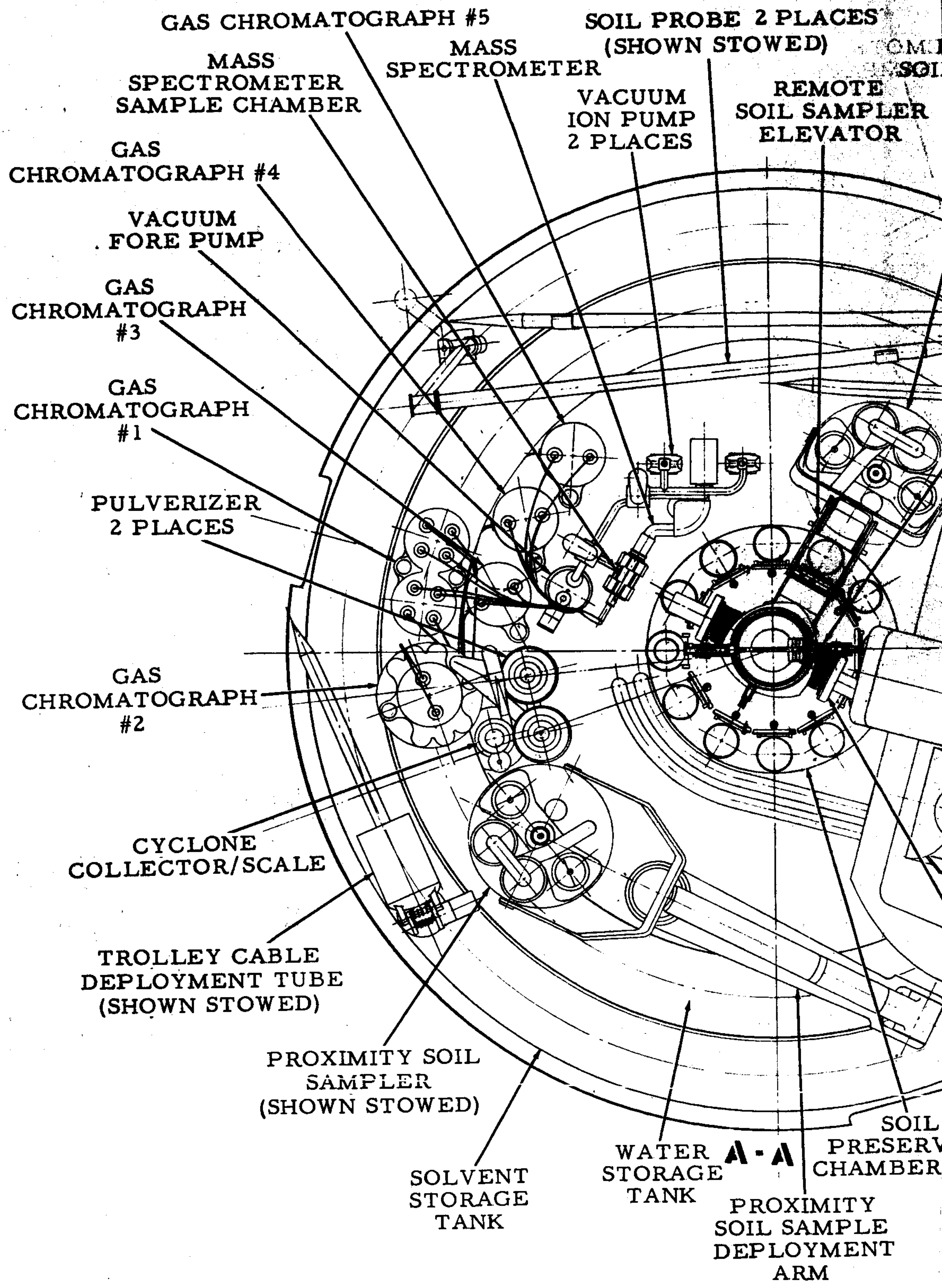
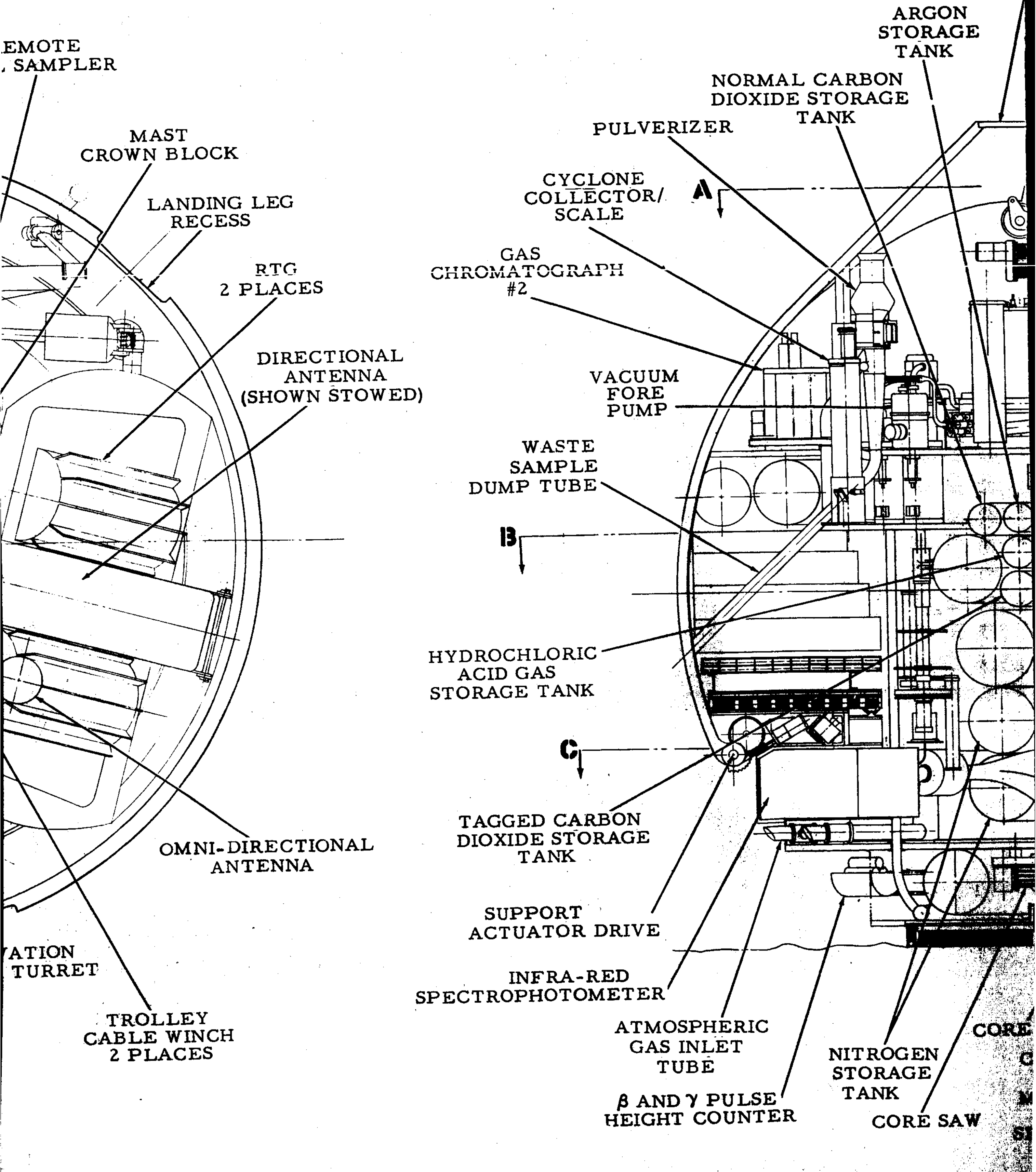

GAS CHROMATOGRAPH #5
SOIL PROBE 2 PLACES (SHOWN STOWED)
MASS SPECTROMETER SAMPLE CHAMBER
MASS SPECTROMETER
VACUUM ION PUMP 2 PLACES
REMOTE SOIL SAMPLER ELEVATOR
GAS CHROMATOGRAPH #4
VACUUM FORE PUMP
GAS CHROMATOGRAPH #3
GAS CHROMATOGRAPH #1
PULVERIZER 2 PLACES
GAS CHROMATOGRAPH #2
CYCLONE COLLECTOR/SCALE
TROLLEY CABLE DEPLOYMENT TUBE (SHOWN STOWED)
PROXIMITY SOIL SAMPLER (SHOWN STOWED)
SOLVENT STORAGE TANK
WATER STORAGE TANK
A - A
PROXIMITY SOIL SAMPLE DEPLOYMENT ARM
SOIL PRESERV CHAMBER


EMOTE
SAMPLER
MAST
CROWN BLOCK
LANDING LEG
RECESS
RTG
2 PLACES
DIRECTIONAL
ANTENNA
(SHOWN STOWED)
OMNI-DIRECTIONAL
ANTENNA
ATION
TURRET
TROLLEY
CABLE WINCH
2 PLACES
ARGON
STORAGE
TANK
NORMAL CARBON
DIOXIDE STORAGE
TANK
PULVERIZER
CYCLONE
COLLECTOR/
SCALE
A
GAS
CHROMATOGRAPH
#2
VACUUM
FORE
PUMP
WASTE
SAMPLE
DUMP TUBE
B
HYDROCHLORIC
ACID GAS
STORAGE TANK
C
TAGGED CARBON
DIOXIDE STORAGE
TANK
SUPPORT
ACTUATOR DRIVE
INFRA-RED
SPECTROPHOTOMETER
ATMOSPHERIC
GAS INLET
TUBE
β AND γ PULSE
HEIGHT COUNTER
NITROGEN
STORAGE
TANK
CORE SAW
CORE
C
M
SI

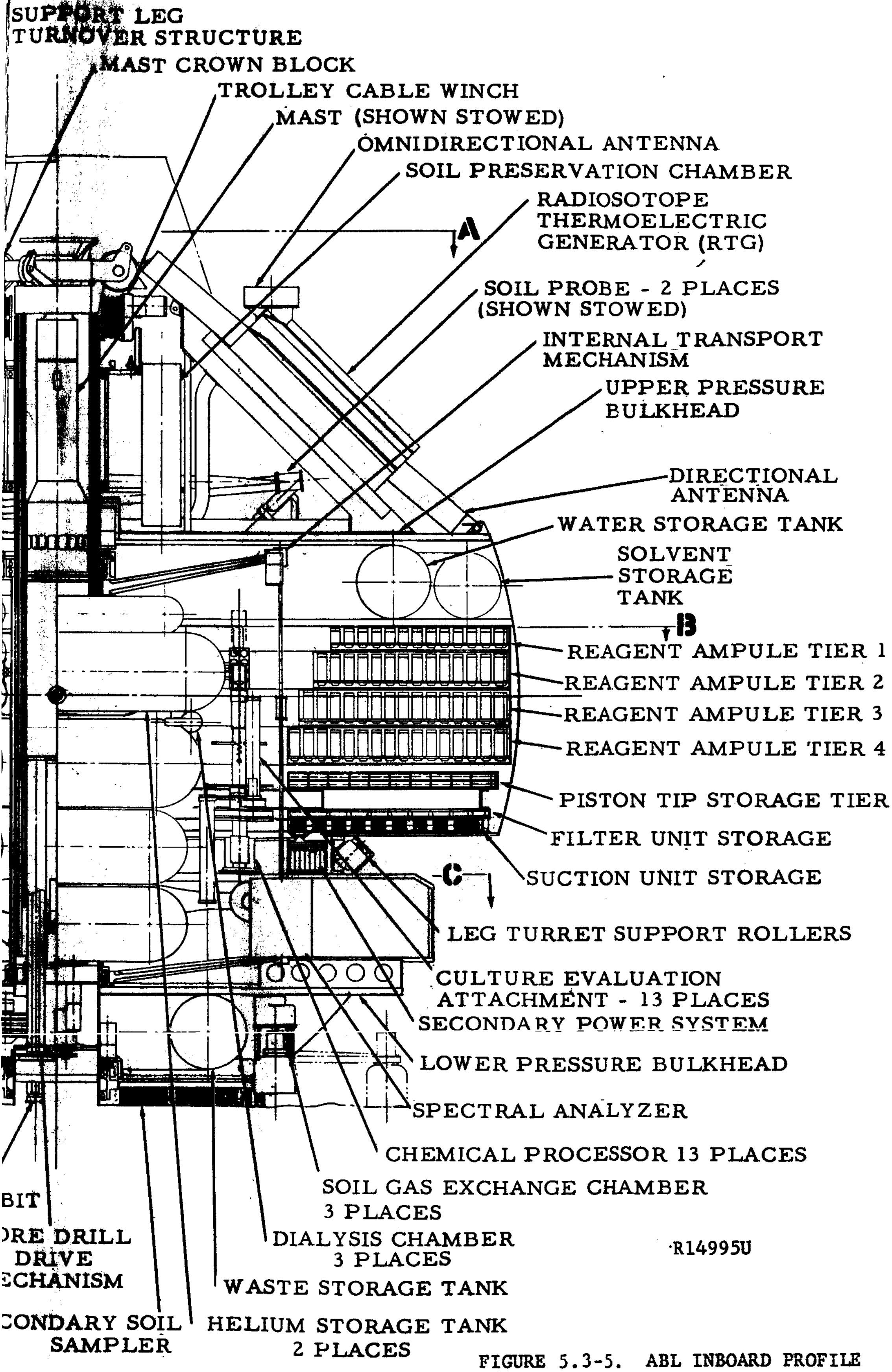


FIGURE 5.3-5. ABL INBOARD PROFILE

[redacted]

atmospheric gas analysis on samples gathered by the soil probes and the atmospheric gas collector. Gas Chromatographs Nos. 3, 4, and 5 are basically similar units used to analyze liquid samples delivered from the chemical processors.

The mass spectrometer is used in conjunction with the β-ionization detectors in Gas Chromatographs Nos. 1, 3, 4, and 5. Vacuum control is supplied to the mass spectrometer by a fore pump (ambient to 10^{-3} Torr) in conjunction with two parallel ion pumps (10^{-3} Torr to 10^{-7} Torr). Heavy duty, motor driven vacuum valves program vacuum control in both the sample chamber and detector segments of the mass spectrometer.

Two Radioisotope Thermoelectric Generators provide primary power. A directional antenna is stored between the two RTG's on a spring loaded mount bracket. Release of the locking pawl allows the antenna to deploy to a position 15 degrees below the horizontal. A fixed omnidirectional command receiver antenna is mounted between one RTG and the proximity surface sampler.

The center section, shown in View B-B of Figure 5.3-5 is devoted to the chemical processing equipment and reagent storage. The internal transport mechanism is mounted on a ball bearing motor driven torque tube concentric with the center spine column. The elevating mechanism is a ball screw jack moving within a slotted tube that provided reaction against the ball nut. A single motor actuating a double shaft clutch elevates and rotates the transport arm. The arm features a segmented spring clip which engages the reagent ampule and secures it firmly during vertical transport. The transport arm rotates through an angle of 347 degrees, leaving a 13 degree corridor through which piping and electrical leads were passed.

The volume between the transport mechanism and the center tube contains the chemical processors, dialysis chambers, and bulk reagent storage. All of these components are supported by horizontal structure affixed to a center column concentric with the transport mechanism torque tube. The support tube is bearing mounted, and a truss-structure supported by upper and lower main bulkheads secures the center structure against rotation. Thirteen chemical processors are mounted in a ring and tangent to the transport mechanism. Reagent ampules and chamber attachments are supplied to storage disks on each processor. Drive mechanisms within the processor utilize the reagents and attachments for conducting chemical processes as described in Paragraph 5.5. Used reagent ampules and processor attachments are transferred to storage by the transport mechanism. Each processor includes a self-contained dispensing and storage device used in culture evaluation and growth detection processes. Culture dishes are dispensed from storage and introduced into the chamber where a small soil sample is injected into prepared media. At preselected intervals, the dish is stepped into place over an optical densitometer for evaluation. Used dishes are stored in a container mounted on the processor. Three dialysis chambers are supplied from each of three chemical processors. Dialysis membrane is stored in tape form and advanced into position, as required. Toroid shaped tanks are used to store nitrogen, helium, argon, carbon dioxide, tagged carbon dioxide, and hydrochloric acid gases. The use of toroidal rather than spherical tanks for high pressure gas storage results in a moderate weight penalty for the ABL. However, the freedom of component orientation provided by using toroidal tanks should more than offset any weight penalty incurred.

The volume between the transport mechanism and the ABL outer shell includes reagent ampule and processor attachment storage and bulk storage of cleaning water and solvent.

Reagent ampules are stored in a fixed, four tier storage tray. Each tier is relieved the depth of one ampule to allow access to each level by the transport mechanism. Ampules containing the same reagent are stored in pie-shaped segments within the racks to simplify modification of the reagent complement. Each segment contains a complete loop of ampules, with unused ampules presented at one end of the loop, and used ampules injected at the rear of the loop. A self-contained feed mechanism advances the ampule string when an ampule is removed, thereby providing an opening at the rear for that ampule after its use.

Chemical processor attachments, i.e., piston tips, filters, and suction units are stored in a bearing mounted, revolving tray. A gearhead steppermotor advances the tray, as required, to the processor being serviced. The transport mechanism transfers attachments, in a horizontal plane only, into the appropriate processor attachment wheel. During operation of the processor, used piston tips are trapped within the filter unit housing. The transport mechanism transfers all used attachments back into storage. The attachments, like the reagent ampules, are stored in a single loop, such that removal of an unused unit, followed by advancing the remaining units, provides an opening for the used unit to eventually be stored in place.

Cleaning water and solvent are stored in toroidal tanks above the ampule tier and clear of the transport mechanism.

The sampler that collects atmospheric dust samples is mounted in the area between the open ends of the ampule tiers. The sampler consists of telescoping tubes extended and locked by pneumatic pressure. The base support is trunnion mounted with single axis freedom in a horizontal direction. A gearhead motor assembly elevates or lowers the sampler to collect soil particles transported by surface winds. These samples are pneumatically transported to the separator scale. This sampler may be lowered to ground level to serve as a back-up surface sample collector.

The lower section, View C-C in Figure 5.3-5, includes the secondary battery, ABL legs and leg support structure, spectral analyzer, IR spectrophotometer, communications and data computer electronics, environmental control system, waste storage, soil gas exchange chambers, β and γ pulse height counter, and a secondary surface soil collection system. The lower section is segmented by a horizontal bulkhead which acts as the lower boundary of the ABL pressure section. The spectral analyzer and IR spectrophotometer are mounted opposite one another above this bulkhead and outside of the transport mechanism envelope. The spectral analyzer is used for UV and visible spectrophotometry, polarimetry, and fluorometry. Extracts of soil samples are prepared in the chemical processors and transferred to the spectral analyzer in a thin walled fused silico cuvette. Reference samples, used for comparison with the test samples, are stored and transferred to the spectral analyzer in a similar manner. After analysis, reference and test samples are transferred to storage.

The infrared spectrophotometer is used for chemical analysis by absorption spectroscopy in the IR range. Test samples are prepared, and transferred to and from the instrument in a manner identical to that used for the spectral analyzer.

Power regulation, communications equipment, and the data automation systems utilize the remainder of the volume available on the lower bulkhead and outside the transfer mechanism envelope.

The atmospheric conditioning systems are housed above the lower bulkhead and within the transport mechanism clearance envelope. Martian atmosphere is drawn into one of two parallel inlet ports through a solenoid valve. Parallel blowers circulate the atmosphere through a particle filter, water separator, heat exhanger, and CO_2 removal system. The scrubbed atmosphere is then stored for use in support of the nitrogen pressurization system and various pneumatic transport subsystems.

The secondary battery system is made of two annular cases containing dry silver zinc batteries. After landing and erection, the electrolyte is fed into each cell by a pressurization system.

The ABL support legs are a tripod arrangement and are stored in recesses provided in the outer shell. The outer end of each leg forms one-third of a frustum of a cone and serves to overturn the ABL enough to allow the legs to erect and level the vehicle as they are deployed. Each leg is cantilevered to a diamond-shaped track which in turn is supported by fixed rollers mounted at regular intervals on the ABL base structure. After erection and antenna deployment, the ABL is rotated by driving leg support structures until the proper orientation of the directional antenna is obtained.

The soil gas exchange chambers are stored below the lower bulkhead. A fused silica bell chamber is rotated out of storage and lowered onto the Martian surface. Naturally evolved gases are collected and, after injection of labeled substrates, are fed to the gas chromatograph for analysis. Alternate sites can be examined by lifting the chamber, rotating it to a new position, and lowering it to the surface.

The β and γ pulse height counter is made up of four detectors supported by a hemi-cylindrical tungsten shield. The entire assembly is supported by parallel arms affixed to a rotary gear. The counter is deployed and elevated well outside the shadow of the ABL to provide a count on β and γ particles directed toward the Martian surface. The counter is then lowered toward the surface and rotated 180 degrees to count the β and γ radiation from the surface.

At the base of the vehicle, a rotating brush is used as a secondary surface sample collector. Two hollow arms contain a large number of small diameter tubes that act as bristles. The entire unit is rotated over the surface and a pneumatic circulation set up by pressurizing the brush arms. The flow is supplied by diverting pneumatic flow from the core drill chip removal supply and directing it outward along the arms and down the bristles. A toroidal chamber plenum collects the air-sample mixture which is transported to the separator scale through a vertical supply line.

5.3.3 DESIGN CONSIDERATIONS RELATED TO STERILIZATION

a. General. This paragraph discusses some of the influences that the sterilization requirements had on the ABL preliminary design. The most fundamental consideration is that of the materials to be used for compatibility with the sterilization processes. Materials normally used in the basic structure, such as aluminum and magnesium, in general, have alloys which are compatible. However, unique problems may still arise in some special cases, e.g., the aging temperature of most aluminum alloys are near the sterilization temperature of 145°C (300°F). After the initial quench, the aluminum alloys are aged at temperatures in the vicinity of 350°F for periods of time comparable to the sterilization soak cycles. The characteristic aging curve shows an increase in strength with soak time to some maximum value followed by a gradual decrease in strength with continued exposure. Repetitive exposures, such as occur in the qualification sterilization cycle, are cumulative and could result in a loss in the initial strength. This is not a major design problem, but must be considered. Another phenomenon is that of grain growth during heat treat. Aluminum and other metallic alloys have exhibited considerable dimensional changes caused by this phenomenon during heat treat. Since for aluminum the sterilization cycle is essentially a continuation of the heat treat and aging process, this could become a significant problem if the material is used as the basic support structure of a precision instrument. This type of problem could not be evaluated in detail in the preliminary design phase except to identify it as a problem area. Other problems associated with materials are more easily defined. Most thermoplastic resins have heat distortion temperatures at 200°F to 250°F, thus eliminating them from consideration entirely. Thus, the use of plastics must be limited to the thermosetting resin of which the most probable candidates are the epoxies, the phenolics, and possibly the melamines. Within the instruments themselves, individual optical elements and sensors, such as photodiodes, will have to be examined for degradation caused by sterilization. A typical example taken into consideration in the study is the use of synthetic sapphire in the infrared instruments rather than the commonly used materials having high transmittance in the far infrared wavelengths. This material is not only highly resistant to thermal shock but has good chemical inertness.

Another material problem exists in the elastomeric compounds used for seals. The general problems of aging and permanent set exhibited by these materials under long time static loading are accelerated at sterilization temperatures. Since no good substitute may be found in every case, the design approach was to eliminate the need for this type of material wherever possible. For example, the sliding seal in the ampule piston probably can be solved by proper design and control of tolerances. To provide the necessary hermetic seal for long term storage, a secondary seal at the end of the ampule piston and cylinder assembly can be made by welding or rolled seam techniques.

In considering the reagent ampule above, another obvious effect of sterilization that must be allowed for is the expansion undergone by liquids and solids. From the viewpoint of chemical contamination and quantitative control during dispension of the reagent, it is desirable to package the ampule with no gaseous void inside. Thus, the ampule design must accommodate the expansion of the contents as well as the increase in the equilibrium vapor pressure. This is provided for in the design by the incorporation of an expansion element, such as a bellows, in either the cylindrical section or the piston. Two typical ampule designs were developed in this study and are discussed in Paragraph 5.5. The cylinder-and-piston ampule is simpler to fabricate and probably dimensionally more accurate, simplifying handling by the internal transport mechanisms. However, it requires that the expansion element be ruptured in use. The ampule with the bellows incorporated in the cylindrical wall does not suffer from this disadvantage and may thus be the more appropriate design to use.

In the case of gaseous storage, sterilization merely imposes the design consideration of increased pressure, since for constant volume processes the pressure increases linearly with temperature. This results in a pressure increase by a factor of 1.44 from room temperature to the qualification temperature. If a factor of safety of 2.0 is applied for pressure tank designs at normal operating temperatures, this increase can be safely handled for the shorter times of increased pressure during sterilization.

b. Thermal Isolation. A basic objective in the ABL design has been the elimination, wherever possible, of components which are incompatible with the thermal sterilization compatibility test conditions. Several components of particularly interesting life-detection experiments appear to be incompatible with these conditions. Rather than eliminate these experiments at this early date before sterilization compatibility was firmly determined, attempts to find alternative design solutions were made. Characteristically, too, little quantitative information is now at hand to say just which of these components will ultimately be suitable for use in the design. If any of the required components are ultimately sterilized internally by a procedure less thermally severe than the terminal cycle, these components then must be isolated thermally from the rest of the ABL during the terminal sterilization heat soak. The temperature sensitive components can be thermally isolated by mounting them on, or surrounding them with, cold plate heat exchanges. The component and cold plates are sterilized by other than high temperatures and then inclosed in a protective structure. During sterilization, coolant is provided to the cold plate heat exchanges to maintain the critical components within acceptable temperature limits. The outside of the protective structure is maintained at the required sterilization temperature by the normal sterilization treatment.

An example of an item which currently appears to require sterilization by the method of 121^{o}C wet stream autoclaving for 15 minutes is the cellophane membrane used in the dialysis process. Subsequent protection for this membrane during dry heat bake sterilization can be achieved with thermal isolation as described above. Another case is ampule storage of Earth-originated growth media which tests have indicated is degraded by the terminal sterilization cycle. A detailed description of the method that can be employed to implement thermal isolation for ampule storage is given in Paragraph 5.6.1.

5.3.4 DESIGN CONSIDERATIONS FOR INTERNAL CONTAMINATION CONTROL

This paragraph discusses the influence of internal contamination in the preliminary design of ABL. Historically, the consideration of internal contamination has been concerned with mechanical and electrical reliability as affected by residual products of the manufacturing and assembly processes. From the nature of the automated biological laboratory, additional emphasis must be placed on contamination in terms of the effect on the experimental results, as well as the reliability of the equipment. Since all assembly processes for ABL are conducted in a cleanroom, this discussion assumes that gross residual products of the manufacturing process have been eliminated. Also, it is assumed that the desired level of initial sterility is achieved in the terminal sterilization cycle. Thus, this discussion is primarily concerned with self-induced contamination during operation whether or not the source of contamination is internal or external to the ABL.

Sources of contamination are inherent in the materials used to fabricate the laboratory, the chemical supplies contained within the laboratory, the Martian environment, and products produced through uncontrolled reactions between each of these. More important than the source of contamination are the modes in which contamination can occur. The primary modes of contamination in the ABL are as follows:

(1) Diffusion and transport through the internal atmosphere.

(2) Mechanical transfer between processing equipment items.

(3) Reactions between storage container or processing equipment materials and reagents or soil samples.

(4) Inadequate recycling procedures or failures in the recycling sequence.

The last two modes of contamination may occur as a result of unexpected conditions, but should be of minimal concern since complete qualification before flight is presumed. The philosophy of recycling developed for the ABL is that critical components such as filters and suction units which are difficult to clean are used only once. The replaceable tip for the piston to seal the chemical processor is also used at the end of a processing sequence to wipe the gross residue from the chamber walls and trap it in the throwaway filter unit. Before returning these items and empty ampules to their storage units, they will be rinsed and baked to dry the unit. If necessary dry heat bake to sterilize these units can be employed. Thus, no wet or active waste products are handled by the internal transport mechanism or placed in storage near unused supplies. Rinse water and residual reagents are transferred to waste storage through waste transport piping from each chamber.

The first two modes of contamination for the ABL are of primary concern in the process of opening ampules, performing chemical processing, and transferring solutions, as required, between equipment items, since evaporated vapors will be inevitably released into the laboratory atmosphere. These vapors can then result in contamination of instruments, by condensing on critical elements such as optical elements and sensors, or of supplies by diffusion through container walls. Since the free volume in the laboratory is generally small, there will undoubtedly be periods of high concentration of such materials in the internal atmosphere for short times until they can be removed. The atmospheric contaminants are removed with the same circulation system used to maintain the internal temperature at the desired level by incorporating a scrubber to remove the undesired vapors or gases. Molecular sieves, lithium hydroxide, activated charcoal, and various other chemicals can be used to effectively remove most of the vapors expected to be released into the ABL atmosphere. Critical instruments, such as those containing optical elements, must be sealed with an individually controlled subenvironment. The infrared spectrophotometer, for example, will probably require an evacuated chamber to reduce absorption losses, or at the very least a very clean, carefully controlled, atmosphere.

In considering the design of reagent containers, it may appear, for example, that a particular material is chemically compatible with the reagent being stored and would be the ideal container material. However, most materials exhibit some degree of permeability which can become significant when the material is used in a very thin form. The permeability of a material is proportional to the pressure differential across it and the temperature, and is inversely proportional to the wall thickness. To illustrate, Figure 5.3-6 shows the variation in permeability with temperature for a typical Teflon resin with a pressure differential of one atmosphere. It can be seen that the volumetric diffusion through the material can increase by an order of magnitude from 20 to 100°C. It is also seen that no definite correlation between permeability and molecular weight for the particular gas exists. To look at permeability variations with material type, Table 5.3-I was compiled. Premeabilities were compared on both a weight and volumetric basis. Again, no correlation between molecular weight and permeability seems to exist. Two trends can be established from the limited data in this table, however. Helium has the highest permeability

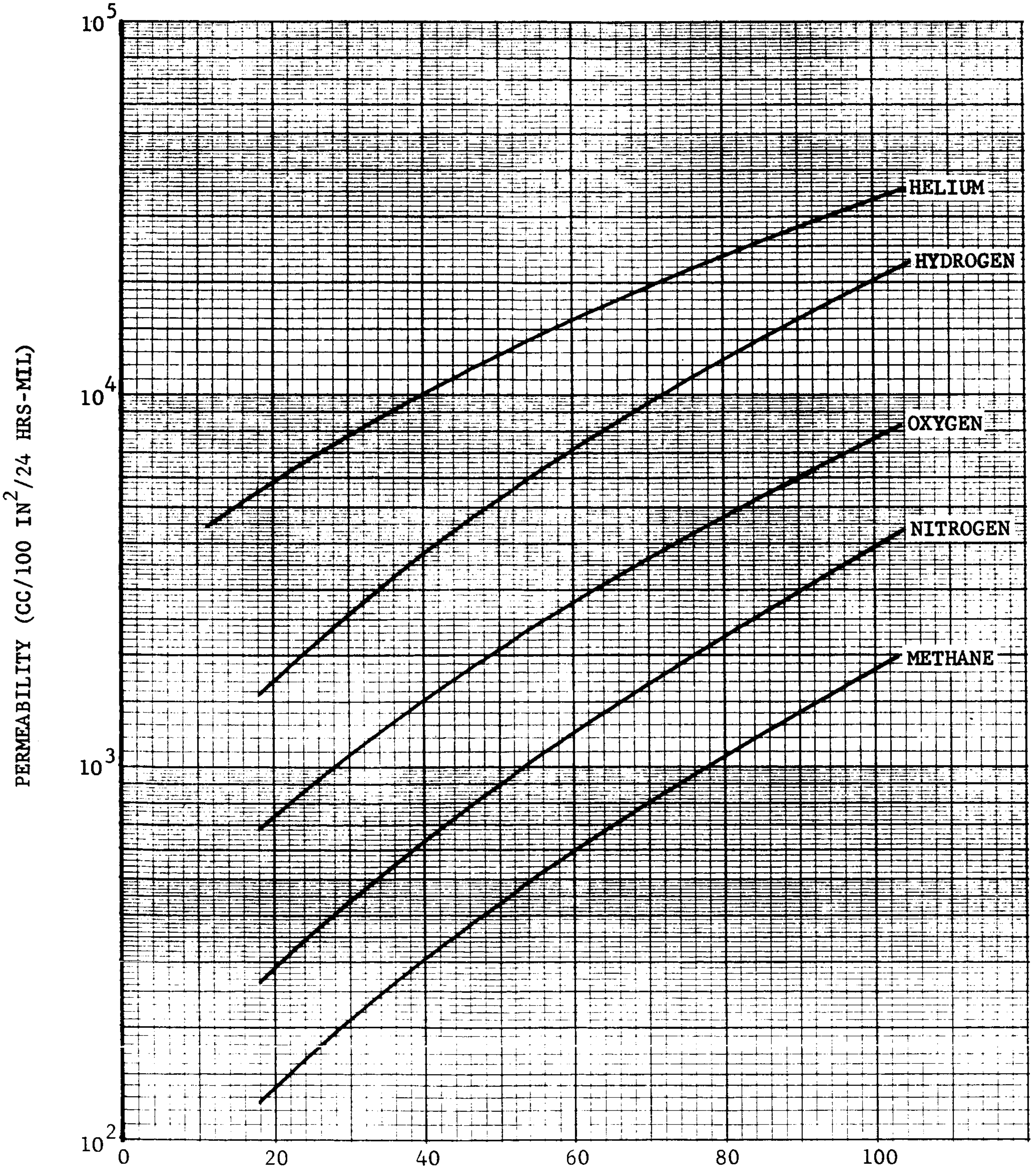


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FIGURE 5.3-6. GAS PERMEABILITY OF "TEFLON" FEP RESINS AT ELEVATED TEMPERATURES

TABLE 5.3-I

TYPICAL GASEOUS PERMEABILITY RATES

Gas		Viton	Mylar	Polyethylene*			FEP Source		Cellophane*	TFE Teflon
				Type I	Type II	Type III	1	2*		
He	Wgt	0.350	0.030				1.3			0.22
	Vol	1960	167				7260			1230
N_2	Wgt	0.0015	0.0012	0.375		0.052	0.18	0.450	0.0038	0.11
	Vol	1.2	1	300		42	144	360	3	88
O_2	Wgt	0.336	0.0014	0.008	0.400	0.286	0.39	1.360	0.0029	
	Vol	242	6	5.5	280	200	273	950	2	
CO_2	Wgt	2.56	0.0316	4.930	1.950	1.140		3.64	0.077	0.66
	Vol	1300	16	2500	990	580		1850	39	335
H_2S	Wgt									
	Vol		10							

Weight - gm/100 in.^{2}/24 hr-mil
Volume - cc/100 in.^{2}/24 hr-mil

*Reference:
Materials Selector, 1964,
Materials in Design Engineering,
Reinhold Publication

on a volumetric basis, whereas carbon dioxide has the higher value when compared on a weight basis. This can become important for the storage of $BA(OH)_2$ which is used to determine carbon dioxide concentration by changes in its electrical conductivity as a function of carbon dioxide absorption.

Several general conclusions can be made regarding the permeability of materials to gases. First, the characteristics of permeability vary drastically for different types of gases and different materials. In fact, it can vary drastically with the particular formulation of a given material. Second, the permeability, in general, increases rapidly with temperature and may change by an order of magnitude or more. There are several methods of preventing this type of contamination which are as follows:

(1) Thicken the walls of the container. This in general is considered to be unsatisfactory for a spacecraft because of the weight penalty involved.

(2) Seal the surface of the material by coating it on the outside with another material having a low permeability, or laminate thin sections.

(3) Eliminate the pressure differential across the wall. A positive excess of internal pressure could be used inside the container but then the possibility of the reagent, or more important, some constituent of the reagent, may diffuse out thereby changing the quantity, concentration, or characteristics of the reagent.

Finally, the processing sequences will demand that chemicals and solutions be transferred from one piece of equipment to the other. To preclude the possibility of spilling and reduce evaporation in transity, solutions should be transferred from point to point in a closed container. The design concepts developed in this study propose to achieve this through the use of transfer ampules in which the solution is drawn into the ampule through a capillary needle. A breadboard ampule of this type of ampule was constructed in connection with a company funded development of a breadboard chemical processor. In operation, the needle is withdrawn into the ampule as it is filled, thus reducing to a minimum the exposed surfaces that could carry excess solutions.

The discussion presented in this paragraph is intended primarily to develop the potential problem areas from the standpoint of internal contamination to highlight the design considerations involved in the preliminary design analysis. Full development of the problem areas and their relative importance can only be accomplished during the prototype development and testing phases of the automated biological laboratory.

5.3.5 DESIGN CONSIDERATIONS RELATED TO RELIABILITY

Reliability considerations and their influences on the design can only be considered in general terms during the conceptual development of a preliminary design effort, such as that accomplished in this study. The general considerations made were in terms of incorporating in the design those qualitative features which are known to influence reliability. As discussed previously in developing the internal transport mechanism, rotating joints utilizing rolling surfaces, such as ball bearings, are used in preference to sliding surfaces, such as those encountered in telescoping cylinders. In general, wherever telescoping cylinders are used in the concept, they are one-operation items being deployed only once at the outset of surface operations. Typical examples are the vertical mast and the atmospheric soil particle collector.

Another consideration is that a spacecraft as complex as the ABL, a large number of drive mechanisms must be powered. The well-known advantages of induction motors in terms of eliminating brush wear and reducing radio frequency interference resulted in the design criteria to use only this type of electric motor in the system. Since the efficiency of an induction motor can be essentially doubled by using a two-phase power supply, this requirement was established for the ABL. Another consideration for motors and drives used externally to the labroatory is that the environment will probably be very dusty and abrasive. This imposes the requirement that a drive either be insensitive to foreign material or be contained in a sealed housing. The design concepts for the equipment required by the ABL in this study could not reflect this level of detail. However, the ring mount in which the laboratory is supported is indicative of a design which is inherently insensitive to foreign material and serves as an example of this kind of design consideration.

In defining the instrument complement, the intent was to arrive at configurations which could typically satisfy the experimental requirements for sensitivity and resolution and determine the approximate sizes and weights for each. As a result, where miniaturized or space-oriented designs were available they were used. In other cases, extrapolations of existing laboratory equipment were mechanized. It is obvious that more reliable designs can be developed if the emphasis is placed on the utilization of passive elements to replace mechanical moving elements.

Every effort has been made to establish operational criteria for the instruments that will lead to the development of equipment with sensitivity and resolution commensurate with that required by the experimental procedures. This has, in many cases, required the utilization of mechanisms which may be subject to higher failure rates than others less sensitive. As an example, the IR spectrophotometer uses a servo-driven prism to disperse light that has passed through the sample cuvette and focus it on the detector to achieve a resolution of 0.2 μ. This procedure requires that dimensional stability and precise control is mandatory for the prism mount and drive system and the entire optical train used in the instrument. An alternative would be the use of an array of detectors to scan discrete bandwidths of the output from a fixed dispersion prism. Thus, the requirements for the prism drive system can be eliminated at some sacrifice in instrument resolution. It is imperative that the entire ABL equipment complement be subjected to this type of analysis and that detailed parametric studies be completed prior to the establishment of the ABL detailed design criteria, to identify the various tradeoffs between reliability and performance.

5.3.6 STRUCTURAL CONSIDERATIONS AND MATERIALS SELECTION

The primary emphasis used during the development of the design point ABL was on physical location and functional arrangement of the equipment and components necessary to perform the experimental program. As such, only those structural considerations required to establish a configurational concept or those with a strong influence on system weight were evaluated. This section discusses the general concept of structural arrangement used in the design point vehicle, and outlines the influence of liquid and gaseous bulk storage tank weights on system weight.

a. Basic Structure. Design criteria established for the chemical processors and other processing and analytical equipment indicated that an ambient pressure near one Earth atmosphere was required. Two approaches were considered. First, each instrument or component requiring a pressure environment could be encased in its own pressure-tight container. Second, the instruments and components could be located within a pressurized section of the laboratory. The latter course was selected because the equipment involved was functionally associated in a manner that led to a pressurized compartment of reasonable size and location, and because the individual container approach involved adding pressure tight openings to the equipment. The basic structure then became a center spine oriented along the vertical centerline, two pressure bulkheads 12 inches above and 21.5 inches below the spherical center, and a thin outer skin. Equipment and component mountings are typical of those employed in other spacecraft designs. The design pressure was assumed to be one Earth atmosphere, increased by a safety factor of 1.5, or 22 psi.

b. Materials Selection. The materials choices in the ABL design have been based upon sterilization, contamination, and chemical compatibility, as discussed previously in this section. To summarize, aluminum, magnesium, titanium, and steels encompass the acceptable metals for general use. Where direct contact is made with chemical reagents, nickel, stainless steel, tantalum, Teflon, Viton, and fused silico must be used. Epoxy and phenolic plastics, and Viton elastomers complete the list of nonmetals considered to be applicable.

c. Bulk Storage Tanks. During the ABL study, it became apparent that a sizeable portion of the vehicle would be devoted to the bulk storage of relatively large quantities of liquids and gases. Tank weights were examined parametrically, and the data reported in detail in Appendix 9. The data as it applies to the design point vehicle are summarized in this paragraph.

(1) Gaseous Storage. Storage tank weights are independent of the storage pressure. The weight varies linearly with the total gas weight being stored, and inversely with the molecular weight for a given temperature and tank material. To obtain a comparison of tank shell materials, spherical tank weights were defined as a function of gas molecular weight and tank material. These data are shown in Figure 5.3-7 and were based upon the expression

$$\frac{W_T}{W_g} = \frac{3 \gamma RT}{2 \sigma_{allow}} \qquad \text{(spherical tank)}$$

where

W_T = tank weight, pounds

W_G = gas weight, pounds

γ = density of tank material, pounds per cubic inch

R = universal gas constant

T = temperature, ^oR

σ_{allow} = allowable tensile stress of tank material, psi

Storage tank size decreases with increasing pressure. In an effort to provide as compact a packaging arrangement as possible for the ABL, the influence of pressure on tank size was evaluated. Figure 5.3-8 shows that for nitrogen and argon, little benefit is gained by increasing storage pressure above 3000 psi. For the lighter gases, however, such as helium, large tanks result even at pressures of 6000 psi or greater. Thus, weight and volumetric efficiency penalties are incurred with the storage of the lighter gases.

Spherical tanks represent the most efficient configuration, from a weight standpoint, for the storage of gases. For the design point, however, the use of toroidal tanks permitted a more efficient use of the space available after those components which were functionally oriented had been positioned. To evaluate weight penalties involved in using toroidal tanks rather than

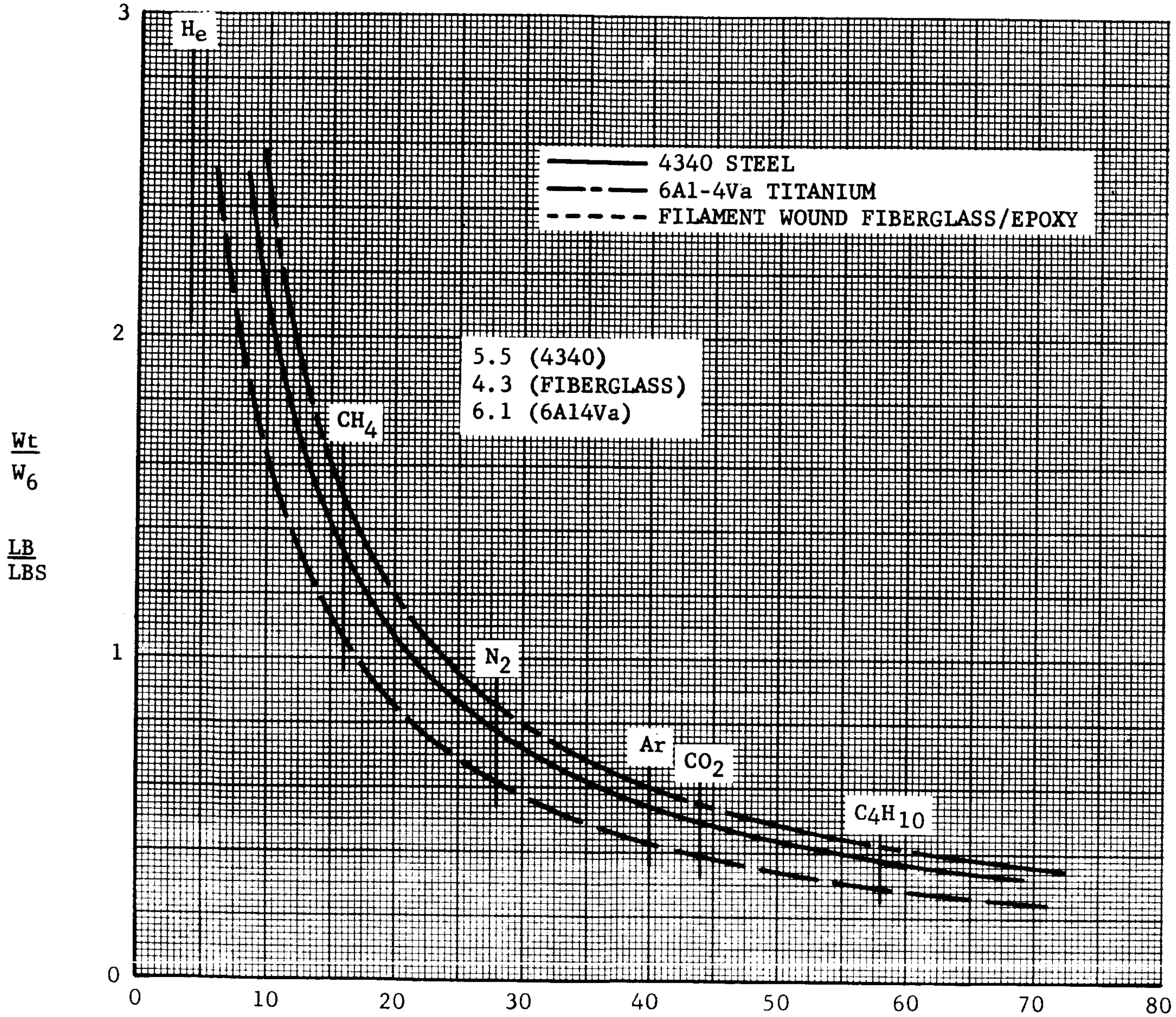

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FIGURE 5.3-7. SPHERICAL TANK WEIGHT VARIATION WITH GAS MOLECULAR WEIGHT

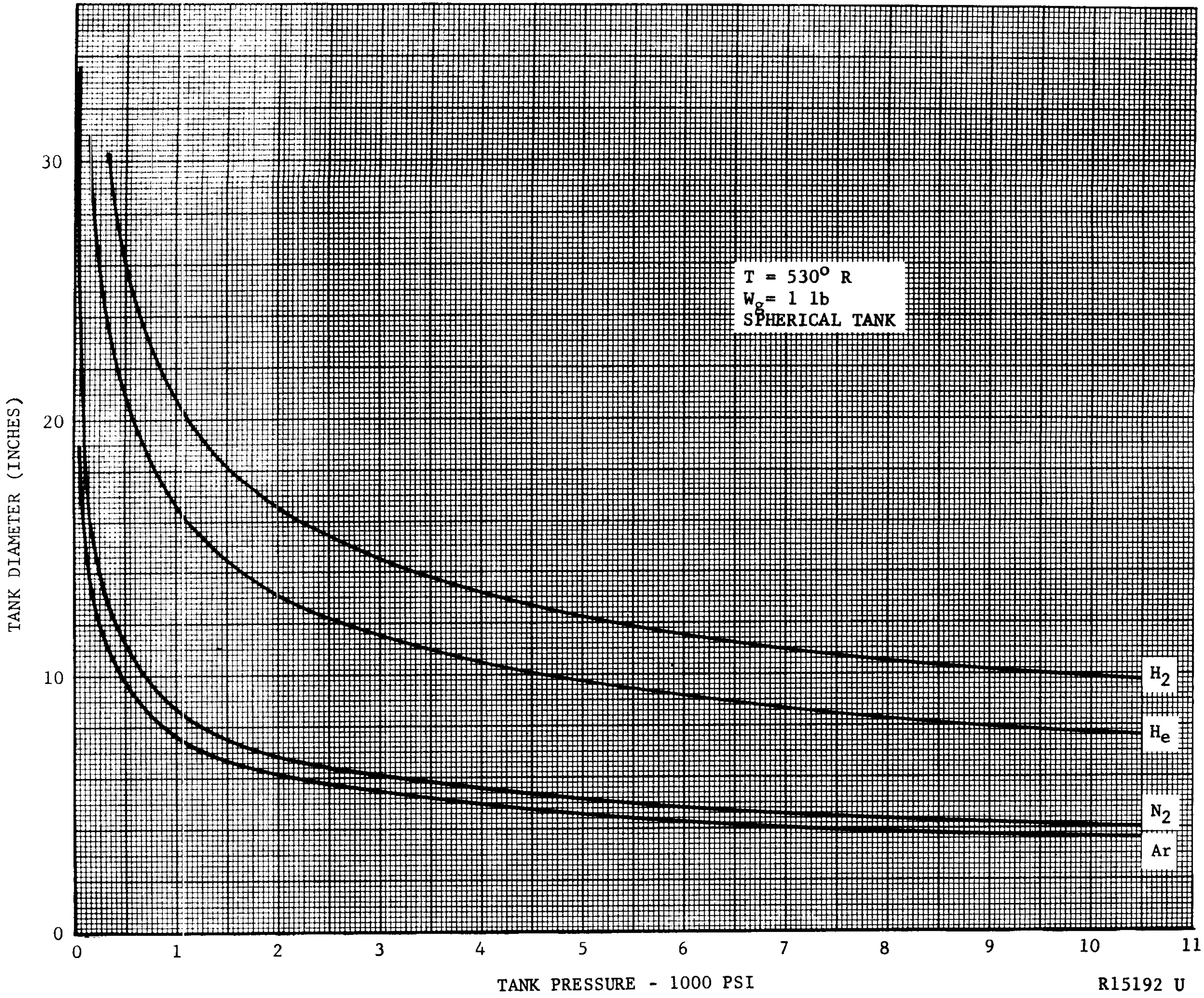

FIGURE 5.3-8. VARIATION OF TANK SIZE WITH INTERNAL PRESSURE

spherical or cylindrical tanks, weight trend curves were defined. Figure 5.3-9 depicts the ratio of toroidal and cylindrical tank weights to spherical tank weights as a function of toroid tank geometry. It can be seen that as the value of K increases, the toroid tank weight approaches that of a cylinder, while at lower values a severe weight penalty is incurred. The data indicate that tanks with large tube diameters and small ring diameters are preferred. In actual practice, toroids with K less than 2 are not usually encountered.

(2) Liquid Storage. An analysis similar to that outlined for gaseous storage tanks was conducted for liquid storage tanks. Pressurizing loads arise from sterilization and from the pressure required to prevent evaporation or to provide a means of transport. Under this basis, the tank weight is no longer independent of pressure, since the fluid density does not vary with pressure. Tank weight varies linearly with pressure or the ratio of material density to fluid density. For most metals, a reasonable minimum gage for fabrication of tanks is 0.01 inch. This defines the minimum pressure below which no weight reduction can be achieved. The trend curve shown in Figure 5.3-10 for various fluids required in the ABL processing cycles, is based upon an internal pressure of 1000 psi. The same trend established for gaseous storage is applicable for fluids. Most of the fluids used have densities that occur in the flat portion of the curve. This indicates a relative insensitivity of tank weight to fluid weight. While tank weight can be shown to vary linearly with pressure, it was found that the design condition for liquid storage tanks was defined by the hydrostatic head imposed by the stored fluid during vehicle acceleration. During entry and upon impact, these accelerations can be in the order of 180 g and 500 g respectively. At 500 g the hydrostatic head in a tank storing 60 pounds of water becomes 290 psi. For a 1.5 safety factor, the design condition increases to 535 psi. As a comparison, during sterilization the vapor pressure of water (safety factor included) is 78 psi provided adequate ullage is available and the water pure. The ratio of tank weight to fluid weight as a function of tank diameter is shown in Figure 5.3-11 for a spherical tank. It is clear that the landing becomes the design condition and the tank weight in the order of 3 to 5 percent of fluid weight can be expected.

d. Ampule Storage. Liquid reagents are stored in 2.5 cc and 5.0 cc quantities in dispensing ampules. Compatibility requirements establish that the material in contact with the stored reagent would, in most applications, be Teflon. The minimum tank weight analysis described above is not valid for the storage ampules for two reasons. First, the small volume of the ampules indicated that a reasonable minimum wall thickness was greater than that prescribed by minimum weight analysis. Second, functional operation of the ampule as a dispensing unit establishes its configuration. It should be pointed out that the large number of ampules required (5288, including transfer ampules), emphasizes the importance of minimizing the weight of each ampule. This in turn establishes that both functional and weight

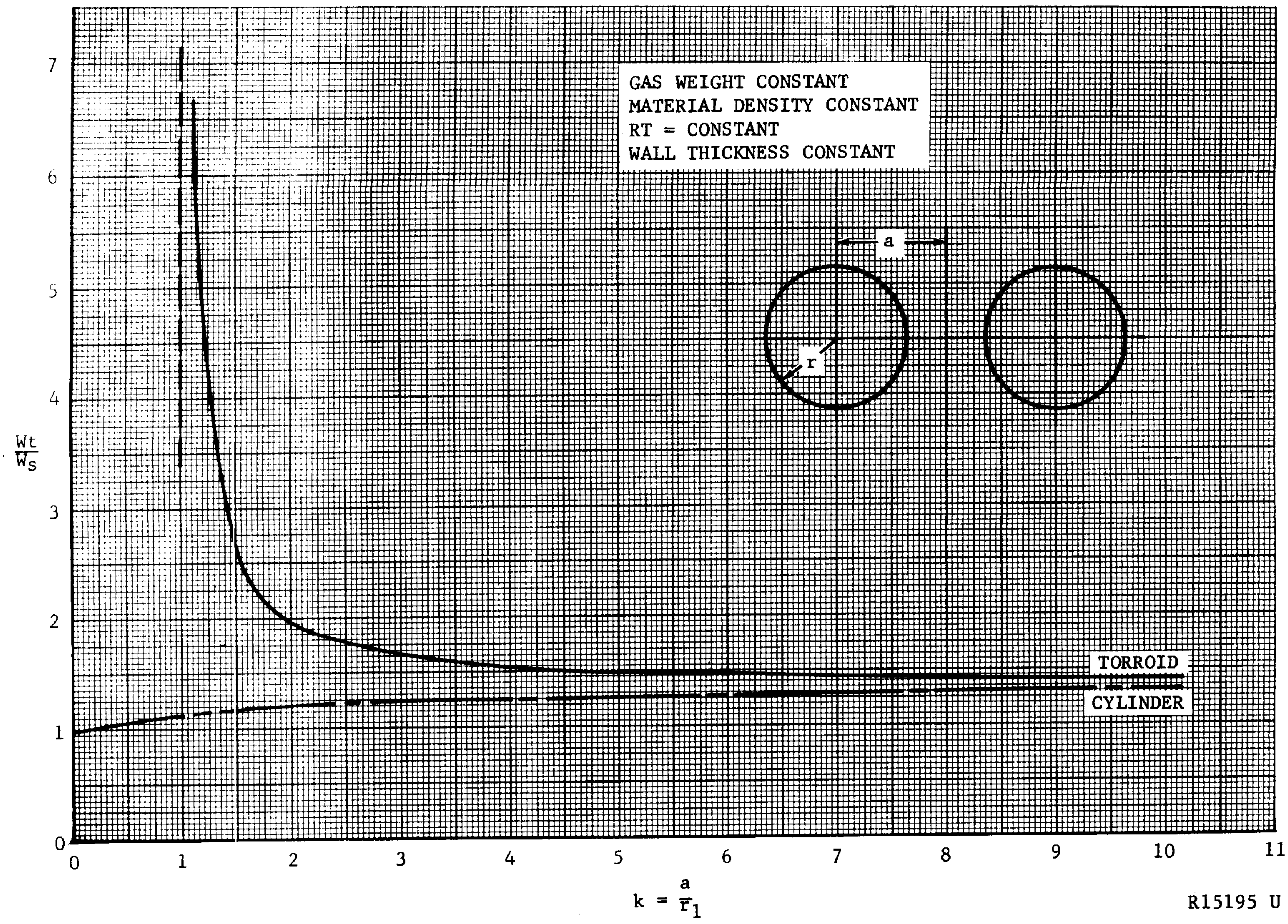

FIGURE 5.3-9. RATIO OF TOROIDAL TANK WEIGHT TO SPHERICAL TANK WEIGHT

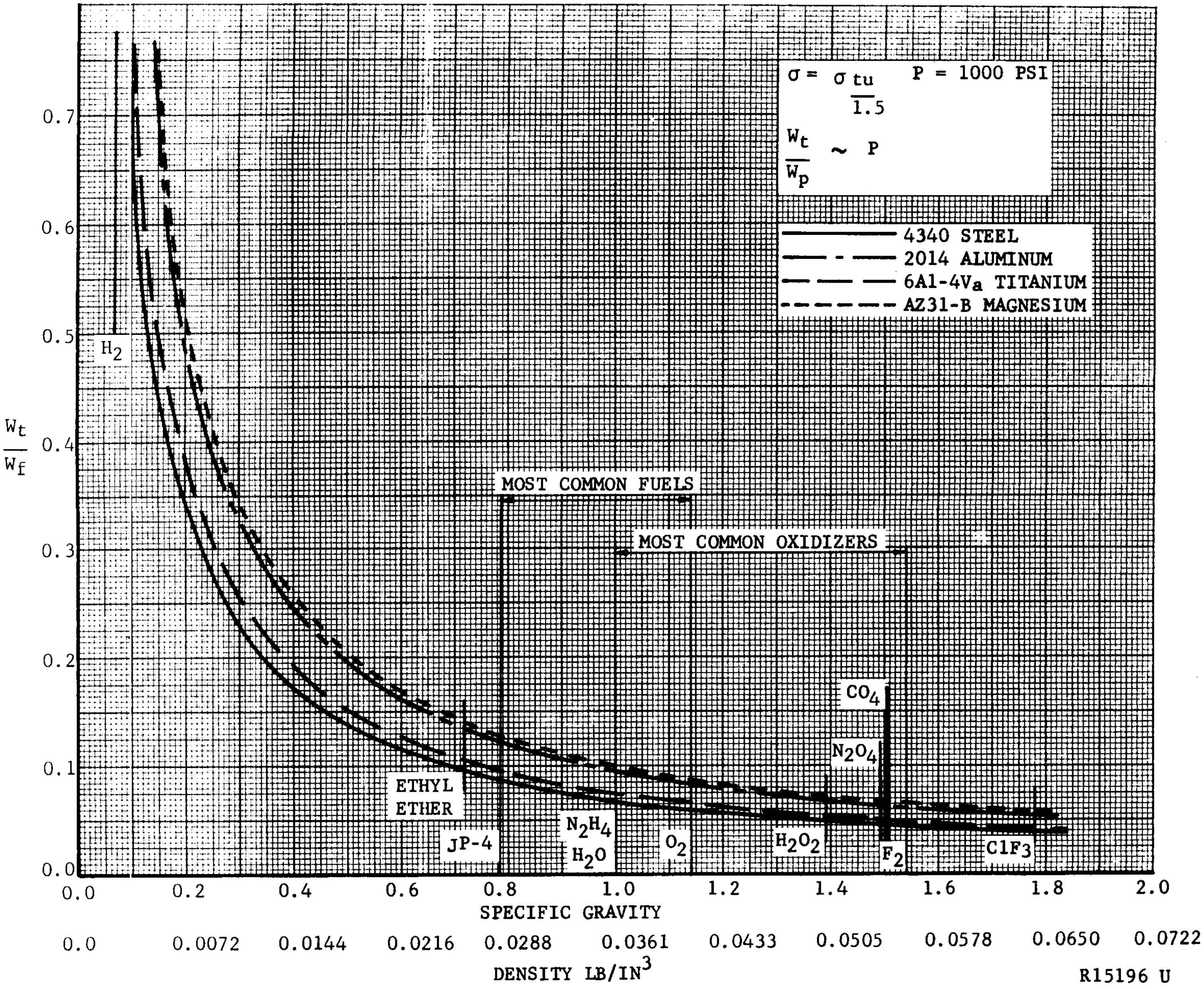

FIGURE 5.3-10. TANK WEIGHT VARIATION WITH FLUID DENSITY

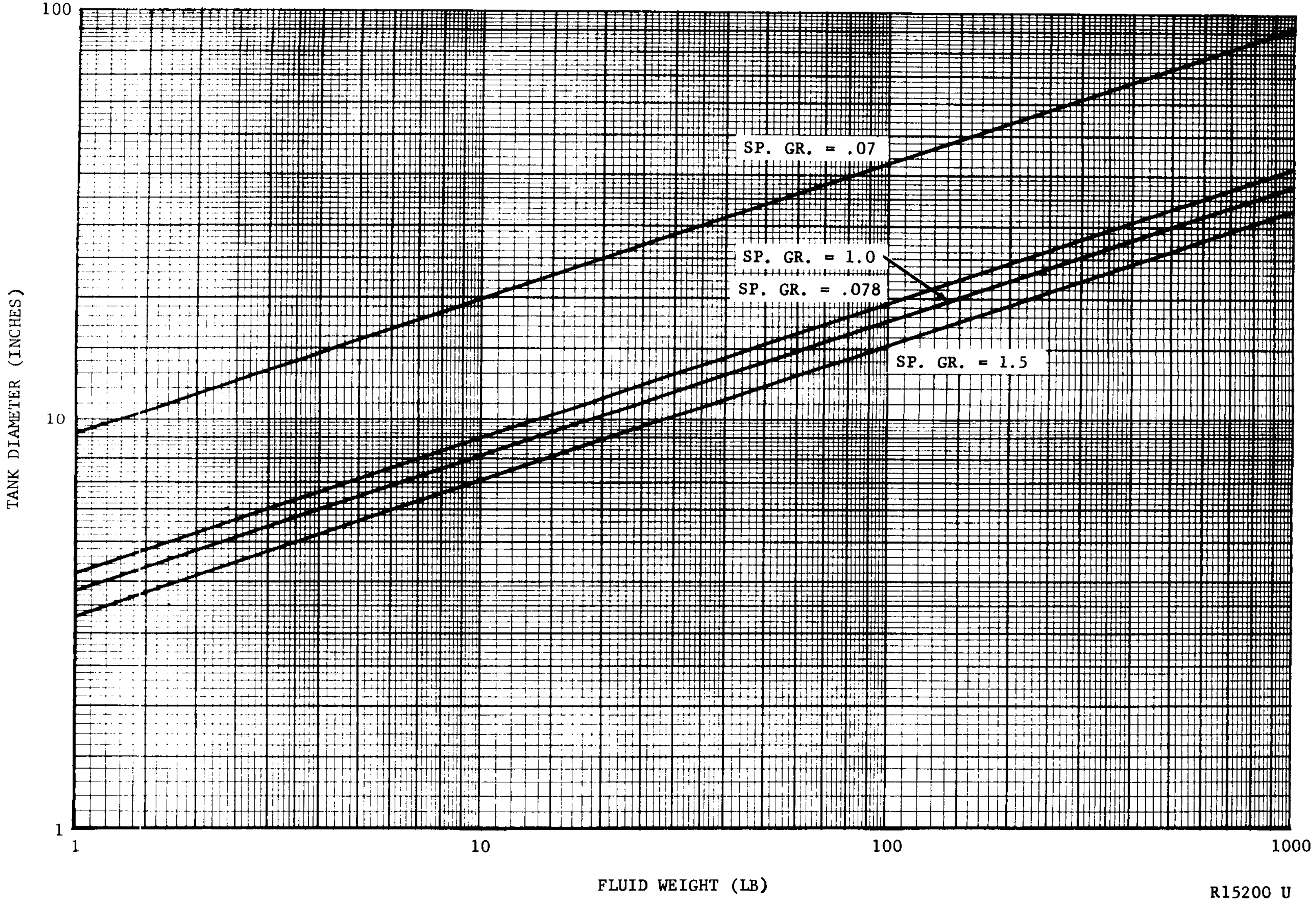

FIGURE 5.3-11. REQUIRED SPHERICAL TANK DIAMETER FOR FLUIDS

requirements be carefully evaluated, and that detailed parametric analysis and design studies be employed to guarantee an ampule configuration which fully satisfies the operational and compatibility requirements at a minimum weight. Specific ampule designs evaluated during this study are discussed in Paragraph 5.5.

5.4 SYSTEM WEIGHT ANALYSIS

This paragraph presents a detailed weight summary of the ABL design point configuration described in Paragraph 5.3 of this volume. The total vehicle weight is 1,186.0 pounds. Detailed weight summaries are presented for various component categories, i.e., analytical instruments and detectors, processing equipment, chemical processor attachments, and support systems for the design point case. The results of weight trade-off and comparison studies are reported in Paragraph 5.4.2.

5.4.1 DESIGN POINT LABORATORY WEIGHT SUMMARY

Weight, volume, and packing density for the design point ABL are presented in summary form in Table 5.4-I, and in a detailed breakdown in Table 5.4-II through 5.4-VI. The components were divided into five general categories:

(1) Analytical Instruments and Detectors - items which are directly involved in providing the analytical output from the experiments.

(2) Processing Equipment - items directly related to the collection and preparation of samples for analysis.

(3) Chemical Processor Attachments - items used in conjunction with the chemical processor to prepare test samples from soil.

(4) Chemical Supply - all gases and liquids required for chemical processing and spacecraft support.

(5) Support Systems - electronics, electrical power, thermal control, and structure.

The design point vehicle is packaged in a spherical configuration, 68 inches in diameter. The effective density of the payload, based upon the total weight (1186.0 pounds) and the total enclosed volume (94.6 ft^3) is 12.5 pounds per cubic foot. The density of any spacecraft is strongly dependent upon the operational criteria required of its components. Aeronutronic Lunar Impact Payload, which is basically a static device, has a packing density of approximately 95 pounds per cubic foot. On the other hand, OAO has a scientific payload packing density of approximately 8 pounds per cubic foot. Using packing density as an evaluation parameter of packing efficiency can be misleading if the operational constraints imposed on the vehicle are not considered.

TABLE 5.4-I

DESIGN POINT ABL WEIGHT SUMMARY

Item	Weight (lb)	Volume (ft^3)	Equipment Density (lb/ft^3)
Analytical Instruments and Detectors	134.0	31.42	4.26
Processing Equipment	268.0	11.64	23.00
Chemical Processor Attachments	121.0	7.35	16.46
Chemical Supply	192.0	-	-
Total Scientific Payload	715.0	50.42	14.18
Support Systems	471.0	5.73	80.45
Design Point ABL Landed Payload Weight Total	1,186.0	56.15	20.94

TABLE 5.4-II

WEIGHT AND VOLUME SUMMARY
ANALYTICAL INSTRUMENTS AND DETECTORS

	Item	Weight (lb)	Volume (in.^{3})
1.	Atmospheric Parameters Sensor	1.0	5
2.	Gold Film Aluminum Oxide Water Vapor Detector	0.1	1
3.	Microphone with Acoustic Resonator	1.0	5
4.	Microphone with Acoustic Reflectors	1.0	5
5.	2π β and α -Ray Pulse Height Counter	14.5	60
6.	Core Hole Traversing Sonde	2.5	16
7.	Soil Mechanics Apparatus and Soil Sampler (2)	24.5	1100
8.	Optical Motion Detector	2.0	20
9.	Optical Density Comparator (13)	1.3	20
10.	Macroimaging System	4.0	60
11.	Infrared Radiometer	0.2	1
12.	Solar Radiation Spectrum Analyzer	0.2	1
13.	pH Meter	0.5	3
14.	CO_2 Detector (Ba (OH)$_2$ cell)	0.1	1
15.	β -ionization Counter (13)	1.9	20
16.	Gas Chromatograph No. 1	12.2	400
17.	Gas Chromatograph No. 2	7.7	350
18.	Gas Chromatograph No. 3	6.4	160
19.	Gas Chromatograph No. 4	6.4	160
20.	Gas Chromatograph No. 5	6.4	160
21.	α -Scattering Analyzer	4.0	260
22.	Infrared Spectrophotometer	10.0	350
23.	Spectral Analyzer	20.0	2160
24.	Mass Spectrometer	6.0	207
25.	Argon Ionization Detector (1)	0.1	1
	Total Instruments and Detectors	134.0	54,297

TABLE 5.4-III

WEIGHT AND VOLUME SUMMARY
PROCESSING EQUIPMENT

	Item	Weight (lb)	Volume (in.^{3})
1.	Soil Pulverizer and Pneumatic Grader (2)*	10.0	230
2.	Internal Transport Mechanism	12.0	120
3.	Cyclone Particle Collector and Weight Scale	3.2	300
4.	Chemical Processing and Culture Chamber (13)	65.0	2100
5.	Dialysis Chamber (3)	4.2	90
6.	Waste Storage	4.8	1650
7.	Soil Probe (2)	4.6	124
8.	Culture Evaluation Processor (13)	5.7	400
9.	Vacuum Pump	5.2	40
10.	Refrigeration Heat Exchanger	2.0	20
11.	Core Drill	15.0	130
12.	Traversing Atmospheric Dust Collector	1.0	76
13.	Sampler Deployment Mechanism	(47.3)	(800)
	Proximity System		
	Boom and Drive Motors	10.3	350
	Remote System (37.0 lb)		
	Cable Anchor Rocket (2)	8.2	400
	Trolley and Sampler Bail (2)	1.4	10
	Cable 1500 ft (2)	22.4	---
	Misc. Equipment	5.0	40
14.	Reagent Supply Storage	(70.0)	(13,056)
	Water Tank	10.6	3670
	Solvent Tank	11.8	3700
	Gaseous Storage		
	Carbon-14 Dioxide Tank	2.0	90
	Carbon-12 Dioxide Tank	2.5	106
	Hydrochloric Acid Tank	1.7	80
	Oxygen Tank	0.5	32
	Argon Tank	2.8	163
	Helium Tank	5.1	3128
	Nitrogen Tank	33.0	2087
15.	Soil Preservation Capsules	18.0	1010
	Total Processing Equipment	268.0	20,146

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*Numbers in parentheses denote quantities.

TABLE 5.4-IV

WEIGHT AND VOLUME SUMMARY
CHEMICAL PROCESSOR ATTACHMENTS

Item	Weight (lb)	Volume (in.^{3})
Filter Units (996)	25.8	880
Suction Units (1080)	1.7	1910
Piston Tip (2808)	9.4	1030
Pyrolysis Culture Dish (1800)	2.9	3180
Reagent Ampule (4196)	55.9	4150
Transfer Ampule (1092)	14.7	1090
Fluorimeter Cell (228)	5.2	118
Spectro Polar Cell (228)	5.2	118
α-Scattering Plates (120)	0.2	212
Total Attachments	121.0	12,688

TABLE 5.4-V

WEIGHT AND VOLUME SUMMARY
CHEMICAL SUPPLY

Item	Weight (lb)	Volume (in.^{3})
Water	60.0	Included in Container
Solvent	60.0	Included in Container
Chemicals	32.0	Included in Container
Gases (40.0 lb)		
Carbon-14 Dioxide	2.8	Included in Container
Carbon-12 Dioxide	3.6	Included in Container
Hydrochloric Acid	2.4	Included in Container
Oxygen	0.1	Included in Container
Argon	3.1	Included in Container
Helium	0.6	Included in Container
Nitrogen	27.4	Included in Container
Total Chemical Supply	192.0	---

TABLE 5.4-VI

WEIGHT AND VOLUME SUMMARY
SUPPORT SYSTEMS

Item	Weight (lb)	Volume (in.^{3})
Electronics	(84.0)	(1380)
Data Automation System	62.0	725
Communications	20.0	400
Antennas (2) and Cable	2.0	455
Electrical Power	(166.0)	(2010)
RTG Power Supply (2)	50.0	1000
Battery Power Supply (2)	60.0	500
Power Control and Regulation	16.0	260
Electrical Wiring	40.0	250
Structure	(191.0)	(4520)
Pressurized Center Section	60.0	600
Upper and Lower Sections	27.0	270
Equipment Support Structure	55.0	550
Vehicle Legs	30.0	1500
Mast Assembly	19.0	1600
Thermal Control System	30.0	2000
Total Support Systems	471.0	10,310

Three factors significantly influence the packing density of the design point ABL.

(1) Fourteen components are deployed after the ABL is erected. Clearance envelopes for each of the items compromise efficient utilization of space in that area.

(2) The steps involved in sample delivery and mechanical and chemical processing directed that specific components be placed adjacent to one another in order to guarantee simple and reliable continuity of processing. This precluded arranging components in the best possible orientation to effect a dense payload. In addition, some components move during operation, sweeping out volumes which cannot be utilized for packaging components.

(3) Finally, the design point vehicle has not been subjected to rigorous minaturization study. Optimum packaging is normally attained only after repeated comparison studies based upon a variety of packaging concepts. The objective in this initial ABL analysis was the synthesis of a representative feasible design and not necessarily one optimized on a density basis. (See further discussion on the effects of payload density on the overall entry vehicle system in Paragraph 6.6.)

5.4.2 PRINCIPAL WEIGHT TRADEOFFS

a. Reduced Mission Length. The design mission length of the ABL experimental program is two years. This time period subdivides into periods of 43 days, during which the entire experimental program can be completed using one proximity soil sample. In the same time period, all of the experiments requiring a soil sample can be completed on a remote sample, except those involving fixation or evolution of $C^{12}O_2$ and $C^{14}O_2$, Experiments 29, 30, 31, and 32. The influence on spacecraft weight of reducing the design mission life from two years to one year, and to 43 days was examined, and is summarized in Table 5.4-VII. The results are plotted on Figure 5.4-1.

(1) Criteria. The criteria on which this analysis was based are as follows:

(a) Reagents and consumables were reduced in preparation to the reduction in total mission time.

TABLE 5.4-VII

WEIGHT REDUCTION FOR REDUCED MISSION LENGTH

Item	Weight (lb) 43 Day Mission	1 Year Mission
Reagents	-180.7	- 96.0
Processor Attachments	-130.8	- 69.5
Reagent Supply Storage	- 65.9	- 35.0
Waste Storage	- 4.5	- 2.4
Equipment Support Structure	- 28.6	- 15.2
Pressurized Section	- 10.2	- 8.6
Total Weight Reduction	-420.7	-226.7
Percentage Weight Reduction	36.8	19.3
Total ABL Landed Payload Weight	755.3	949.3

(b) Reagent and consumable storage requirements and the laboratory structure were reduced in proportion to the reduction in reagents and consumables.

(c) No reduction in electrical power is assumed since the single cycle (43-day) basic power requirement which sized the system remains unchanged, and with the RTG, there is no penalty for added total energy at a fixed power level within the operating life of the RTG.

(2) Discussion. Several effects relative to the results of this analysis are of interest:

(a) If the experimental functions utilizing consumables were proportioned, not just as a function of mission time but in relation to the way in which experiments are likely to be scheduled, i.e., more frequently at the beginning of the program, the slope of the curve in Figure 5.4-1 would be less and would, therefore, indicate a smaller penalty with increasing lifetime.

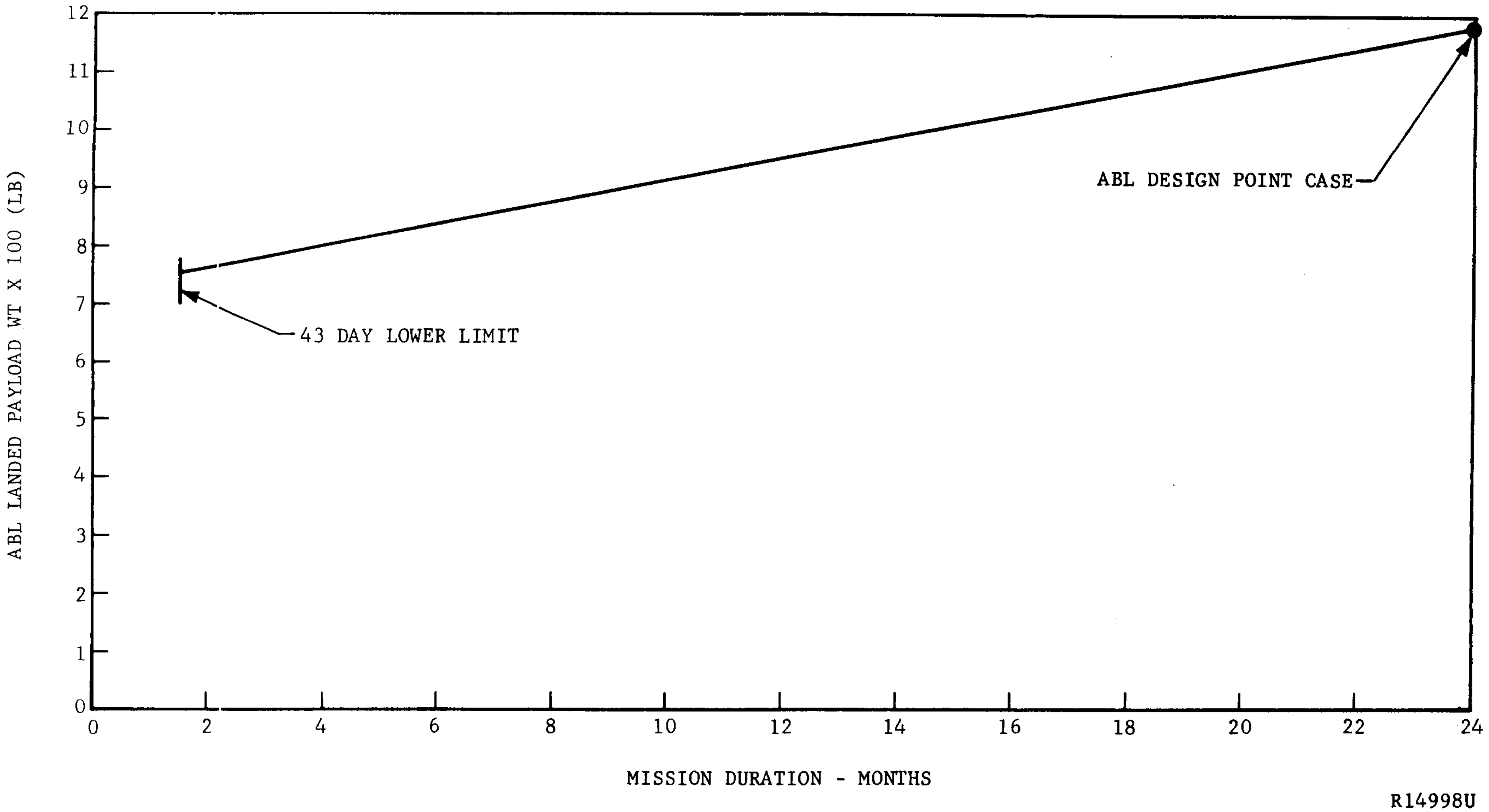


FIGURE 5.4-1. WEIGHT REDUCTION VERSUS MISSION TIME

(b) If the example analysis had assumed identical reliability from the system for performing the total experiment complement, both at 43 days and at two years, the penalty for the two-year life would have greatly exceeded that shown in Figure 5.4-1 because of the increased requirement for redundancy. The analysis was based on a more realistic case, however, namely the one employed for the ABL design point reliability analysis discussed in Paragraph 4.4. In this case, redundancy is applied to give an acceptably high reliability for the 43-day period (0.98 for the conditions assumed) and the degraded reliability resulting from this design accepted for the two-year case (approximately 0.50 for the same conditions). The rationale for this approach is related to the probable decreasing importance of the data with time, as discussed above and in Paragraph 4.4.

b. Equipment Removal. The influence on total weight of removing certain equipment was examined. The core drill is used to prepare a core hole from which subsurface soil samples may be obtained, and into which the subsurface sonde may be introduced. If the ABL landing site is on a solid, rock-like surface, satisfactory cores may be extracted. If, however, the preliminary indication, that the Martian surface is extremely dry and loosely packed, is substantiated, no core samples will be obtained within the limited drill depths available. In addition, the data received from the core samples are applied to a single experiment, and the data produced by the core hole sonde are applied to two experiments. These experiments are not part of the biological procedures, but are directed toward the gathering of supporting geophysical data. Further analysis may indicate the desirability of removing this capability from the ABL. The weight reduction achievable by the removal of the core drill is summarized in Table 5.4-VIII.

TABLE 5.4-VIII

WEIGHT REDUCTION FOR REMOVING CORE DRILL AND SONDE

Item	Weight (lb)	Volume (in.^{3})
Core Drill	-15.0	130
Core Hole Traversing Sonde	- 2.5	16
Batteries $\frac{\text{500 watt hr}}{\text{42 watt hr/lb}}$	-12.0	100
Equipment Support Structure (0.075) 29.5	- 2.2	22
Total Weight Reduction	-31.7	268
Percentage Weight Reduction	2.70	

Completion of the desired experiments within a 43-day period requires the use of thirteen chemical processors. This is primarily due to the use of multiple processors in the $C^{12}O_2$ and $C^{14}O_2$ fixation and evolution experiments. Experiments 29 and 32 require six processors, and Experiments 30 and 31 require four processors. If the experimental cycle is extended such that Experiments 29, 30, 31, and 32 can be conducted sequentially, six processors will satisfy all of the experimental requirements. Table 5.4-IX summarizes the reduction in weight involved in reducing the number of chemical processors from thirteen to six.

TABLE 5.4-IX

WEIGHT REDUCTION FOR REMOVAL OF SEVEN CHEMICAL PROCESSORS

Item	Weight (lb)	Volume ($in.^3$)
Processing Chamber	- 35.0	1,130
Reagents	- 38.4	
Chemical Supply Containers	- 27.8	2,740
Reagent Supply Storage	- 14.0	2,611
Waste Storage	- 1.0	300
Culture Evaluation Processor	- 3.1	215
Equipment Support Structure	- 8.9	89
Pressurized Center Section and Upper and Lower Sections	- 4.2	
Total Weight Reduction	-132.4	7,115
Percentage Weight Reduction	11.26	

c. Addition of Drag Line Samplers. A drag line technique for collecting remote soil samples was discussed in Paragraph 5.5 of this Section. This is an alternate design that would replace the trolley system depicted for the design point vehicle. Eight samplers are required to collect the soil samples required by the experiments. The incremental weight incurred by the addition of drag line samplers is shown in Table 5.4-X.

TABLE 5.4-X

WEIGHT SUMMARY
DRAG LINE SAMPLER

Item	Weight (lb)
Projectile	(13.0)
Sampler	1.9
Rocket and Cone	3.6
Cable (1000/ft)	7.5
Recovery System	(3.0)
Total Drag Line Sampler	16.0

Eight such samplers result in a positive weight increment of 128 pounds; removal of the trolley system results in a negative weight increment of 49.3 pounds, for a net gain in weight of the ABL vehicle of 78.7 pounds. The total weight of the ABL would increase to 1,264.7 pounds.

d. Alternative Laboratory Mechanizations

(1) Summary. The results of an investigation of the weight differences between alternative payload mechanizations employing (1) individual sampling and instruments, (2) integrated sampling and individual instruments, and (3) integrated sampling and instruments are presented below. The comparison is based on the ABL experiment components and experimentation life as a function of number of experiments.

Weight of the analytical instruments (and related sampling) alone for the three cases is plotted versus number of experiments in Figure 5.4-2. Adding processing equipment and consumables (including reagents) to the analysis equipment yields the scientific payload weight which is plotted in Figure 5.4-3. Figure 5.4-4 presents the total payload weight which includes the scientific payload plus electronics (including communications and data automation system), electrical power generation, structure and deceleration device (including retrorocket, parachute, and altimeter). Total entry system weight is plotted in Figure 5.4-5 for an Apollo shape vehicle based on the work is in Paragraph 6.6. This figure shows a considerable weight savings for the integrated sampling and instrumentation approach over the other two cases. A weight summary for the 6 cases is given in Table 5.4-XI.

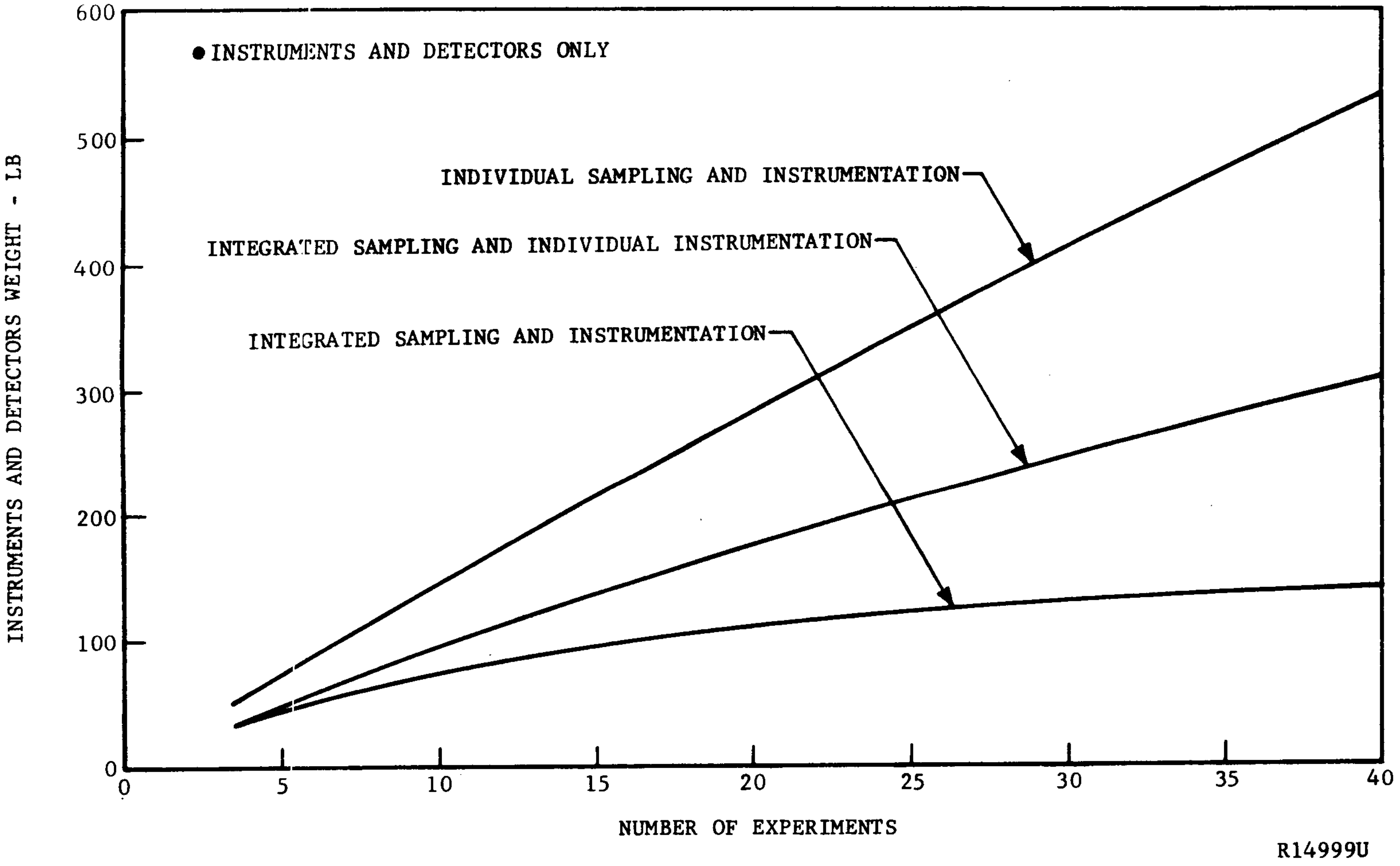
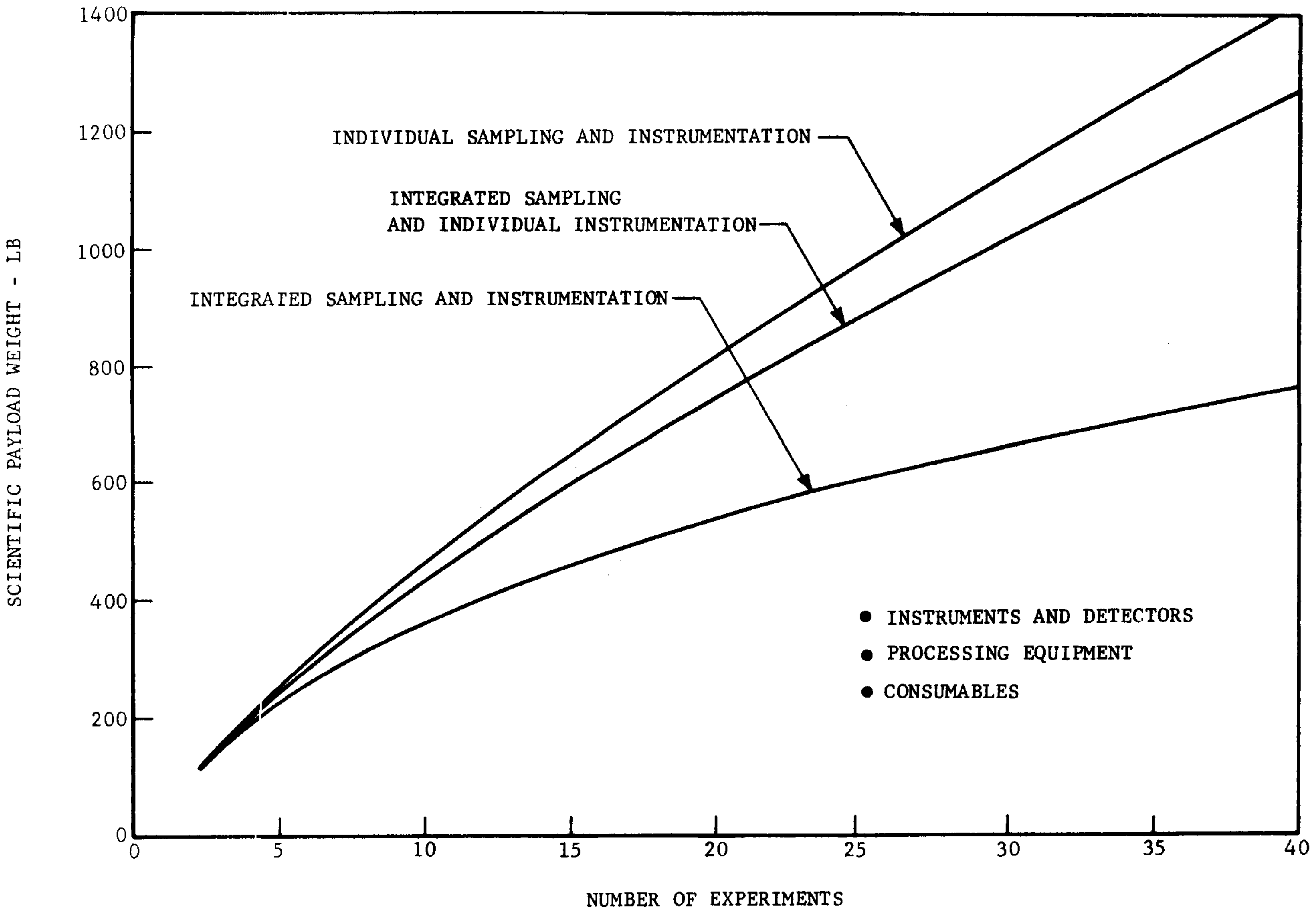
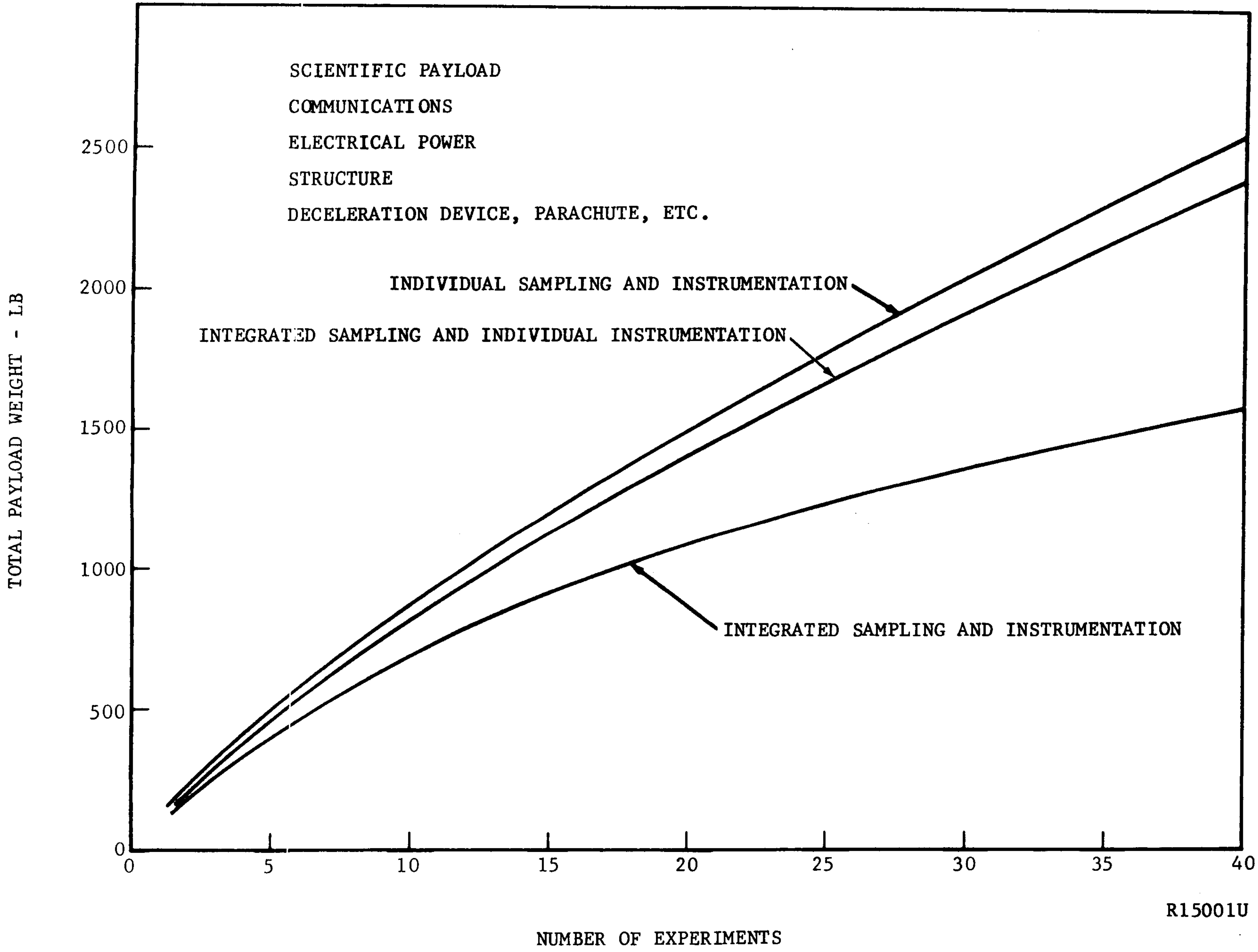


FIGURE 5.4-2. WEIGHT COMPARISON ANALYTICAL INSTRUMENTS AND RELATED SAMPLING



R15000U

FIGURE 5.4-3. WEIGHT COMPARISON - SCIENTIFIC PAYLOAD


SCIENTIFIC PAYLOAD
COMMUNICATIONS
ELECTRICAL POWER
STRUCTURE
DECELERATION DEVICE, PARACHUTE, ETC.
INDIVIDUAL SAMPLING AND INSTRUMENTATION
INTEGRATED SAMPLING AND INDIVIDUAL INSTRUMENTATION
INTEGRATED SAMPLING AND INSTRUMENTATION
TOTAL PAYLOAD WEIGHT - LB
2500
2000
1500
1000
500
0
0
5
10
15
20
25
30
35
40
NUMBER OF EXPERIMENTS
R15001U

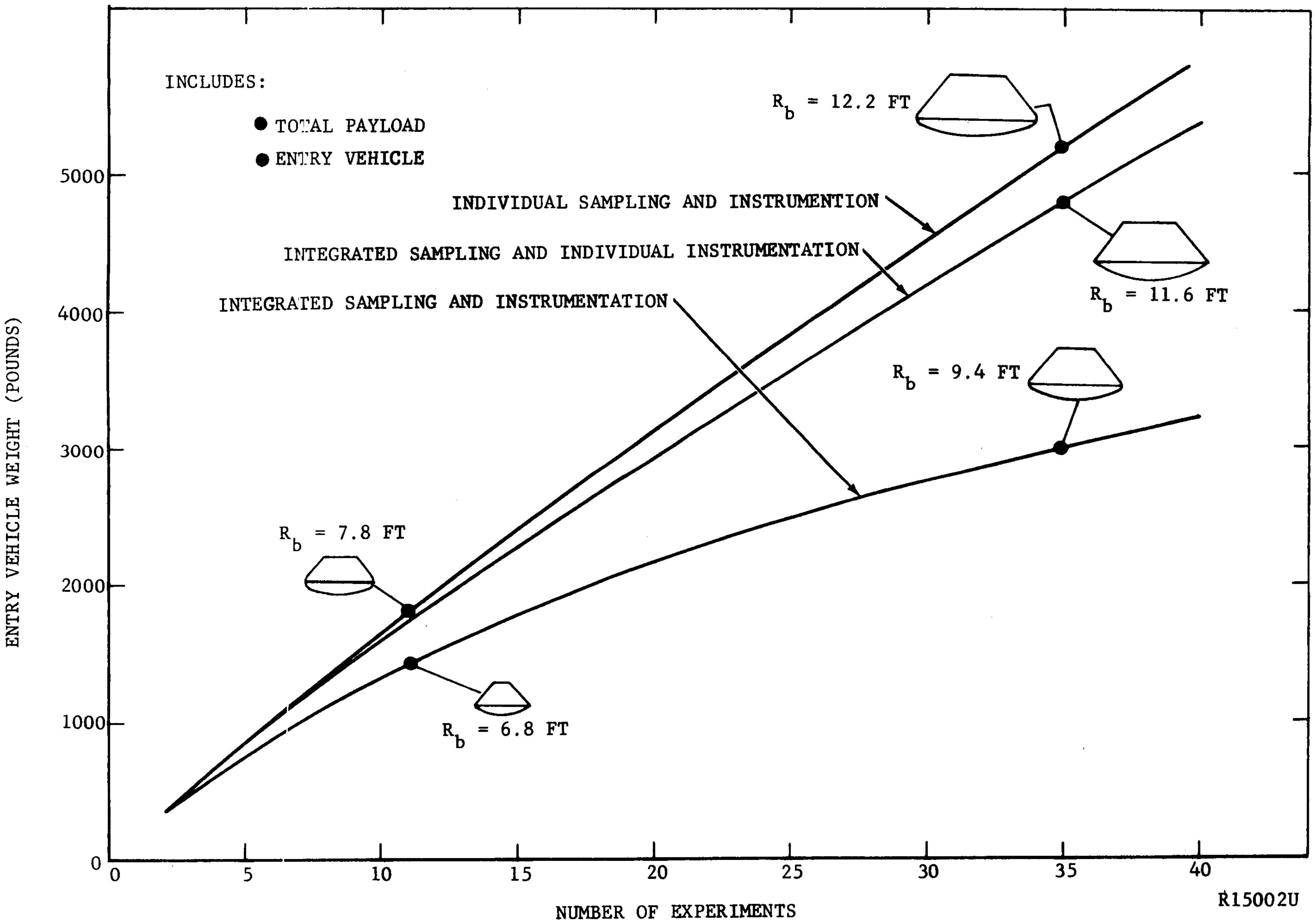


FIGURE 5.4-5. WEIGHT COMPARISON - ENTRY VEHICLE COMPLETE

TABLE 5.4-XI

WEIGHT SUMMARY

Description	Individual Sampling Individual Instruments	Integrated Sampling Individual Instruments	Integrated Sampling Integrated Instruments
35 Experiments			
Analysis	471	276	134
Processing Equipment	779	827	581
Scientific Payload	1250	1103	715
Support Systems	610	580	461
Deceleration Device	460	437	294
Total Payload	2320	2120	1470
Entry Vehicle	2880	2680	1530
Entry Weight	5200	4800	3000
13 Experiments			
Analysis	192	127	89
Processing Equipment	387	417	329
Scientific Payload	579	544	418
Support Systems	280	271	239
Deceleration Device	211	205	163
Total Payload	1070	1020	820
Entry Vehicle	1030	980	780
Entry Weight	2100	2000	1600

(2) Analysis. Two points were used to generate the weight trends; point 1 was the 35 ABL experiments and point 2 employed a representative complement of 13 experiments. The ABL component weights are those defined in Paragraph 5.4.1 above.

(a) Experiments. The complete list of 35 ABL experiments was used for point 1. Experiment numbers 1, 7, 8, 18, 19, 20, 22, 23, 24, 25, 26, 31, and 35 were the 13 experiments employed for point 2. The number of instruments and processors required in the scientific payload depends on the amount of integration and is discussed below.

(b) Analysis Instruments. The analysis function consists of analytical instruments and detectors and varies with the amount of integration. The individual sampling units are less sophisticated than the ABL units and the deployment and sampler mechanism together weigh only 10 pounds each. This corresponds to the simplest single sampler employed on the ABL.

(c) Processing Equipment. The processing equipment including reagents, chemicals, and tankage were proportioned according to the experiment and instrumentation capability identified above.

(d) Support Systems. The electrical power required for the two alternate approaches is basically the same as for the ABL if the instruments are used for the same amount of time. This has been assumed for this analysis and, therefore, the weight of the electronics, electrical power, and thermal control are the same as ABL weights. The structure was taken as the same percentage of the scientific payload weight as for the integrated case, a slight bias in favor of the individual experiments.

The weight for the support systems (except structure) for the 13 experiment case was ratioed in proportion to the number of experiments. The structure was determined by a percentage of the scientific payload weight.

(e) Entry Vehicle. An Apollo shaped entry vehicle was used in this analysis. The weight and size were determined from the work of Paragraph 6.6.

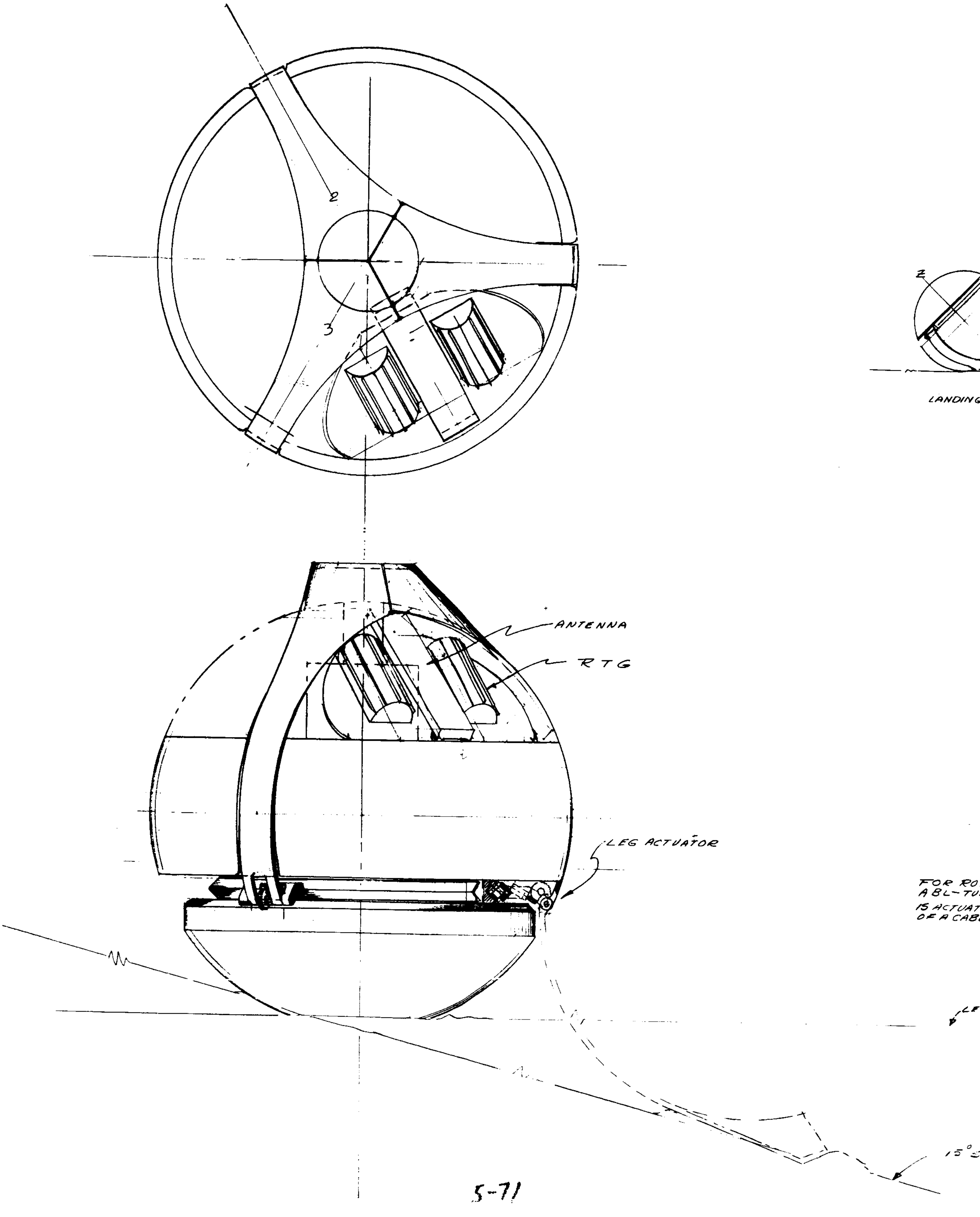
5.5 PRINCIPAL LABORATORY SUBSYSTEMS

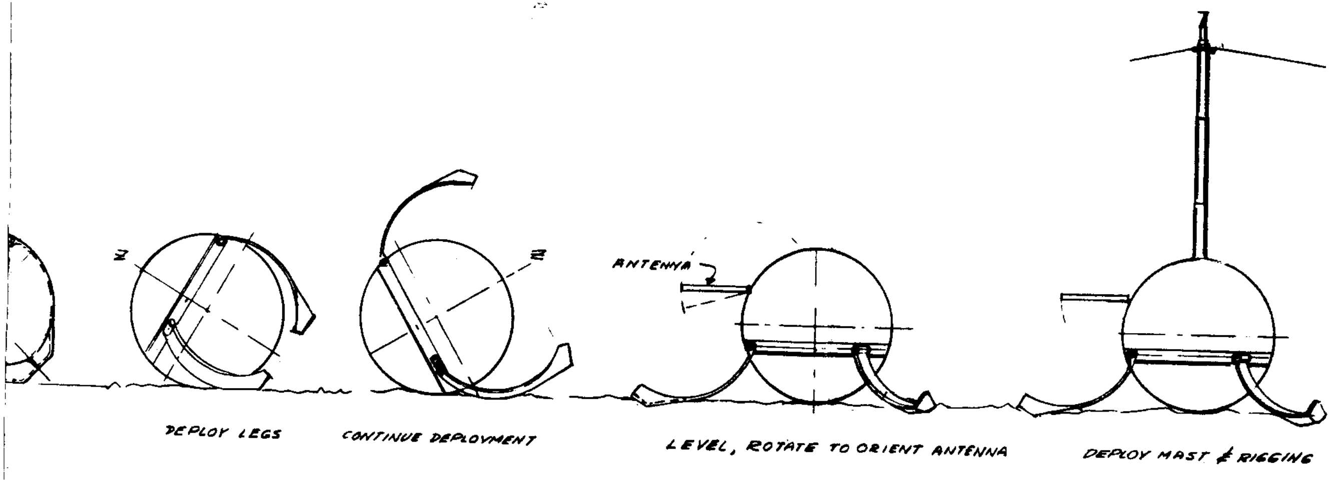
The major mechanical subsystems discussed in this paragraph are those used to deploy, and in some cases retrieve, analytical and sample collection equipment previously described. These include the deployment subsystems for the soil gas exchange chamber, β and γ pulse height counter, soil probes, and sample collectors. In addition, the operation of the ABL erection leg system, soil pulverizer, cyclone separator scale, and the chemical processor and its attachments are discussed.

5.5.1 LABORATORY ERECTION AND ORIENTATION SYSTEM

Vertical erection and alignment and directional antenna steering are provided by the ABL support leg subsystem. A tripod leg arrangement was provided. Prior to deployment the legs are stored in rectangular recesses in the ABL spherical surface. The leg deployment sequence is shown in Figure 5.5-1. The outboard end of each leg forms one third of a cone frustum so that when the legs are in the stored position, the conical section thus formed acts as a turnover structure. This permits the ABL to be erected by the deployment of the support legs regardless of its static attitude on the Martian surface. The legs feature individual suspension from a diamond shaped turret ring. The leg deployment system consists of a motor-gearhead worm and worm gear drive train controlled by a level sensor that positions each leg so that vertical orientation of the ABL is accomplished. Vertical orientation permits the use of gravity controlled functions and operations in the laboratory which result in equipment and component concepts far simpler than if they were required to accommodate a random repose angle. The leg turret ring is supported by an orthogonal pair of 2-inch diameter, ball bearing rollers located at 30 degree intervals around the ring. This permits rotation of the ABL about its vertical centerline by means of a motor-gearhead driven drum and endless cable drive system. ABL rotation is necessary to orient the directional antenna to a position parallel to the axis of rotation of Mars.

The directional antenna is mounted above the upper pressure bulkhead of the ABL and, in its stored position, nests between the two RTG power supply units. The deployment actuator is a torsion-spring drive which is loaded when the antenna is rotated into its stored position. Nesting clips on the antenna and RTG support structure are interconnected with pyrotechnic shear pins. Primary and secondary signal sources are provided to ensure separation of the antenna interlock. After separation, the antenna is driven by spring torque to a position 15 degrees below the horizontal when it is locked into place by spring loaded detent pawls.


2
3
ANTENNA
RTG
LEG ACTUATOR
Z
LANDING
FOR RO
ABL-TU
IS ACTUAT
OF A CAB
15°



ERECTING SEQUENCE

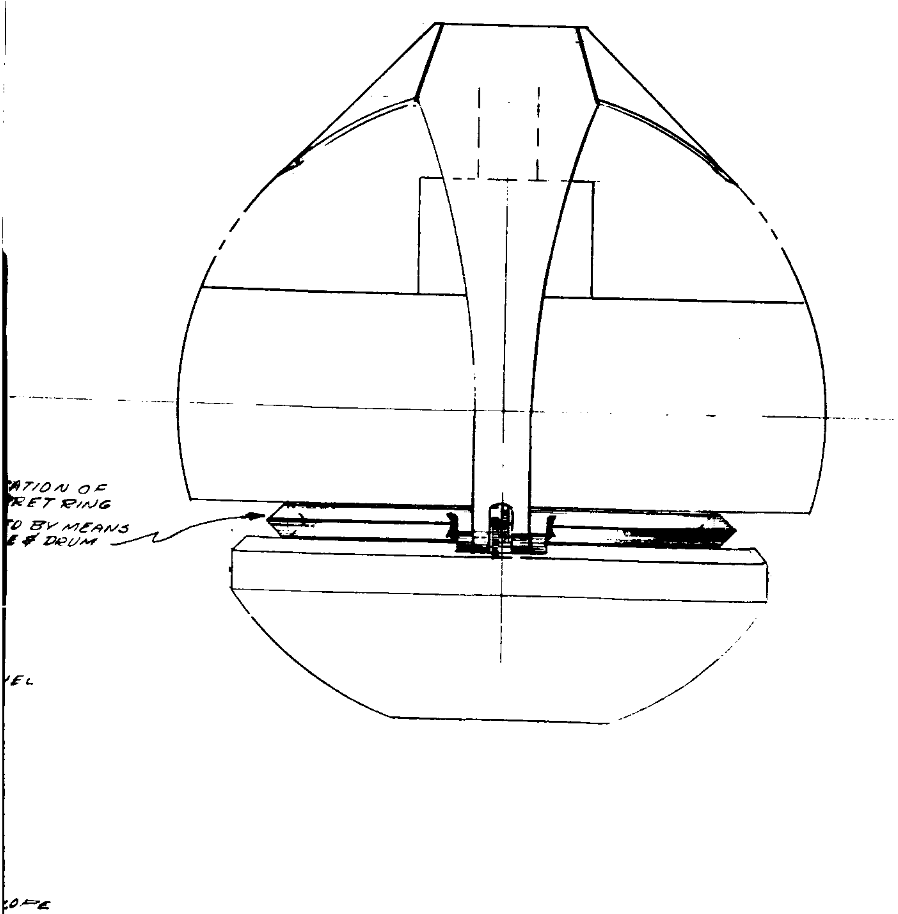


FIGURE 5.5-1. ERECTION AND SUPPORT STRUCTURE

[redacted]

Orientation for positioning the directional antenna is provided by the macroimaging system in its radiometer mode. The macroimaging system, pitot system, anemometer, hygrometer, motion detector, and sampling system crown block are located in the upper segment of the telescoping mast. The mast is made up of four, thin-wall aluminum tubes that are errected pneumatically. Each segment interlocks with the segment within and without to form a rigid, fixed length mast. Each segment has a 14-inch faying surface in which its guide and interlocking units are contained. Tube guiding and pneumatic seal are accomplished with Teflon O-rings and guide collars. The interlock is a steel split ring that is preloaded into a recess on the outer diameter of each tube. During deployment, the guide collars maintain concentric travel on each tube, and the split ring expands into a recess on the inner diameter of the outer segment to provide a positive, rigid interlock.

After mast deployment, the radiometer is used as a sun-seeker, and the elevation and azimuth of the sun with respect to the ABL is stored within the computer. A typical scanning sequence is depicted in Figure 5.5-2. The radiometer is set on a horizon scan to detect sunrise. The azimuth of the sun and the time of sunrise are stored in the computer. Three hours after sunrise, the radiometer is placed in a vertical scan mode and records the elevation and azimuth of the sun's position. Nine hours after sunrise, the previous search is repeated, and then the radiometer is set on horizon scan to detect sunset. The results of these readings provides the data necessary to establish the latitude of the landing site and the vehicle rotation necessary to place the antenna surface parallel with the rotational axis of Mars. Typical procedures for vehicle orientation are depicted in Figure 5.5-3. The positioning of the antenna at an angle of 15 degrees below the horizontal was based upon the assumption that the selected and attained landing site would be between 30°N and 30°S latitudes. Landings outside this band require that the antenna be actively oriented throughout the mission. With the restriction on landing site latitudes imposed during this study, only the initial aiming described qbove is required and the ABL then locked against any further rotation. All subsequent antenna beam orientation is accomplished electronically (see Paragraph 6.2).

5.5.2 EXPERIMENT DEPLOYMENT SYSTEMS

Those subsystems that are basically self contained processing systems and which do not require preliminary preparation and sample collection for the operation are described below.

a. Soil Gas Exchange Chamber (Figure 5.5-4). This subsystem collects soil gases from undisturbed soil in situ and from soil that has been infused with labelled substrates. The chamber is a bell-shaped transparent container open on the lower end. It is positioned on the soil without disturbing the soil contained within the walls. The transparent container permits solar insolation so that natural soil gas evolution can occur.

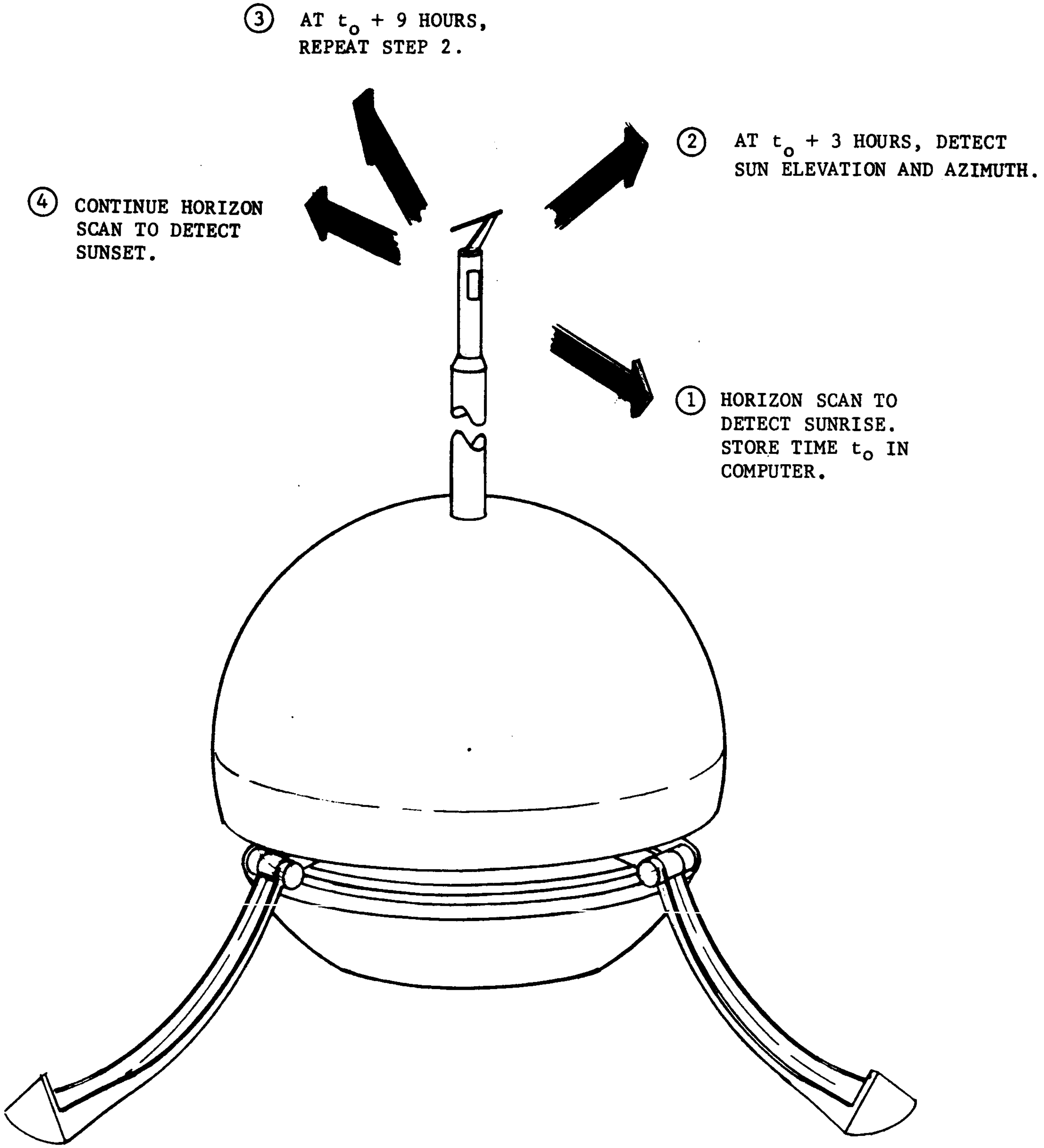
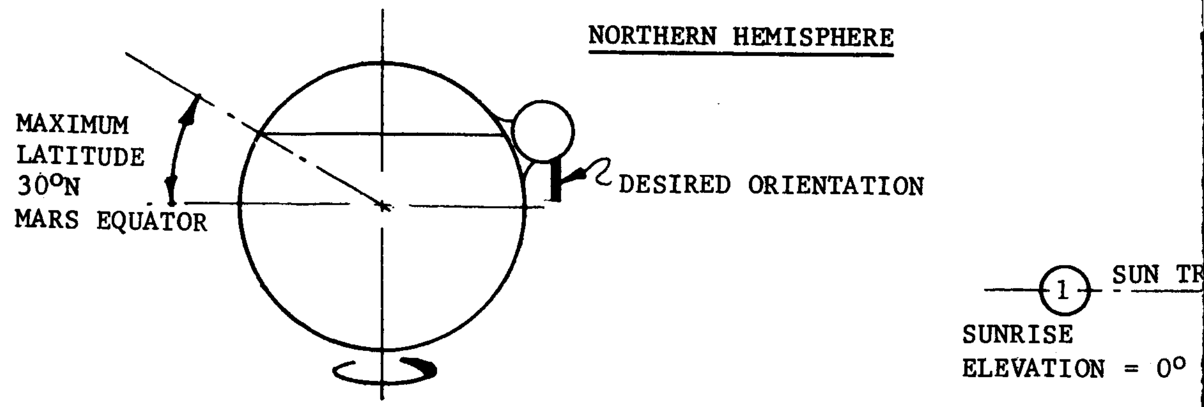
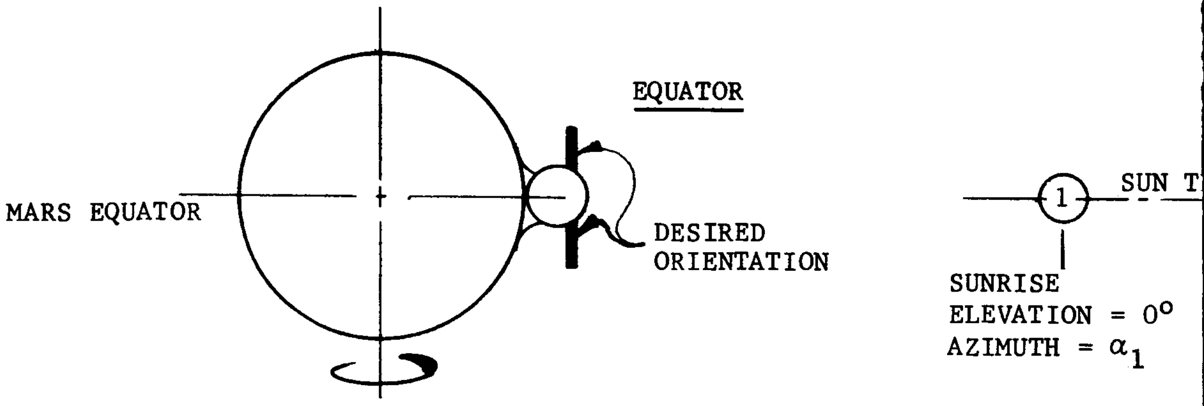
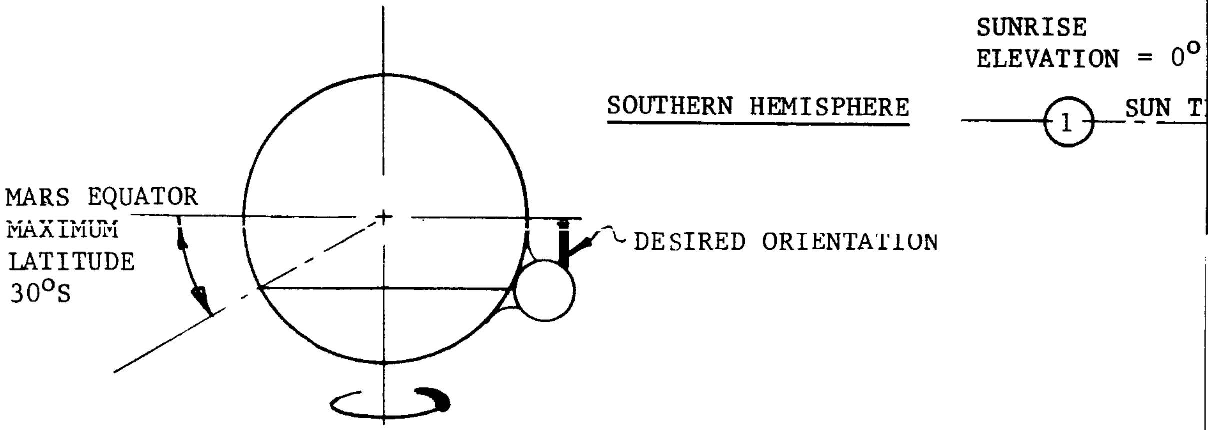


FIGURE 5.5-2. RADIOMETER SCANNING SEQUENCE R15004U

ABL LANDING LOCATION







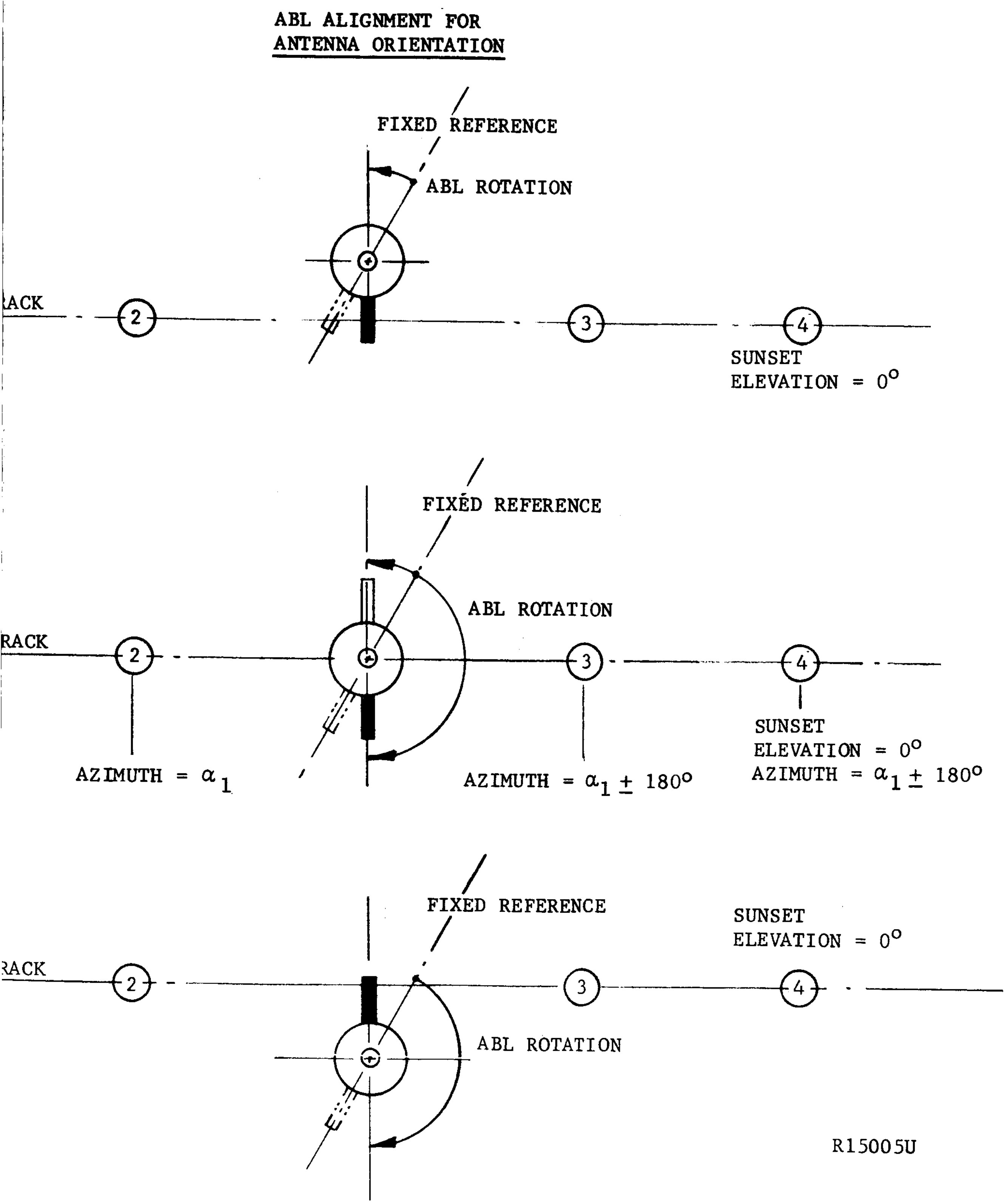
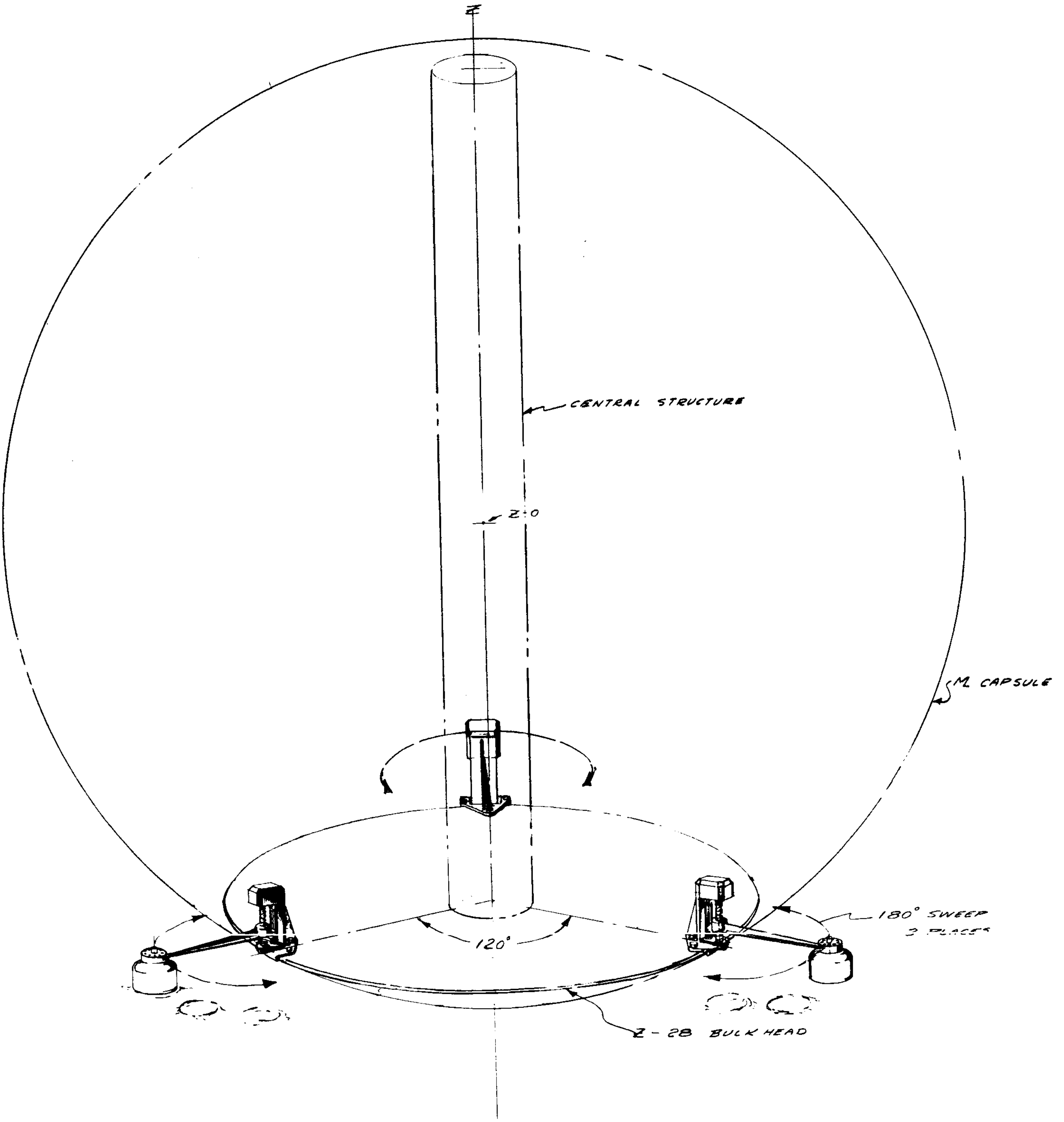


FIGURE 5.5-3. ANTENNA ORIENTATION.

[redacted]


Z
CENTRAL STRUCTURE
Z-0
M CAPSULE
120°
180° SWEEP
3 PLACES
Z-28 BULK HEAD

¼ SIZE

F-76-1

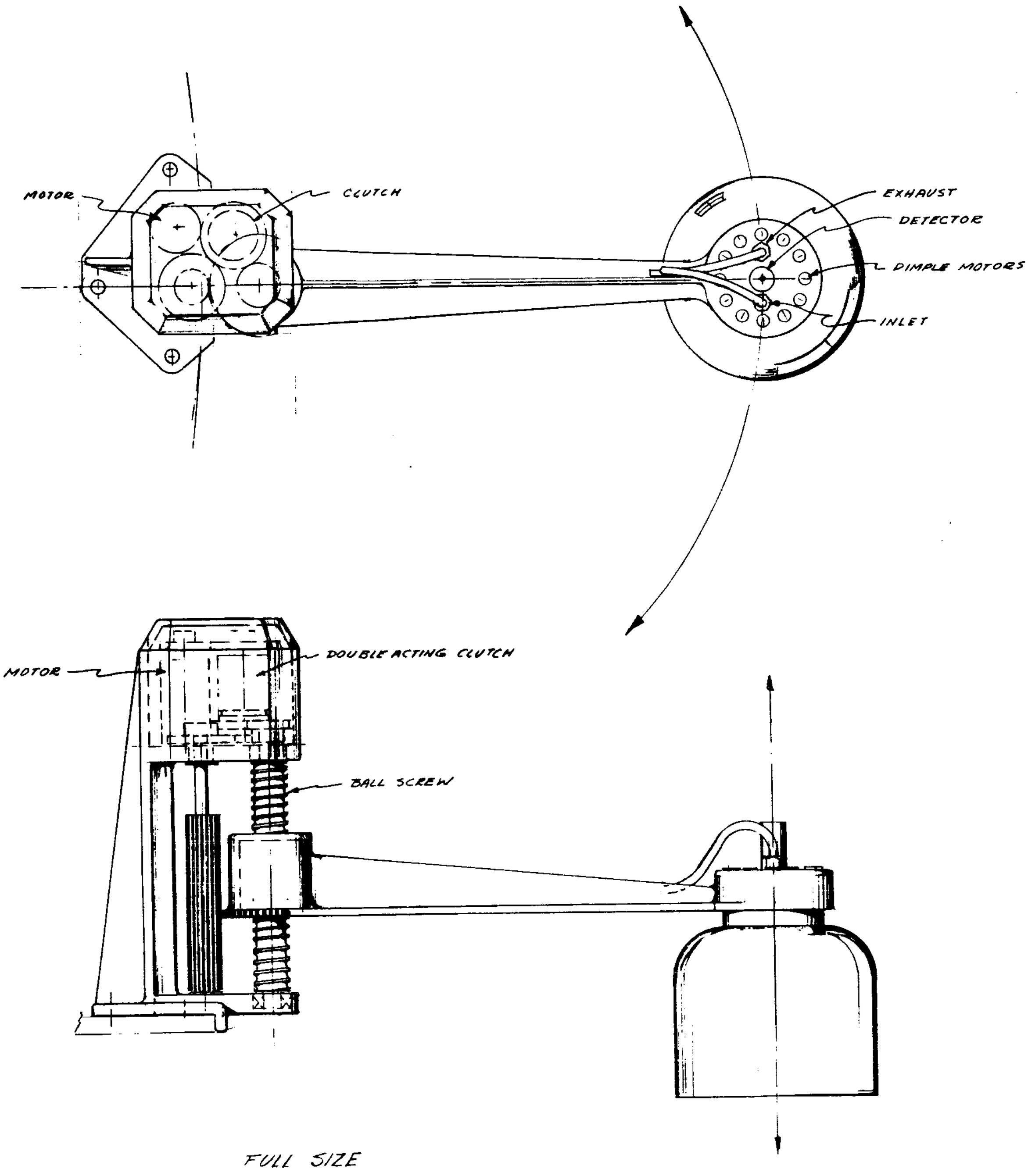


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FIGURE 5.5-4. SOIL GAS RESPIRATION SYSTEM

A β-ionization counter is mounted in the container head along with small quantities of labelled substrates. A closed loop circulation system transports the gases evolved from the chamber to the gas chromatograph and mass spectrometer for analysis. Three units are equally spaced on the lower accessory shelf of the ABL and supported in a free-standing housing. The chambers are suspended from a rotating arm that is deployed from its stored position to its utility position by a splined pinionsector gear drive train. The entire arm is lowered into place by a ball-bearing screw jack. Both mechanical operations are supplied by a motor-gearhead combination operating through a concentric shaft clutch. This permits the chamber to be raised from one site, moved over an unused site, and lowered into position. After natural soil gas evolution has been measured, labelled substrates are injected into the chamber by squib-operated motors housed with each substrate supply. The circulation system guarantees independent results from each substrate by thoroughly venting the chamber between substrate injections.

b. β and γ Pulse Height Counter (Figure 5.5-5). This counter determines background radiation levels incident at the surface and scattered from the surface. The detector consists of three counter tubes shielded against penetration by β particles and one tube which allows both β and γ particles to penetrate. The three tubes are mounted in a hemi-cylindrical tungsten shield that permits only a 2π steradian field of view. The detector assembly is supported by two parallel arms, 30 inches in length and mounted to the lower accessory shelf of the ABL. Parallel linkage ensures that the vertical exposure of the detector tubes remains vertical regardless of the elevation of the detector assembly. Positioning is accomplished by a rotary drive located within the arm support structure. A motor-gearhead in combination with a concentric-shaft, two-position clutch drives a ring gear for detector rotation and system deployment from the stored position. Elevation of the detector is supplied through actuation of a bellcrank driving one of the two parallel links. Several techniques of supplying the required force and travel were considered. If a vertical traverse of the detector is required, a ball screw drive may be used. If only two positions are required, a cam operated plunger or a pneumatic piston plunger could be incorporated. In use, the detector assembly will be rotated from its stored position within the spacecraft and elevated to a position several feet above the ground. After incident radiation has been evaluated, the detector is inverted and lowered to a position several inches above ground. Surface scattering is measured from this position, and then the detector assembly is returned to storage.

c. Atmospheric Dust Collector (Figure 5.5-6). This instrument is used to collect wind borne particles of Martian surface soil and transfer them to the separator-scale for grading and subsequent analysis. It may also be put to use in a secondary mode of collecting Martian surface soil samples.

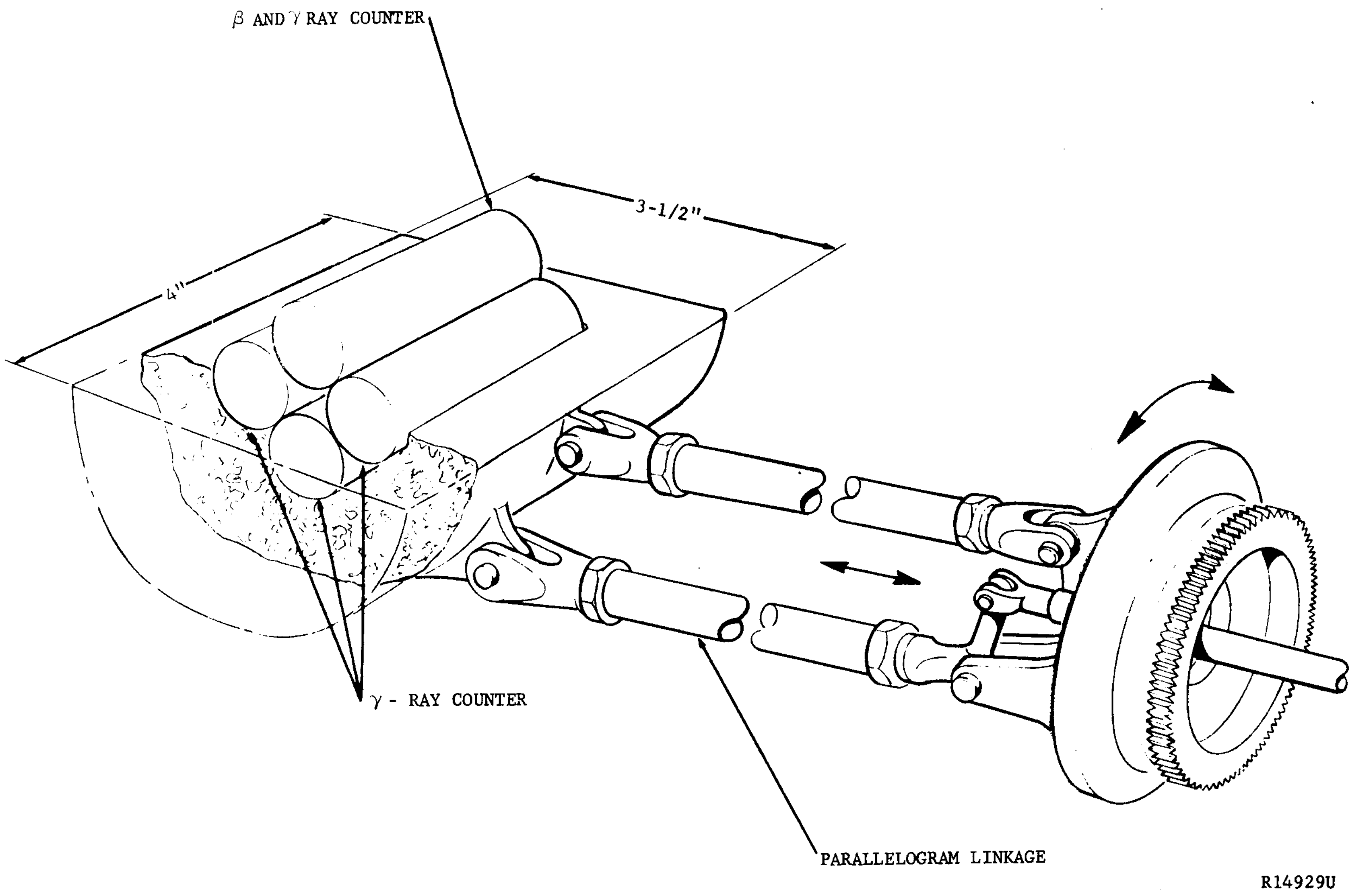
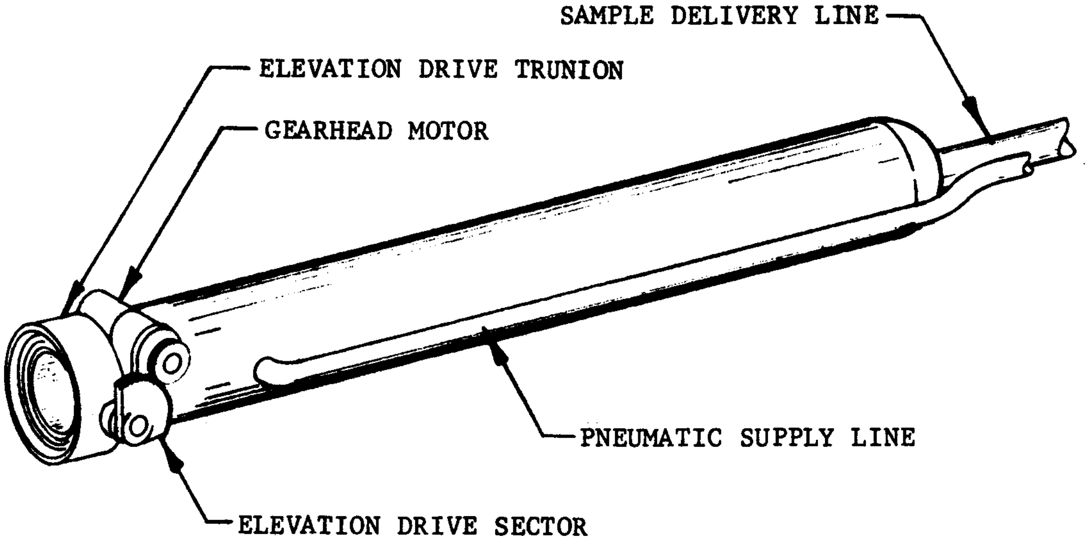
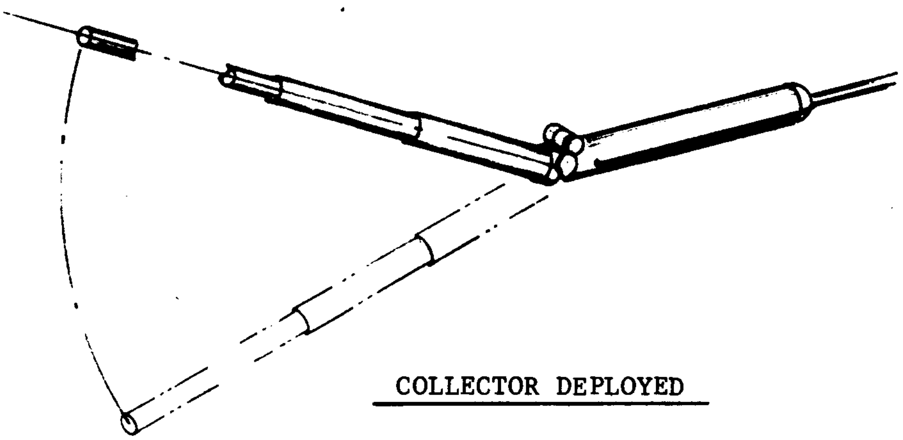


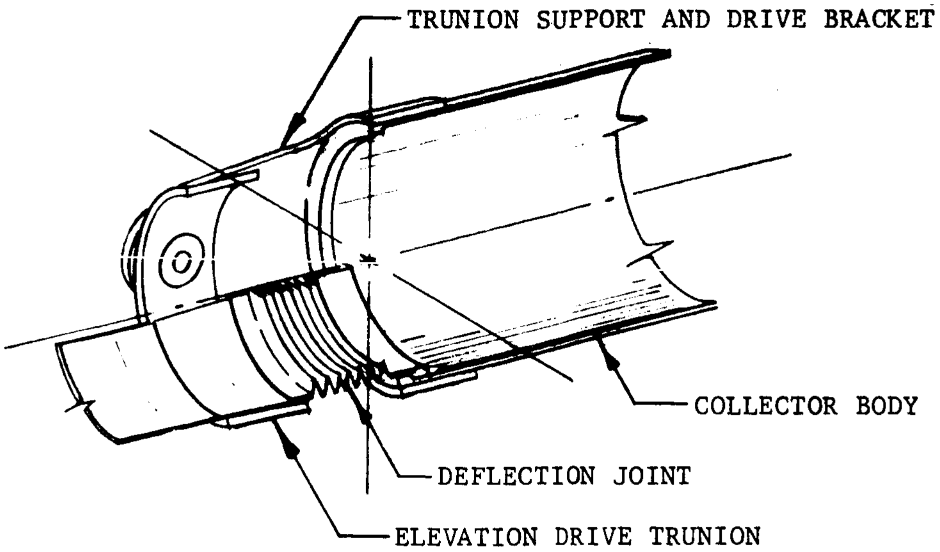
FIGURE 5.5-5. β AND γ RAY COUNTER ARRAY



COLLECTOR STOWED



COLLECTOR DEPLOYED



R15006U

CUTAWAY VIEW OF DEFLECTION JOINT

FIGURE 5.5-6. ATMOSPHERIC DUST COLLECTOR

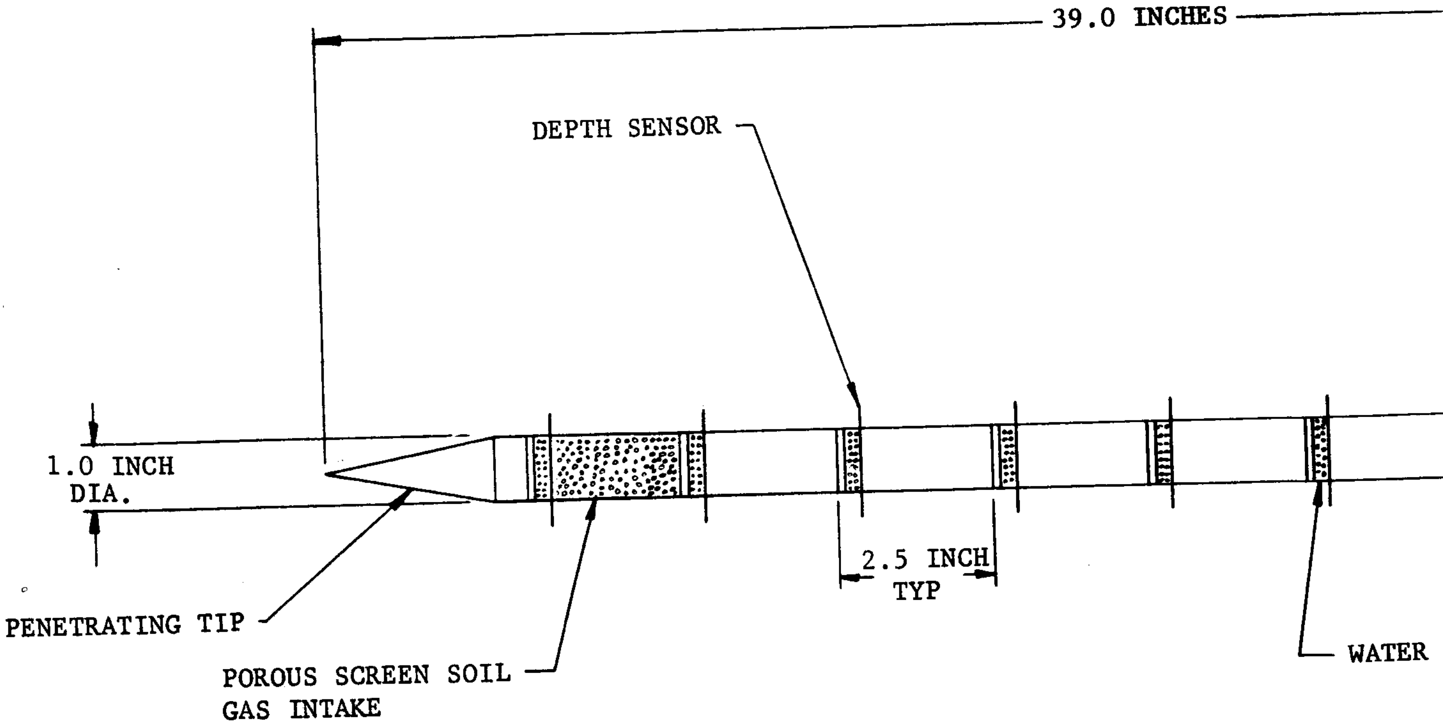
The collector consists of four telescoping lengths of thin wall tubing. The ends of each tube are preformed so that they swage into a rigid tube during deployment. The tubes are deployed pneumatically, and the last tube contains a bellows segment which interlocks with the support tube and permits vertical excursion of the collector. A motor-gearhead segmented spur gear combination is used to elevate the collector to the desired height above the ground. In use, the collector is deployed and elevated to a height of about 10 feet. Pneumatic circulation is set up and wind transported particles collected and directed into the separator scale. After a fixed length of time, the air flow is terminated and the weight of the particles determined. The collector is then lowered into a new position and the cycle repeated.

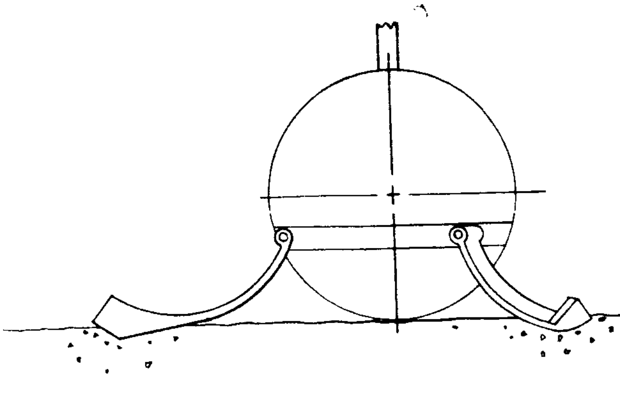
d. Soil Probe (Figure 5.5-7). This instrument is used to detect subsurface soil water vapor and temperature at discreet intervals below the surface. The probe is composed of two concentric thin wall tubes joined at the probe nose to a solid penetrator. The inner tube contains the pyrotechnic launcher and the outer tube houses the detectors, soil gas and water vapor delivery tubes, and wiring. A launch tube sandwiched between the two probe walls guides the probe during launch and protects the tubing and wiring from the launcher blast. The launch tube is mounted to a double-canted rotary link that permits horizontal storage and vertical deployment of the probe. The rotary link is spring loaded in the storage position and retained with pyrofuze or a similar pyrotechnic structural material. When deployed, the probe is pawl latched into the vertical position and the launcher firing initiated.

5.5.3 SAMPLE COLLECTION SYSTEMS

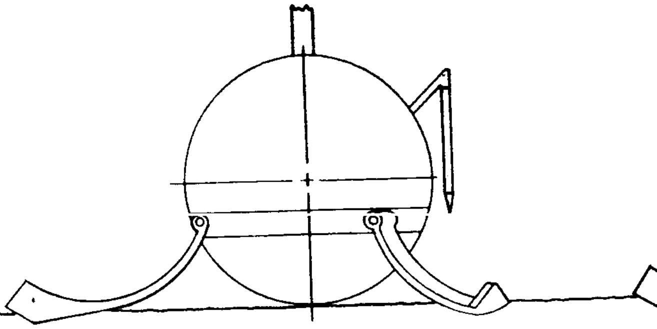
The equipment required to collect surface and subsurface soil samples from remote and proximity sample sites is described below.

a. Core Drill. The core drill is used to bore a 3-meter deep core hole and to extract subsurface core samples as discreet intervals. The core hole is subsequently used for a traverse by the subsurface sonde. Mechanical details of the drill system are depicted in Figure 5.5-8A. The operational sequence employed in preparing the hole, collecting core samples, and sounding the hole is summarized in Figure 5.5-8B. The drill mechanism and storage is contained in the lower portion of the center spine tube within and below the stored mast. The drill stem is made up of five segments of hollow hexagonal rod 26 inches in length. The five segments and the core hole sonde are stored within thin wall tubing mounted on a turret supported by the center spine and lower pressure bulkhead. The turret is rotated to step the successive stem segments into place by a motor driven geneva mechanism. The rotary table is driven by a large motor-gearhead combination. In operation, the first segment of stem, containing the core bit, is advanced into starting position by the axial drive system which features a gearhead motor and spring loaded stem feed





LAB ERECTED



DEPLOY PROBE

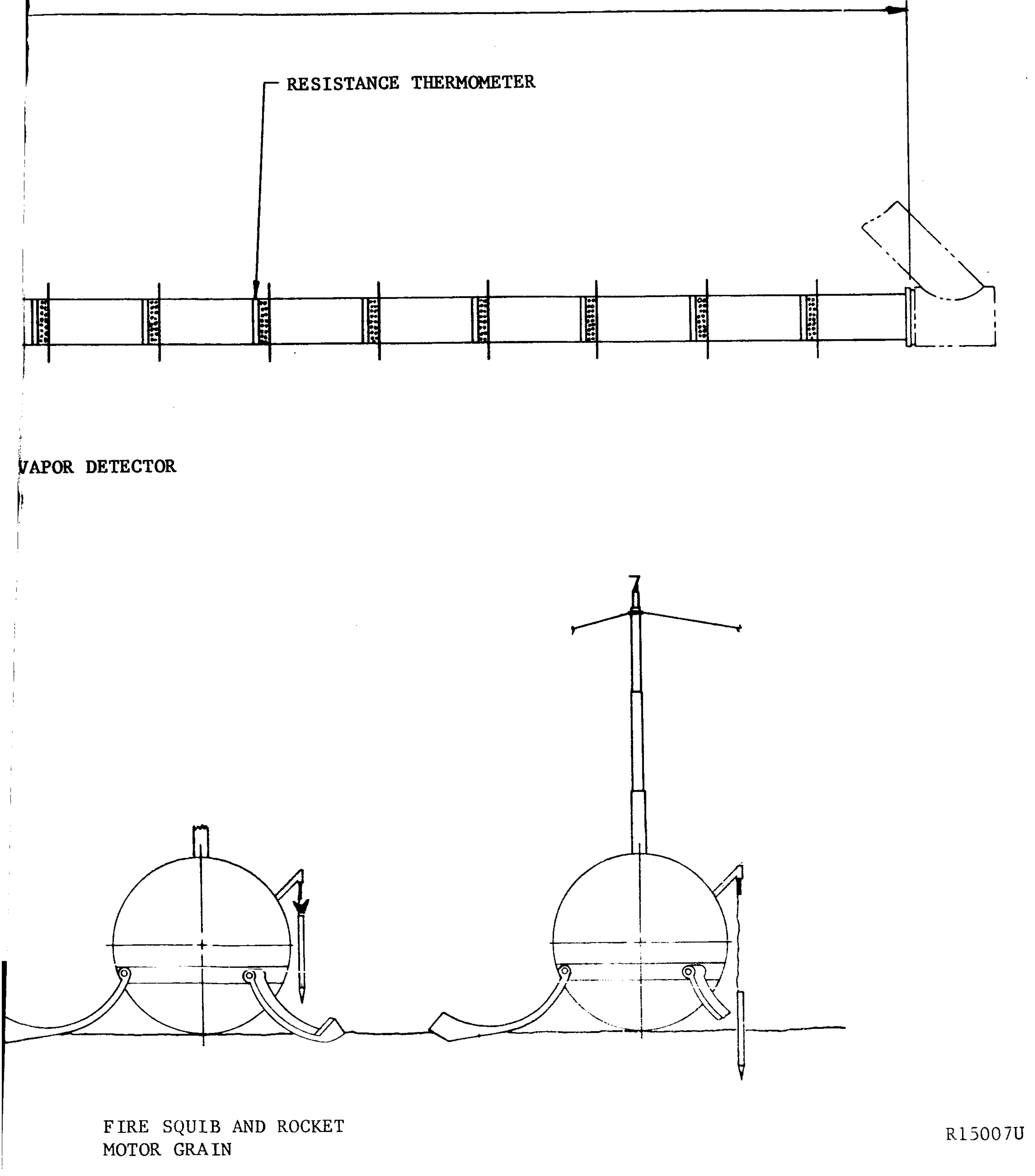
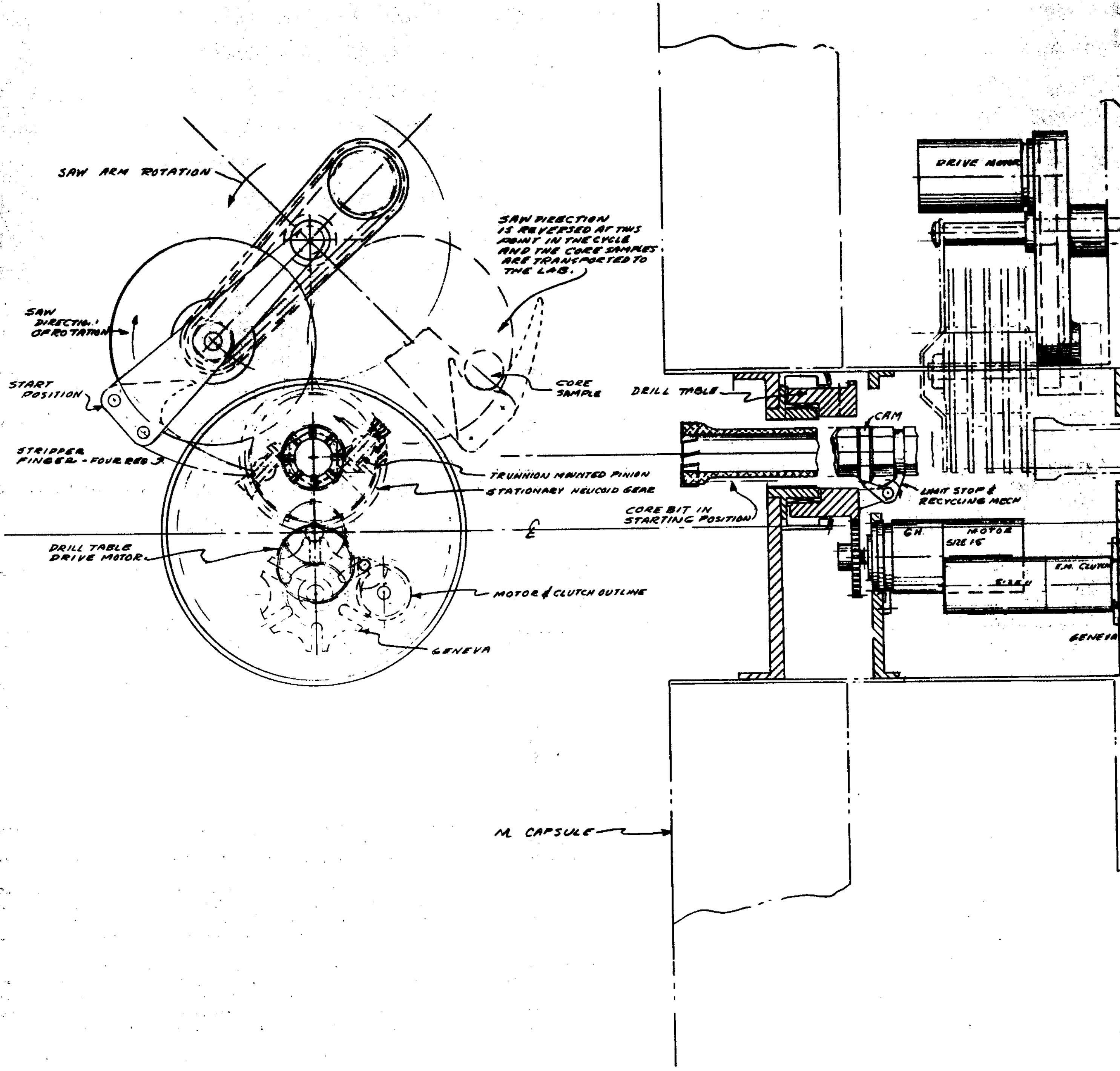
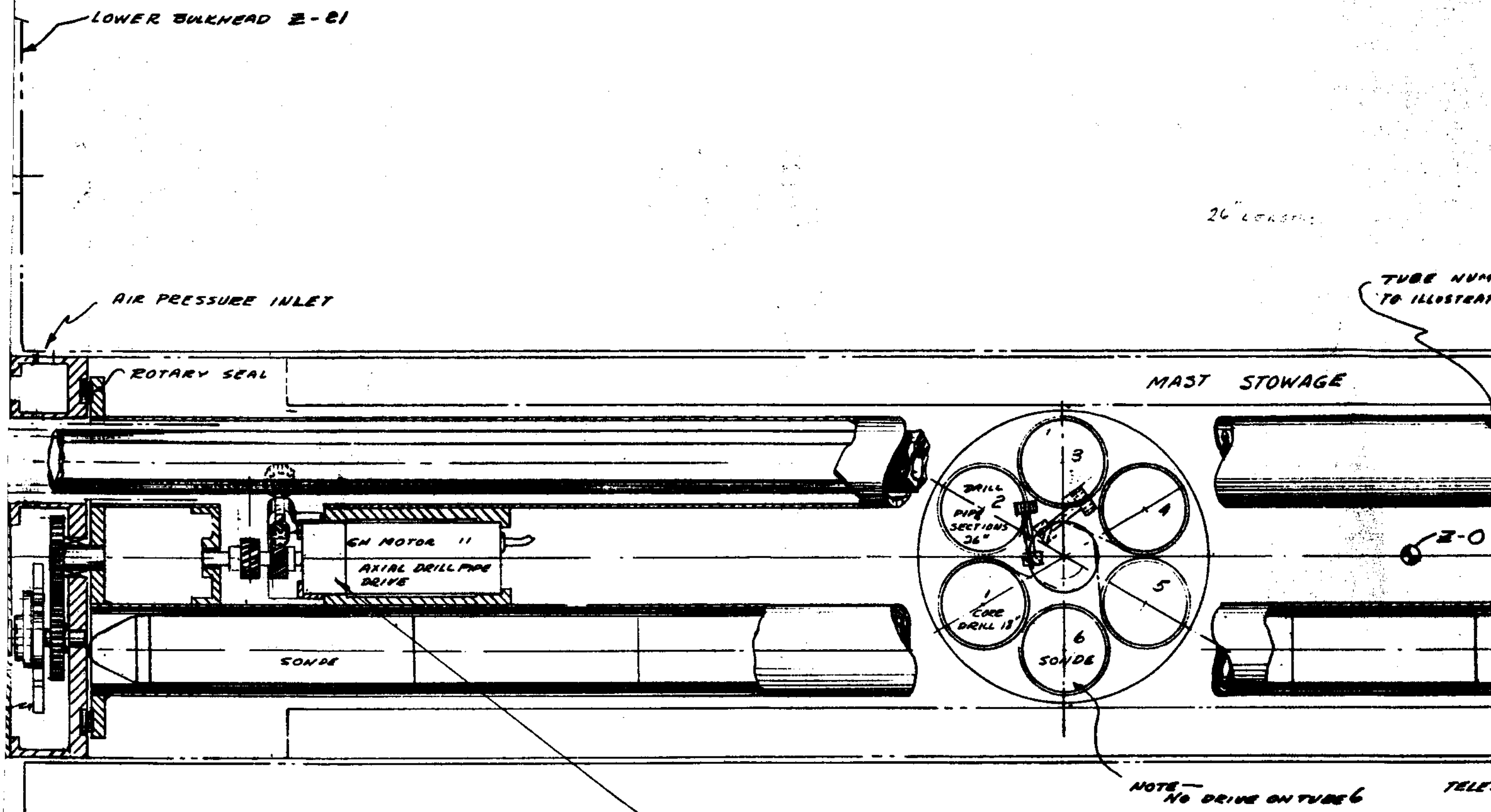


FIGURE 5.5-7. SOIL PROBE


SAW ARM ROTATION
SAW DIRECTION IS REVERSED AT THIS POINT IN THE CYCLE AND THE CORE SAMPLES ARE TRANSPORTED TO THE LAB.
SAW DIRECTION OF ROTATION
START POSITION
CORE SAMPLE
STRIPPER FINGER - FOUR REQ'D.
TRUNNION MOUNTED PINION
STATIONARY HELICOID GEAR
DRILL TABLE DRIVE MOTOR
℄
MOTOR & CLUTCH OUTLINE
GENEVA
DRILL TABLE
CAM
CORE BIT IN STARTING POSITION
LIMIT STOP & RECYCLING MECH
DRIVE MOTO
GH.
MOTOR SIZE 15
E.M. CLUTC
SIZE 11
GENEV
M CAPSULE



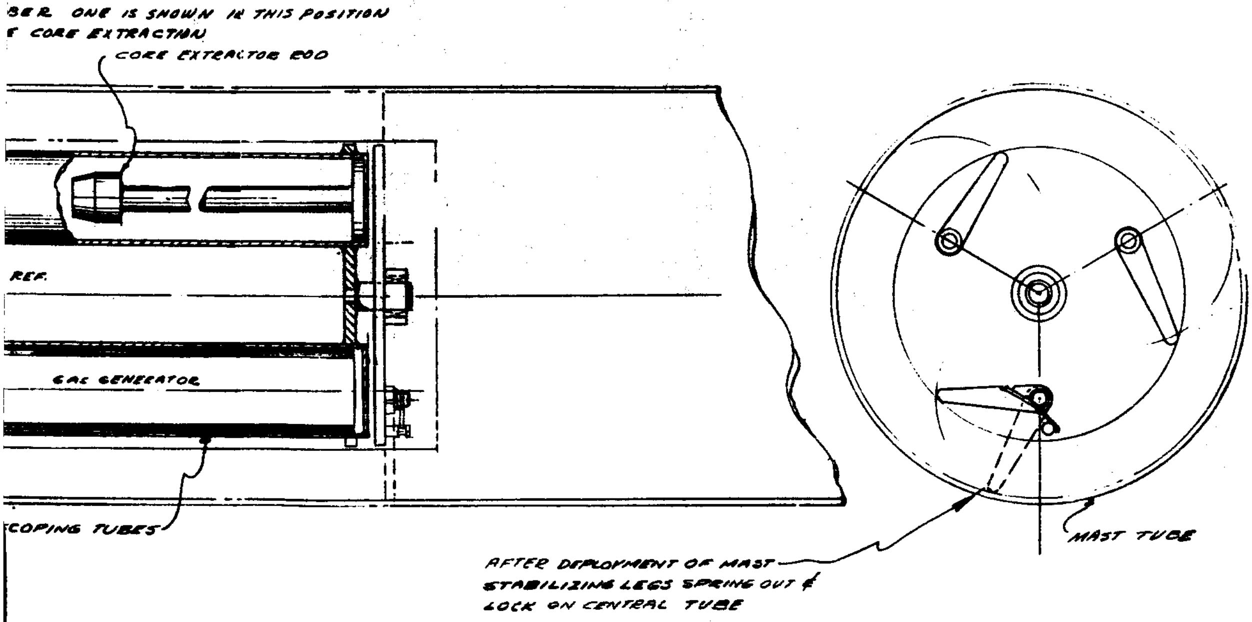
DRIVE ASSEM IS SPRING LOADED AWAY FROM THE DRILL PIPES

WHEN MOTOR IS ENERGIZED THE COUNTER TORQUE APPLIES PRESSURE TO THE FEED ROLLERS

OPERATIONAL SEQUENCE—

1. OPERATION STARTS WITH CORE BIT DEPLOYED TO DRILL POSITION AND THE TURRET IN POSIT
2. CORE BIT IS ROTATED & FED BY THE DRILL TABLE
3. AXIAL STOP FOR THE DRILL PIPE SECTIONS IS LOCATED ON THE DRILL TABLE AND PIPE SECTIONS AS FOLLOWS.
   - A. THE LIMIT STOP LATCH DROPS INTO THE RELIEF GROOVE ON THE DRILL PIPE. A SWITCH TH THE DRILL MOTOR. THE TURRET IS ADVANCED TO POSITION (2) BY A GENEVA TRANSFER ME
   - B. PIPE NUMBER TWO IS FED OUT OF THE TURRET BY MEANS OF THE TURRET FEED DRIVE.
   - C. WHEN SECTION TWO CONTACTS SECTION ONE THE DRILL TABLE IS STARTED THUS COUP TWO AND DISENGAGING THE LIMIT STOP.
   - D. THE CYCLE IS REPEATED UNTIL PIPE NUMBER FIVE HAS TRAVELED PARTIALLY OUT THEN ALL OF THE DRILL PIPES ARE TRANSFERED BACK IN THE TURRET EXCEPT THE
   - E. THE CORE BIT IS RETRACTED UNTIL THE CORE EXTRACTOR ROD PUSHES THE CORE O CORE BIT AN AMOUNT DETERMINED BY THE RETRACTION TRAVEL OF THE BIT AS SHOWN
   - F. THE CORE IS SLICED SO AS TO RETRIEVE FOUR ONE QUARTER INCH SAMPLES. THE ROUG BACK INTO THE, HOLE.
   - G. THE CORE SAMPLES ARE TRANSPORTED TO THE LAB. AS SHOWN IN THE END VIEW.

5-82-2



ON(1)

RE ADDED

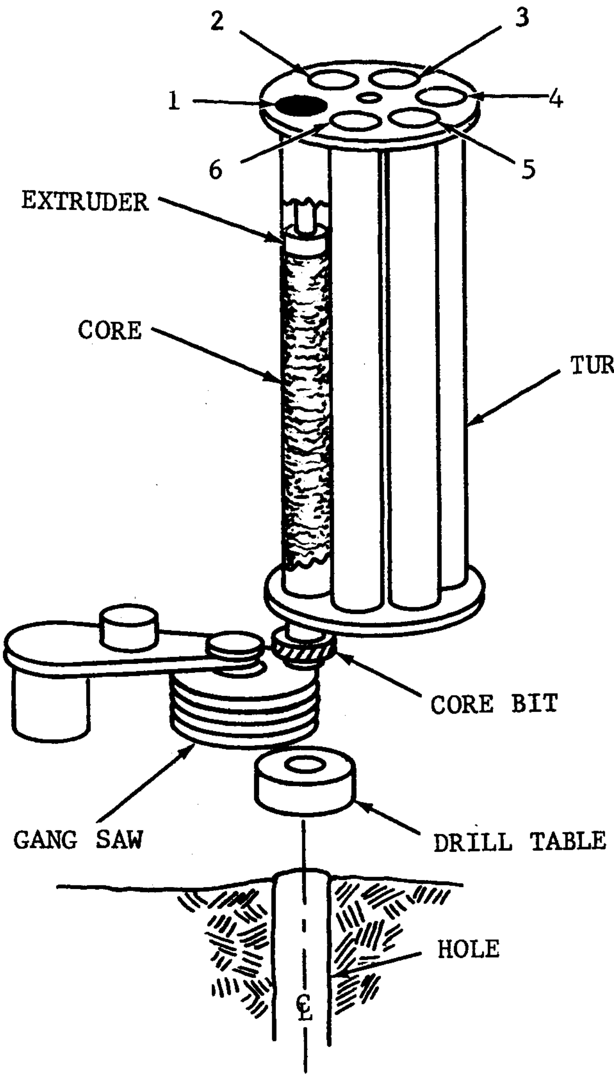
N STOPS
[illegible].

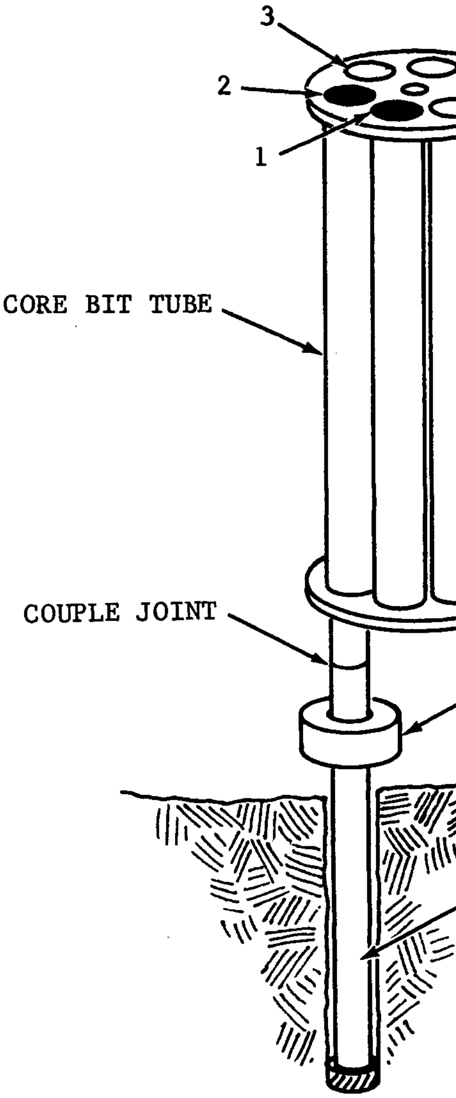
ING ON SECTION

F THE TURRET.
CORE BIT.
T OUT OF THE

END IS DUMPED

FIGURE 5.5-8A. CORE DRILLING AND SAMPLING MECHANISM



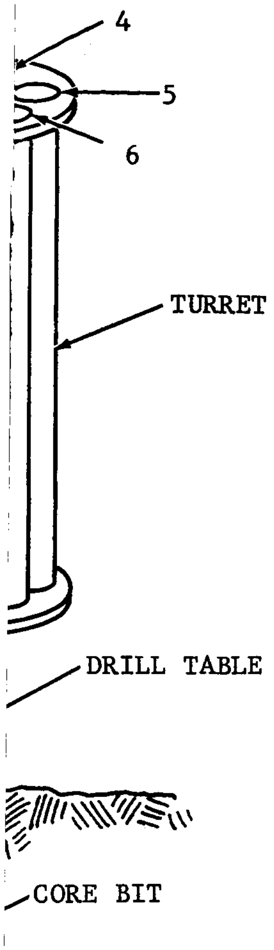


CORE DRILL OPERATION FOR COLLECTING FIRST SAMPLE

1. CORE DRILL IS DRIVEN INTO THE SOIL 15 INCHES, THEN RETRACTED INTO TUBE (1 WHERE THE CORE IS EXTRUDED TO A DISTANCE OF 2 INCHES. THE GANG SAW SLI FOUR ONE-QUARTER INCH PROCESSING SAMPLES.

SECOND TO FIFTH TURRET OPERATIONS

2. RETRACT CORE SAW.
3. DRIVE CORE BIT INTO ROTARY TABLE.
4. INDEX TURRET TO POSITION (2).
5. COUPLE DRILL STEM (2) TO CORE BIT STEM.
6. ADVANCE STEM TO A TOTAL DEPTH OF 30 INCHES. THE REMAINDER OF THE FIRST C IS FORCED INTO TUBE (2).
7. RETRACT DRILL STEM. STEM (2) IS RETRACTED INTO TURRET.
8. INDEX TURRET BACK INTO POSITION (1) AND PREPARE SECOND CORE SAMPLE.
9. REPEAT PROCEDURE THROUGH STEM (5).
10. RETRACT AND STOW ALL STEMS INTO ORIGINAL TUBES.
11. INDEX TURRET INTO POSITION (6).



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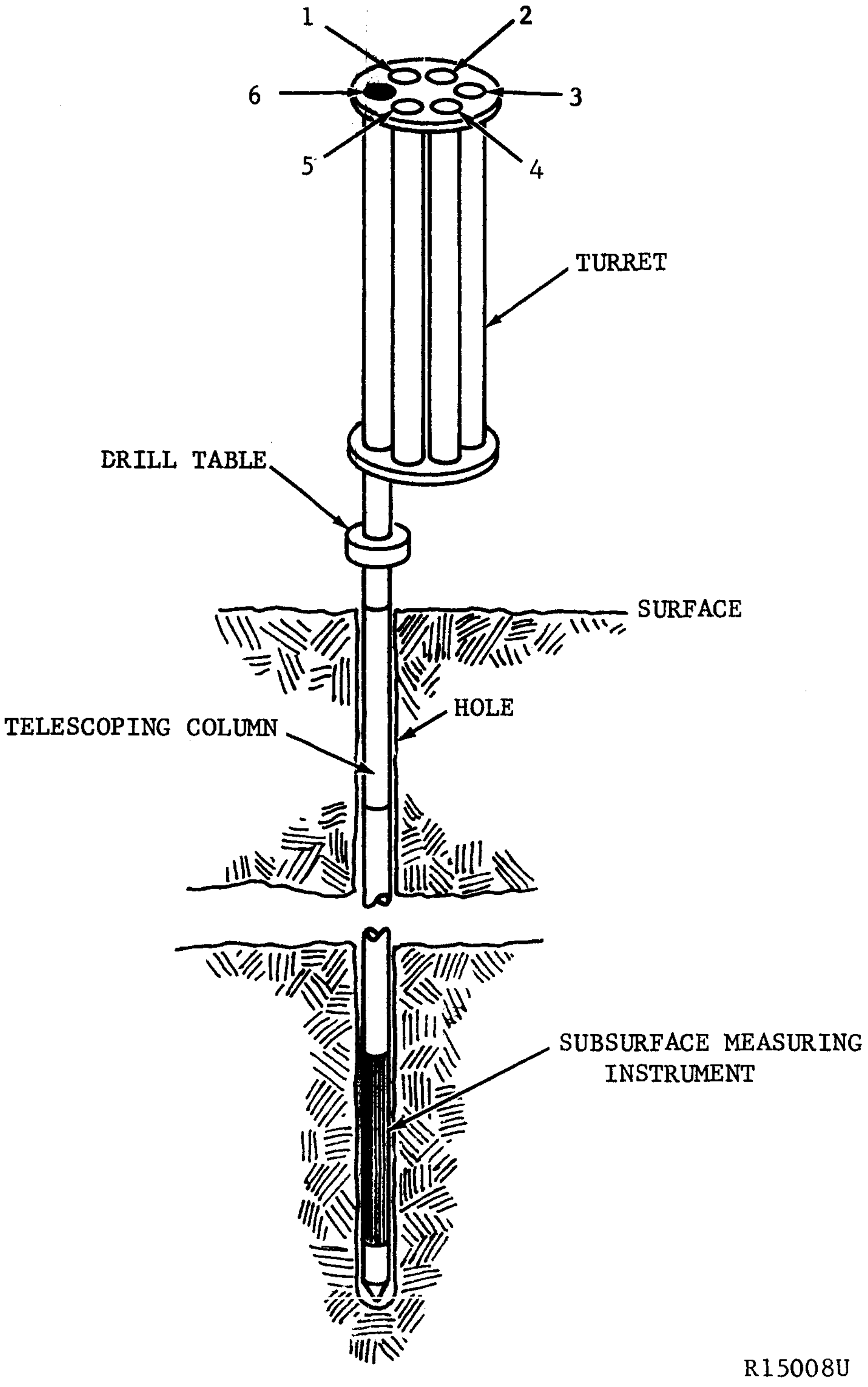


ORE

DEPLOYMENT OF SUBSURFACE SONDE

12. SONDE IS DEPLOYED THE FULL DEPTH OF THE CORE HOLE BY PRESSURIZING THE TELESCOPING COLUMN. SONDE MAY BE RETREIVED BY WINCHING OF THE BAILING LINE.

FIGURE 5.5-8B. CORE DRILLING AND SAMPLING MECHANISM (Continued) rollers. The drive assembly is spring loaded away from the stem, and when the motor is energized, the counter torque applies pressure to the stem by means of the feed rollers. The rotary table is energized and drilling effected until the first segment reaches a limit stop mounted on the rotary table ring gear. Rotary and axial drives are interrupted and the turret rotated, stepping the second stem into place and coupling it to the first segment. This process is repeated until all five segments have been used, and the core hole is completed. Pneumatic pressure is used for drill chip removal.

Retraction of the drill stem is accomplished in the reverse of the drilling operation except that as each segment is replaced in its storage tube, an extractor rod is used to present a 4-inch length of core sample to the core saw. The core saw, mounted below the lower pressure bulkhead, is composed of five motor driven blades. Four 1/4-inch core segments are trapped within the blades. These segments are removed after the sawing operation with stripper fingers that also position the samples for subsequent transport into the analytical section of the laboratory.

After the drill stem segments have been replaced in storage, the core hole sonde is stepped into position by the turret drive system over the core hole. The sonde is mounted with four telescoping cylinders. The cylinders are deployed pneumatically in incremental steps effecting the core hole traverse by the sonde. The sonde is used to measure subsurface temperature, soil electrical conductivity, magnetic susceptibility, and soil density.

b. Soil Sampling Mechanism (Figure 5.5-9). The soil samplers collect surface and subsurface soil samples and conduct soil mechanics measurements. Two samplers are used, one for sample sites in the proximity of the ABL and one for remote sites. The basic sampler is the same in either case; only the means of deploying the sampler differs. The sampler case is cylindrical with pressure sensors mounted on the open (lower) end. These indicate the continuity of contact with the surface. A flange mounted on the periphery of the shell above its base provides additional footprint area when the sampler is forced into the ground.

In operation, the sampler is lowered to the surface until contact is made. After pressure sensor continuity readings are made, a center spike with fluted anchors is pyrotechnically forced beneath the surface. The penetration drive system forces the can into the surface up to the flanges used to increase the footprint area of the sampler. Rotation of the surface brush and circulation of high pressure atmosphere by means of a multistage pump aerosolizes and collects surface samples in a cyclone separator. Two subsurface samples are collected at each site by forcing soil augers into the surface to a depth of 20 cm. A sprag clutch drive system is used to rotate the cylindrical housings in which the auger cylinders are retained. Canted rollers mounted to the fixed structure

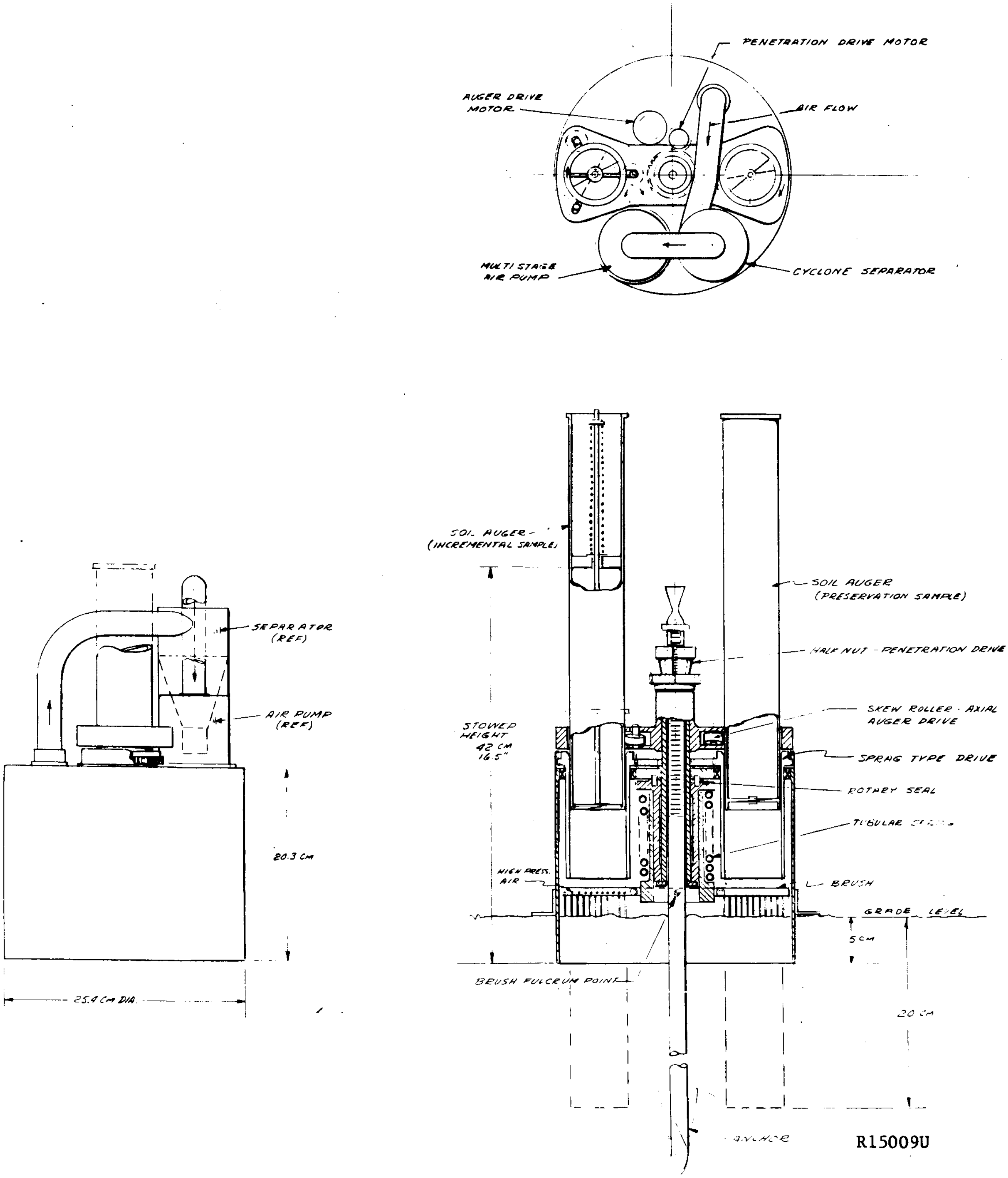
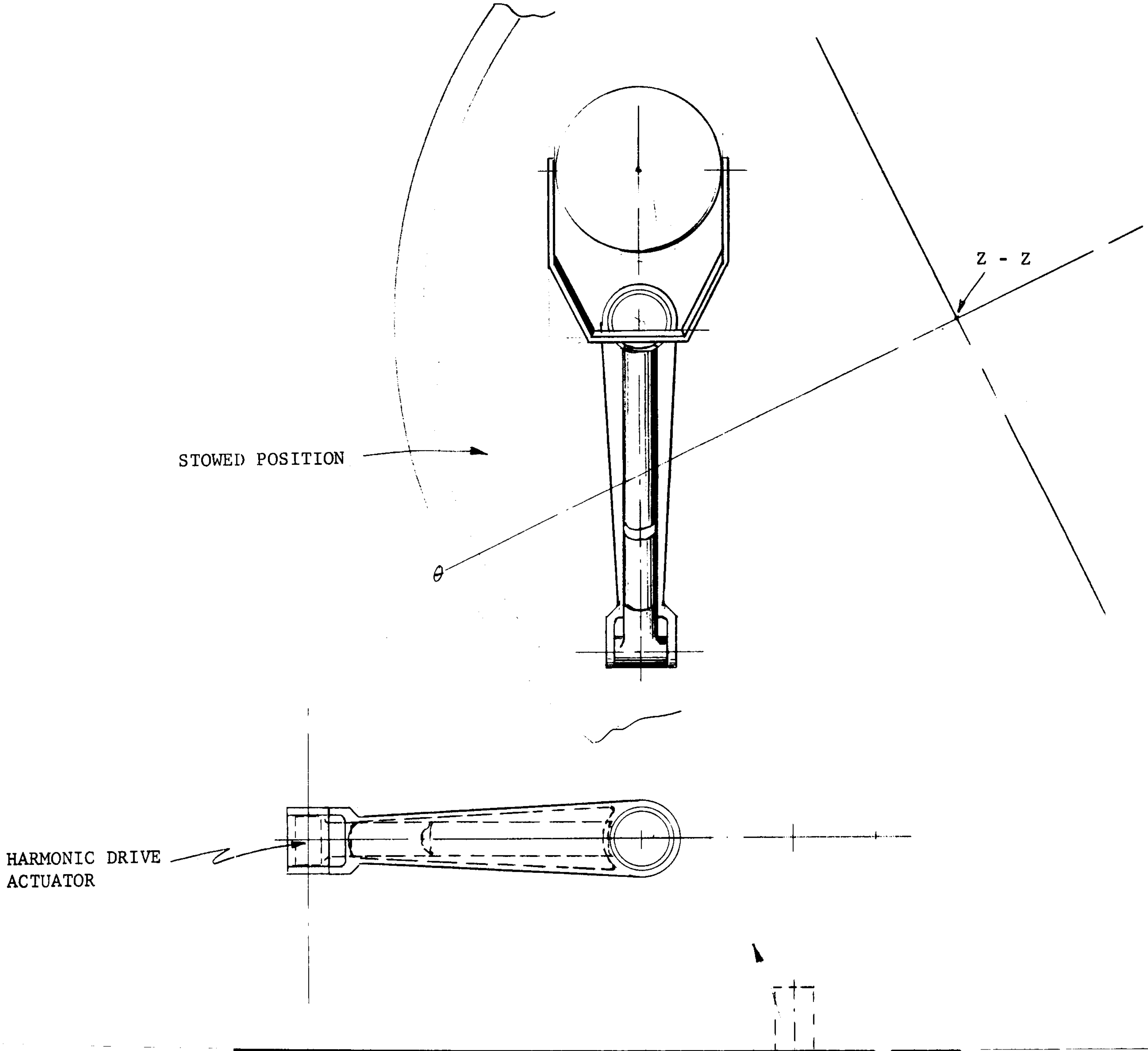


FIGURE 5.5-9. SOIL MECHANICS AND SAMPLING MECHANISMS


Z - Z
STOWED POSITION
θ
HARMONIC DRIVE
ACTUATOR

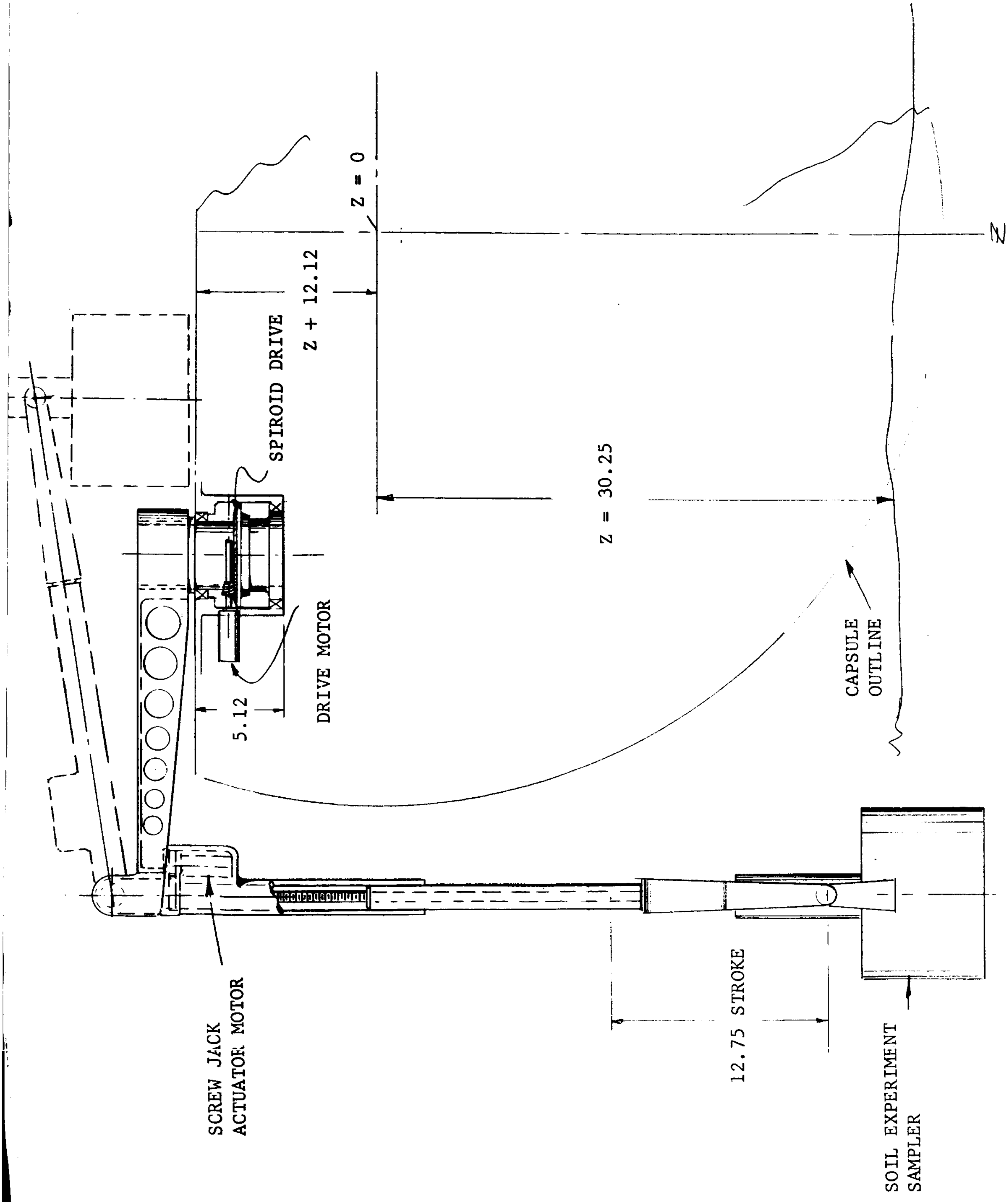


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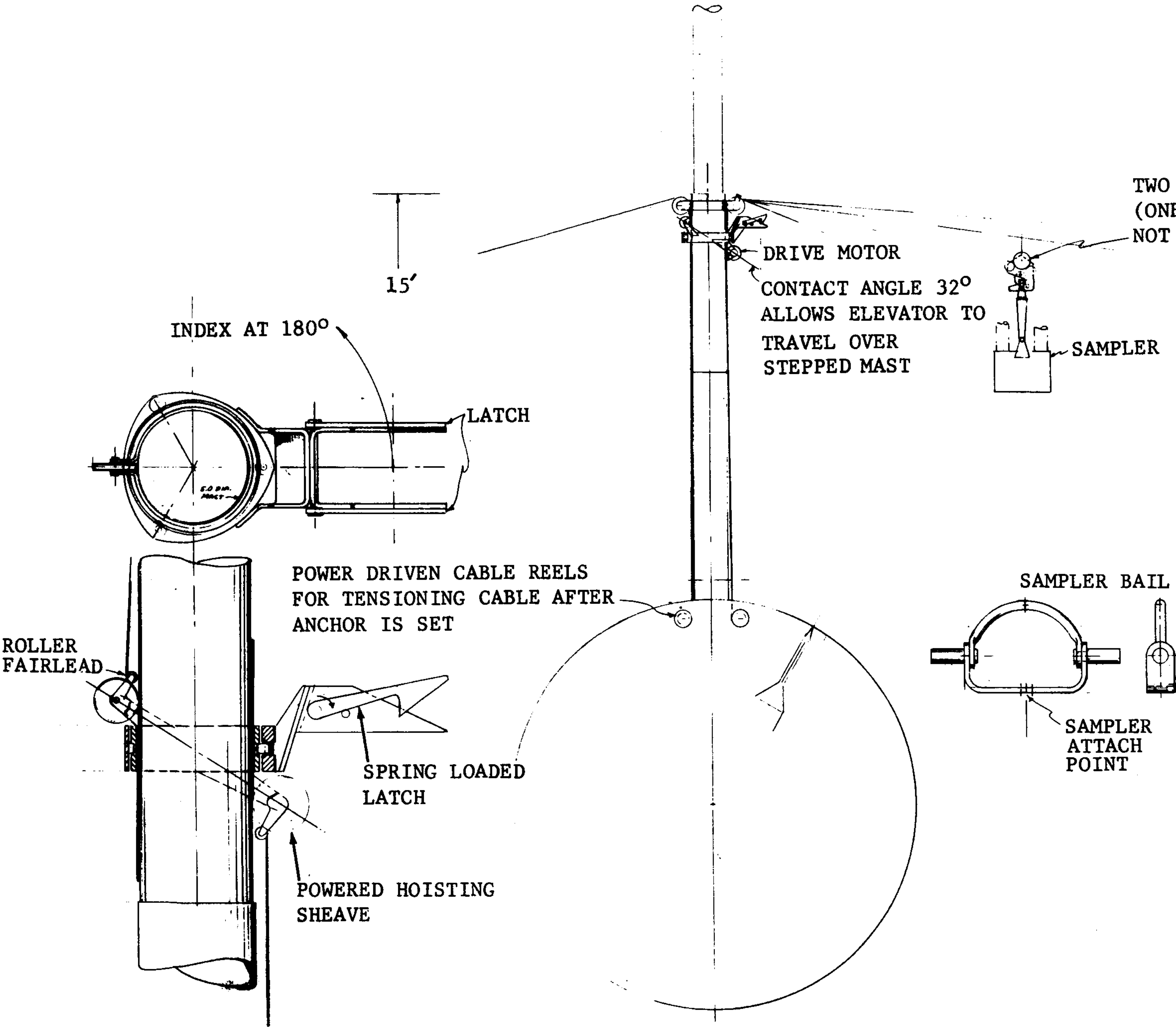
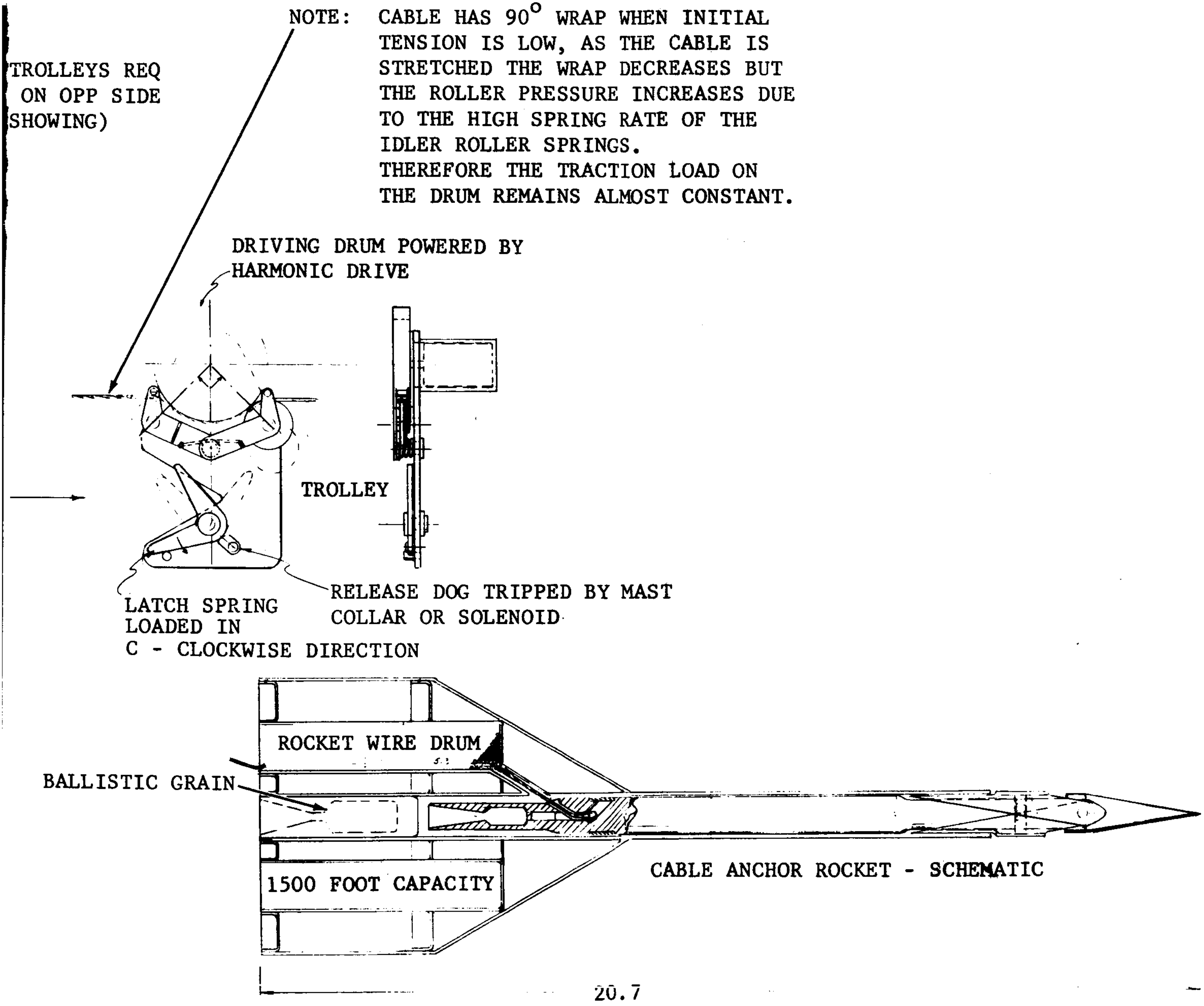
FIGURE 5.5-10. SOIL SAMPLER DEPLOYMENT MECHANISM


TWO
(ON
NOT
15′
DRIVE MOTOR
CONTACT ANGLE 32°
ALLOWS ELEVATOR TO
TRAVEL OVER
STEPPED MAST
SAMPLER
INDEX AT 180°
LATCH
5.0 DIA. MAST
POWER DRIVEN CABLE REELS
FOR TENSIONING CABLE AFTER
ANCHOR IS SET
SAMPLER BAIL
ROLLER
FAIRLEAD
SPRING LOADED
LATCH
SAMPLER
ATTACH
POINT
POWERED HOISTING
SHEAVE


NOTE: CABLE HAS 90° WRAP WHEN INITIAL TENSION IS LOW, AS THE CABLE IS STRETCHED THE WRAP DECREASES BUT THE ROLLER PRESSURE INCREASES DUE TO THE HIGH SPRING RATE OF THE IDLER ROLLER SPRINGS. THEREFORE THE TRACTION LOAD ON THE DRUM REMAINS ALMOST CONSTANT.

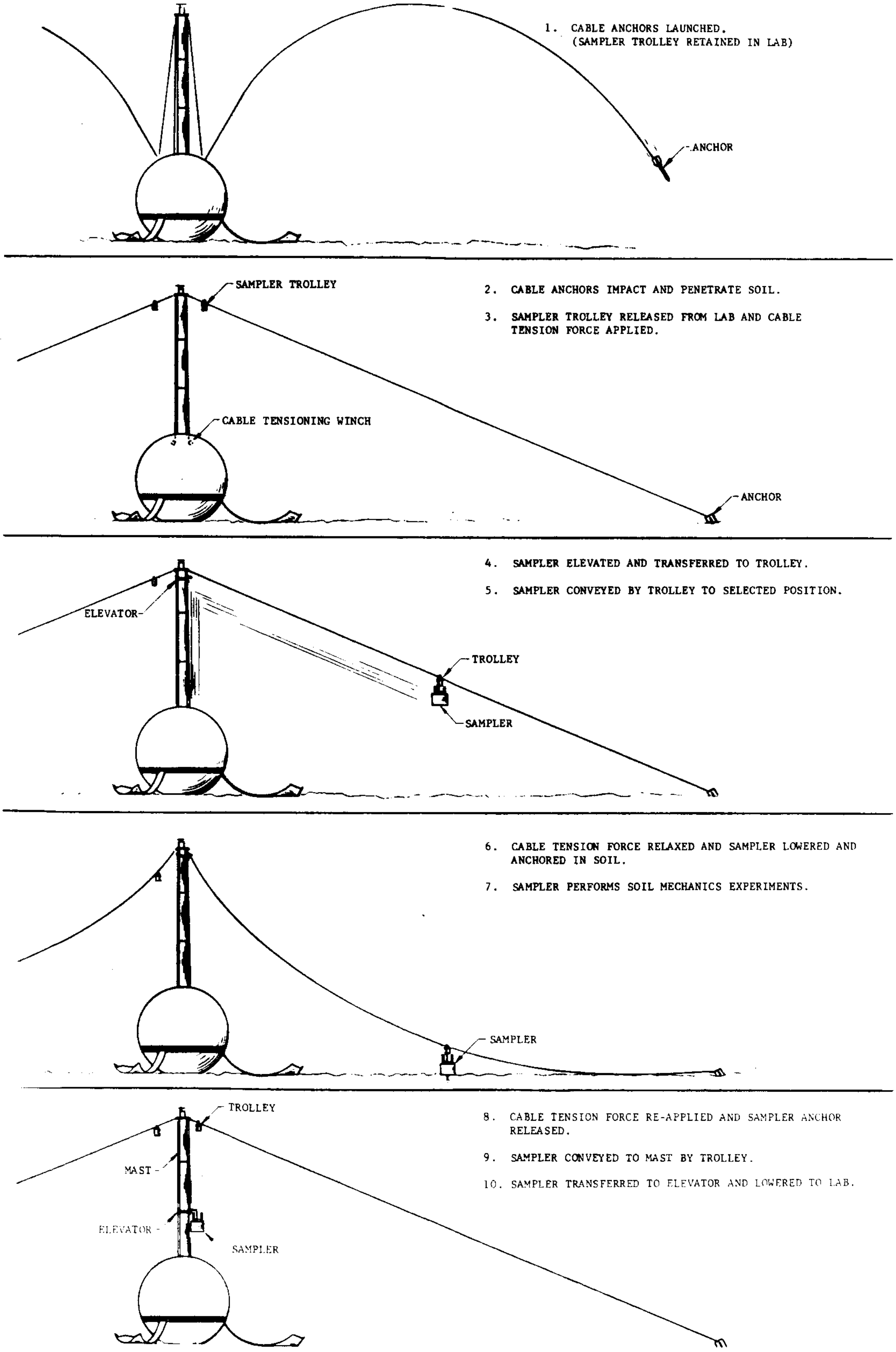
R14896U

FIGURE 5.5-11. REMOTE SAMPLER DEPLOYMENT SYSTEM provide an axial force to sink the augers the required depth. After the soil mechanics measurements are made and the samples are collected, the sampler is withdrawn and transported to the ABL. The aerosolized sample and one auger sample is delivered to the pulverizer for processing and analysis. The remaining auger sample is encapsulated and preserved for examination at some future date by manned landing expeditions.

The proximity sampler deployment system is shown in Figure 5.5-10. A hinged arm is mounted to a yoke affixed to the soil sampler and to a rotary bearing recessed into the upper pressure bulkhead of the ABL. A harmonic drive located in the arm elbow joint deploys the sampler through 270 degrees and a separate lead screw drives the sampler to the local surface. The sampler can be rotated to sample various sites by means of a spiroid drive system contained within the rotary mount bearing. The reverse of the deployment sequence is used to deliver the collected samples to the pulverized and encapsulation units.

The remote sampler deployment system is shown in Figure 5.5-11. The sampler is suspended from cables deployed by anchor rockets launched from the upper bulkhead of the ABL. The rocket launcher is spring loaded into the horizontal position and upon release of the locking mechanism erects to a position 30 degrees from the local vertical. A worm-worm gear drive system rotates the launcher base toward sample sites scanned by the macroimaging system. The deployment rocket launched by a self contained rocket system travels a ballistic trajectory to impact. Each unit deploys 1500 feet of stranded cable. At impact, a second charge is fired, forcing the anchor unit into the surface. Tongs mounted to the rocket nose are forced out when tension is applied to the cable by motor-driven winches mounted at the base of the mast on the upper bulkhead.

A trolley unit mounted on each cable is used to deploy the sampler. The trolley is driven by a motor-powered harmonic drive utilizing pressure on the cable from two spring loaded rollers to provide traction. A spring loaded latch and pawl retains the sampler ball which is mounted on the sampler yoke. The trolley deploys the sampler along the cable and when a sample is required, locks onto the cable at the prescribed location. The tension in all cables is then relaxed, lowering the sampler to the surface. After the samples are collected, tension is once again applied to the cables and the trolley returns the sampler to the ABL mast. An elevator unit engages the sampler bail and releases the trolley latch mechanism. The elevator is driven by a powered sheave and canted roller along the support cables. The canted roller alignment collar is arranged to allow the elevator to accommodate the steps in the mast which are a result of the telescoping mast section. The elevator can rotate about the mast to change the sampler from trolley to trolley and to deliver the the collected samples to the pulverizer and encapsulation units. The operations involved in deploying the trolley cable, and in deploying and retrieving the remote sampler are depicted in Figure 5.5-12.



1. CABLE ANCHORS LAUNCHED. (SAMPLER TROLLEY RETAINED IN LAB)

2. CABLE ANCHORS IMPACT AND PENETRATE SOIL.

3. SAMPLER TROLLEY RELEASED FROM LAB AND CABLE TENSION FORCE APPLIED.

4. SAMPLER ELEVATED AND TRANSFERRED TO TROLLEY.

5. SAMPLER CONVEYED BY TROLLEY TO SELECTED POSITION.

6. CABLE TENSION FORCE RELAXED AND SAMPLER LOWERED AND ANCHORED IN SOIL.

7. SAMPLER PERFORMS SOIL MECHANICS EXPERIMENTS.

8. CABLE TENSION FORCE RE-APPLIED AND SAMPLER ANCHOR RELEASED.

9. SAMPLER CONVEYED TO MAST BY TROLLEY.

10. SAMPLER TRANSFERRED TO ELEVATOR AND LOWERED TO LAB.

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FIGURE 5.5-12. TROLLEY DEPLOYMENT SEQUENCE

c. Secondary Sampling System (Figure 5.5-13). A backup surface sampling system has been provided in the base of the ABL vehicle. In essence, it is a larger version of the aerosolizing brush system used in the deployed samplers. The brush consists of two hollow arms which contain small diameter tubing bristles. The arms are mounted on a gear driven housing that is in turn mounted on the center spine of the ABL. A continuous bellows mounted seal surrounds the housing and accommodates any unevenness in terrain. Pneumatic supply is fed into the rotary housing, along the arms, and out through the bristles. The return line is a toroidal duct connected to the separator scale delivery line.

5.5.4 SAMPLE PROCESSING SYSTEMS

The equipment required to prepare the soil samples for analysis is discussed below.

a. Pulverizer (Figure 5.5-14). The pulverizer eliminates agglomeration of soil particles, whether of a natural origin or as a result of their collection. The unit is basically a hammermill, utilizing staged blades rotating at high rpm to break up the samples. The unit is not intended to grind the sample or reduce its grain size beyond that which occurs naturally. The barrel of the pulverizer is tapered at the upper end to facilitate entry of the sample barrel. After seating of the sample barrel within the pulverizer, the sample is fed into the pulverizer in discrete batches. Interlocking vee blades close about the dumping auger to permit approximately one-fourth of the sample to be released into the pulverizer. The flared waist on the pulverizer barrel permits passage of solid particles 1/2-inch in diameter past the auger without interference. A cylindrical collar with three heavy blades is ball bearing mounted in the pulverizer barrel and flush with its interior surface. The collar acts as the armature for the drive motor which is an integral part of the pulverizer. Field windings and a separate motor shell complete the drive system. A solenoid actuated gate located in the pulverizer wall just below the drive motor deflects small quantities of ungraded soil directly to the gas chromatograph for analysis. A pneumatic flow through the processor is used to transfer all soil particles 300 μ or smaller directly to the separator scale. Articles greater than 300 μ diameter continue down the delivery tube and are carried overboard.

b. Cyclone Collector Scale (Figure 5.5-15). This instrument collects the 300 μ diameter soil particles delivered from the pulverizer, weighs, and dispenses them to the chemical processor in approximately 1-gram increments. The collector portion is a standard cyclone separator in which air and soil are introduced tangentially into the chamber. In the circulation thus formed, the solid particles settle out of the air stream and are collected, and the air flow is diverted out the top of the unit. During collection, the scale segment of the instrument is caged in place by three

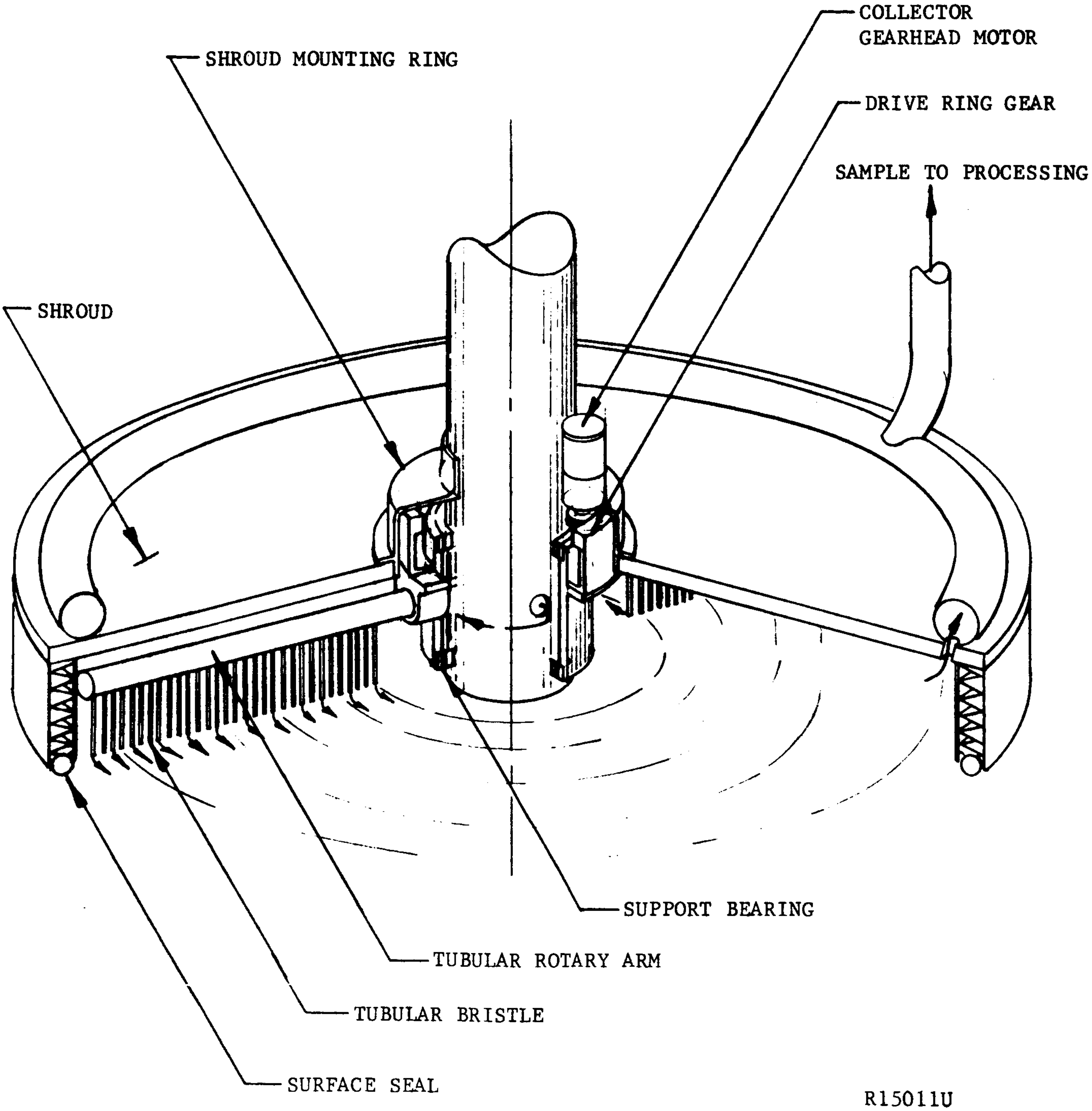

FIGURE 5.5-13. SECONDARY SOIL SAMPLING SYSTEM

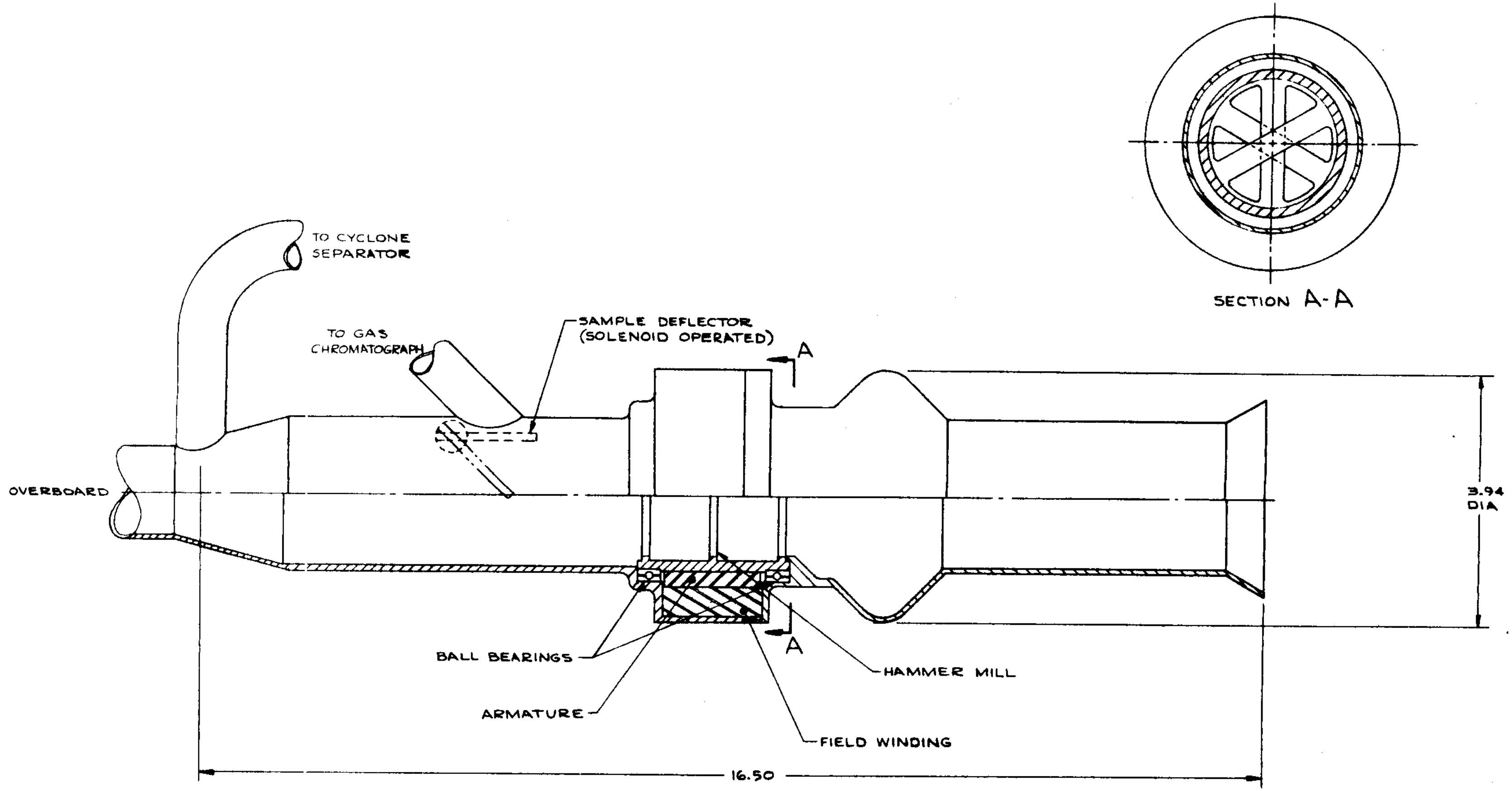

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FIGURE 5.5-14. SOIL PULVERIZER

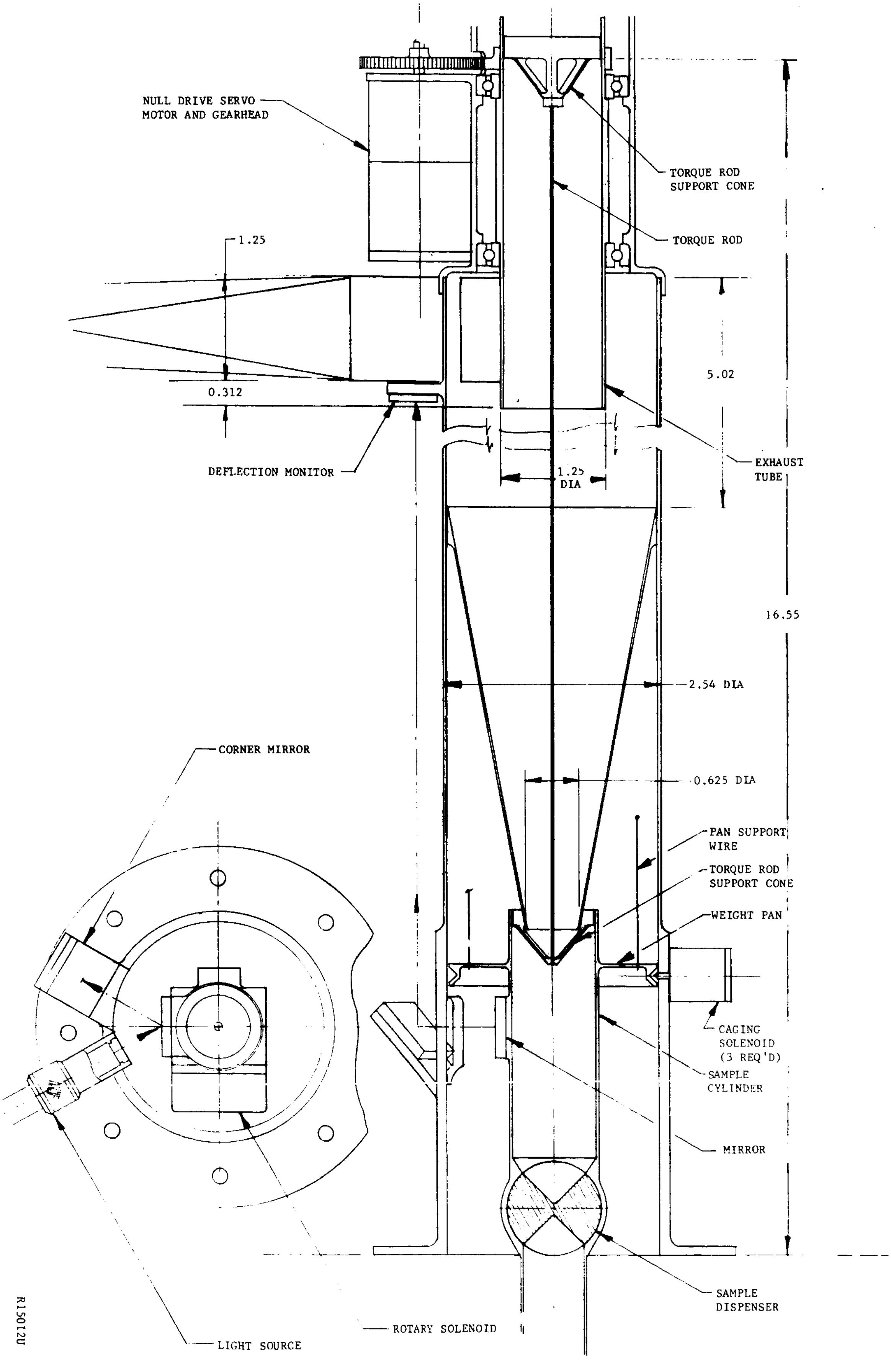


FIGURE 5.5-15. CYCLONE COLLECTOR SCALE

small solenoid plungers. After the pulverizer is secured, the caging plungers are withdrawn. The weight cage is supported by two small diameter wires that are oriented at equal angles from the vertical. The weight of the sample, when reacted by the canted wires, induces a rotation into the weight pan. This rotation is resisted by a torsion rod mounted in the center of the scale and suspended from the top cover of the collector. The upper fitting for the torque rod is designed such that the rod can undergo torsion loads without producing any vertical reaction to the applied weight. An optical null system is used to transfer the torsional deflection of the rod into sample weight data. A light source, mounted on the fixed portion of the scale, is focused on a mirror mounted on the weight pan. The image is then deflected to a second mirror and from that point to a strip detector. The detector is mounted on the top of the collector in order to effect a long optical moment arm. The detector output is fed to a null servo drive system, through a shaft encoder, to a sector gear supporting the upper end of the torsion rod. When weight is applied, detector voltage generated is amplified to drive the servo motor until no deflection is read. The shaft encoder deflection indicates the weight of the sample collected (for additional details of the scale see Appendix 6, Volume VI).

After weighing, the weight pan is caged by seating the solenoid plunger. The dispensing unit is a rotary valve with two conical cups located at 180-degree intervals. The cups are sized so that their volume is approximately 1 gram, based upon a specific gravity of 2.6 and an effective porosity of 50 percent. The rotary shaft is actuated on signal by a ratchet drive rotary solenoid. The samples are then gravity fed to the filter attachment on the chemical processors. A ratchet drive rotary solenoid was selected because agitation caused by the intermittent motion would assure that a maximum of the sample dispensed would reach the filter attachment.

5.5.5 CHEMICAL PROCESSING SYSTEM

The chemical processor which is used to prepare liquid and gaseous samples from processed soil samples is discussed below.

a. Requirements. The operation requirements for the chemical processor were established by the experiment procedures discussed in Volume II, Paragraph 5.2.2. These processes include:

(1) Soil extraction. Preparation of a soil filtrate by flushing of the soil samples with suitable reagents, filtering, and retaining the filtrate.

(2) Solution preparation. Preparation of reagents into solutions not stored in ampule or bulk form, or modification of stored reagent concentrations.

(3) Liquid/liquid phase separation. Removal of specific layer of liquid after solution stratification by settling.

(4) Controlled evaporation. Applying heat in specific heating rates for specific time periods.

(5) Growth culture. Replication of microorganisms in selected growth media.

The processor was sized by volumetric requirements established within the experimental procedures. Soil sample sizes ranged from 1 to 5 grams. Reagents were used, generally, in volumes less than 5 milliliters, to a total of about 20 milliliters for each experimental process. Five grams of soil at a specific gravity of 2.6 and effective porosity of 50 percent occupies 6.5 cc, and reagent density was assumed to equal water for a total volume requirement of 26.5 cc. It was also assumed that unused volume approximately equal to the used volume should be provided. Thus, a nominal value of 50 cc volume for the chamber was established.

Reagent ampules were sized by considering the individual application of given reagents within each experiment. With the exception of applications of ethyl acetate-acetic acid in Experiment 20 and ether-acetone in Experiments 22 and 23, ampule volumes of 5 milliliters will satisfy the procedural requirements. In addition, even smaller increments are required for approximately 25 percent of the applications. It was assumed, however, that reliable dispensing of reagents volumes of 0.1 to 1 milliliter could be accomplished by storing those reagents in somewhat larger ampules than required, and absorbing the weight penalty thus incurred. Two ampule sizes were utilized: 5 and 2.5 milliliters. The larger quantities required in Experiments 20, 22, and 23 would be provided by repetitive use of 5-milliliters ampules. A discussion of ampule and bulk storage of all chemicals is presented in Paragraph 4.3.2 of this Volume.

b. Configuration Studies. Conceptual design of the chemical processor is dependent upon the functional requirements of the reagent ampule. Several reagent designs, based upon 5-milliliters storage volume, were considered. Two conceptual designs are depicted in Figure 5.5-16 and 5.5-17. Figure 5.5-16 represents the piston approach to dispensing the reagent. The ampule is filled with reagent and hermetically sealed by rolling the soft aluminum seal into place around the piston lip and ampule wall. The dispensing needle is retained in the recess shown in the ampule tip. During operation, seating of the ampule forces the needle into the reagent cavity. Advancing the feed mechanism parts the piston from its retainer and dispenses the reagent.

The ampule design shown in Figure 5.5-17 utilizes a collapsing bellows to dispense the reagent. Sealing and needle provisions are basically identical to the approach used for the piston design. The piston design was selected for use during the ABL study primarily from the simplicity standpoint in that little development effort would be involved in minimizing the weight while maintaining structural integrity.

Both concepts shown were considered to be fabricated from Teflon because of their direct contact with the chemical reagents. During sterilization, the volumetric expansion of the contained fluid may require the application of a more substantial structural material. In this event, an aluminum liner surrounding the Teflon walls could be used as the structural component. Figure 5.5-18 depicts a conceptual needle design mounted in the piston type ampule. Chemical compatability requires that the needle be fabricated from commercially pure nickel or stainless steel. The tip configuration is dependent upon the requirements established for individual drop size. If it is assumed that a drop will fall from the needle when the drop weight exceeds the tensile force T (per unit length) of the rim, an expression can be developed for drop volume under Mars gravity conditions (see Figures 5.5-18 and 5.5-19).

The tensile force, T, is due to surface tension of the fluid and is independent of gravity influences. At the instant of release, the following conditions must prevail:

$$\text{Drop weight, } mg = \pi d\, T \cos\theta \qquad (1)$$

Since $m = \rho_L V_L$,

$$\pi d\, T \cos\theta = \rho_L V_L\, g \qquad (2)$$

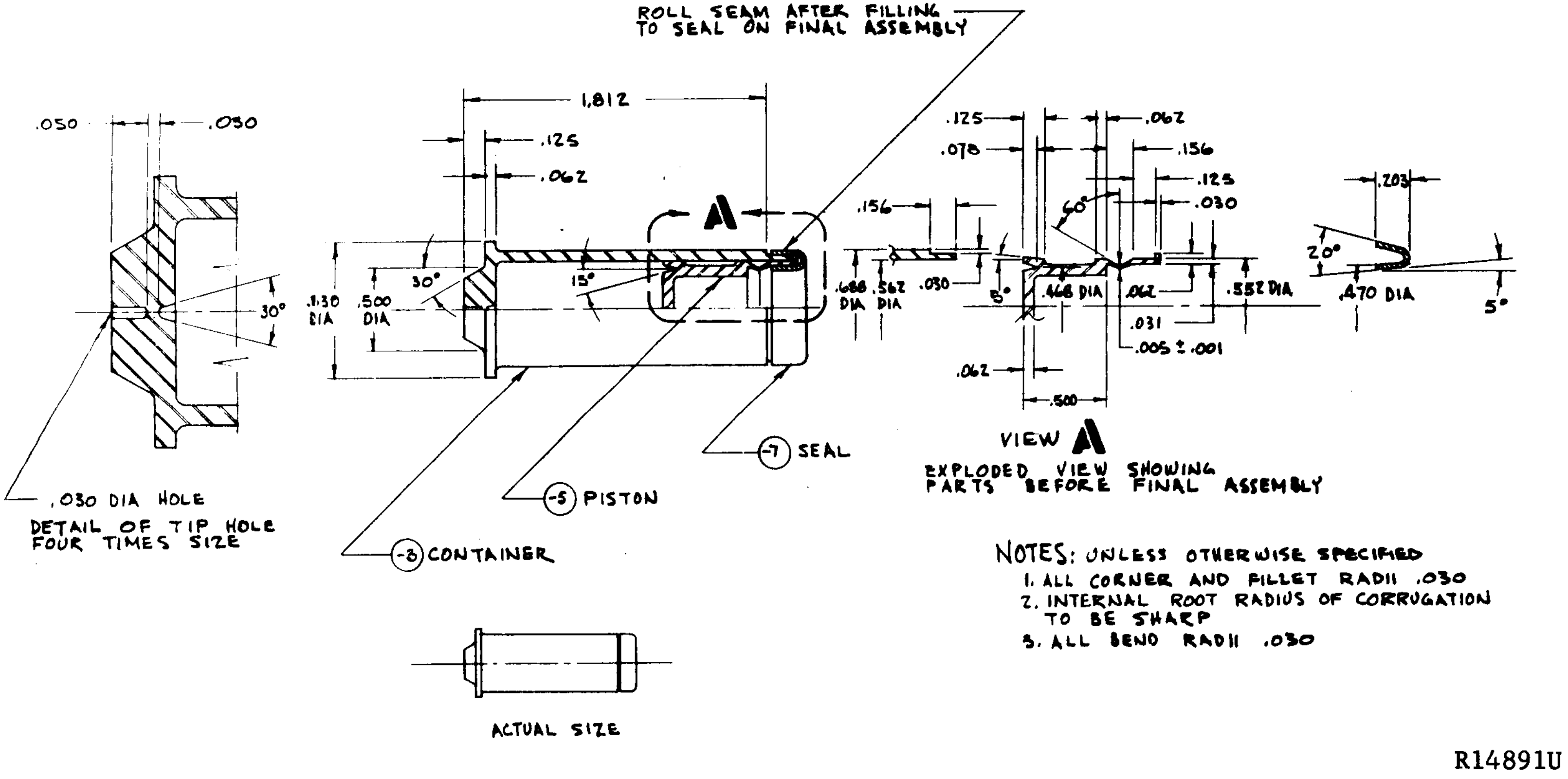
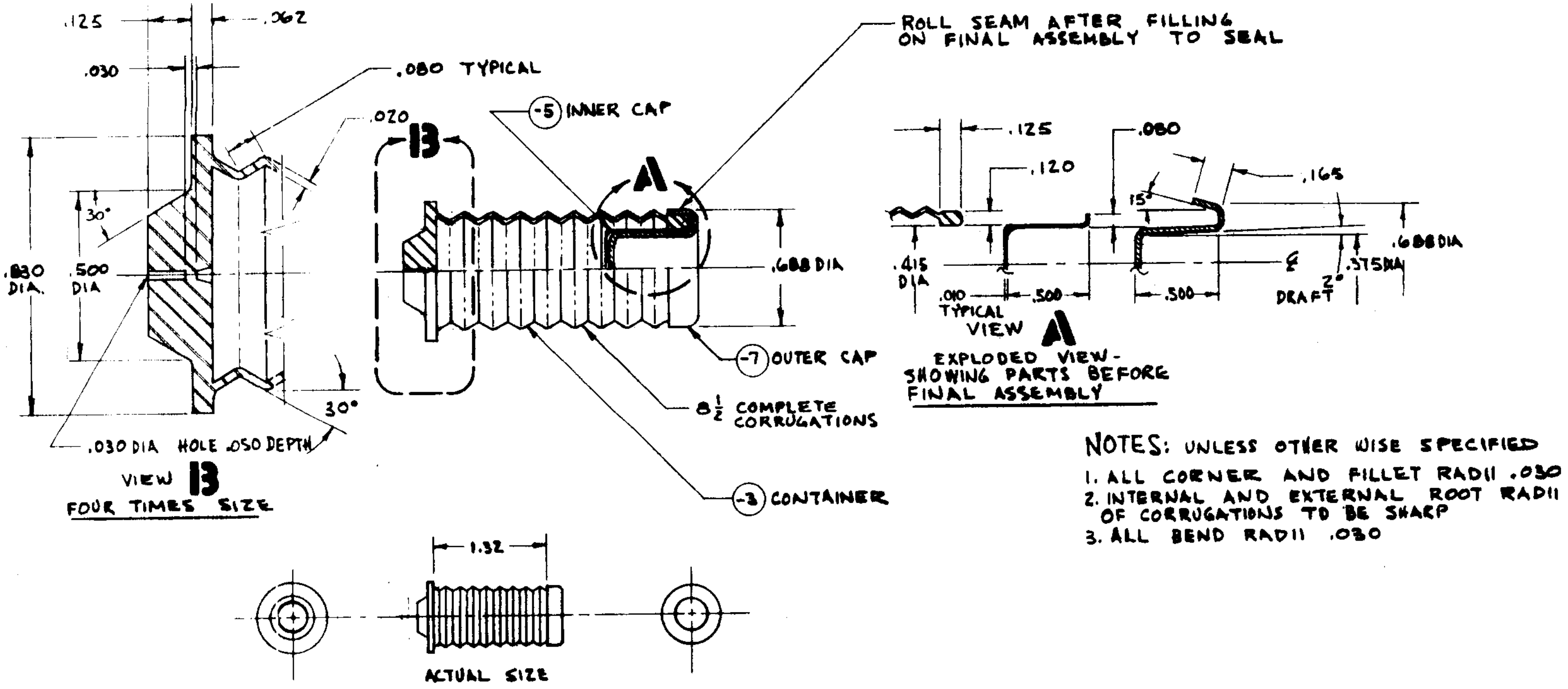


FIGURE 5.5-16. AMPULE ASSEMBLY PISTON



NOTES: UNLESS OTHER WISE SPECIFIED
1. ALL CORNER AND FILLET RADII .030
2. INTERNAL AND EXTERNAL ROOT RADII OF CORRUGATIONS TO BE SHARP
3. ALL BEND RADII .030

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FIGURE 5.5-17. AMPUL ASSEMBLY - BELLOWS

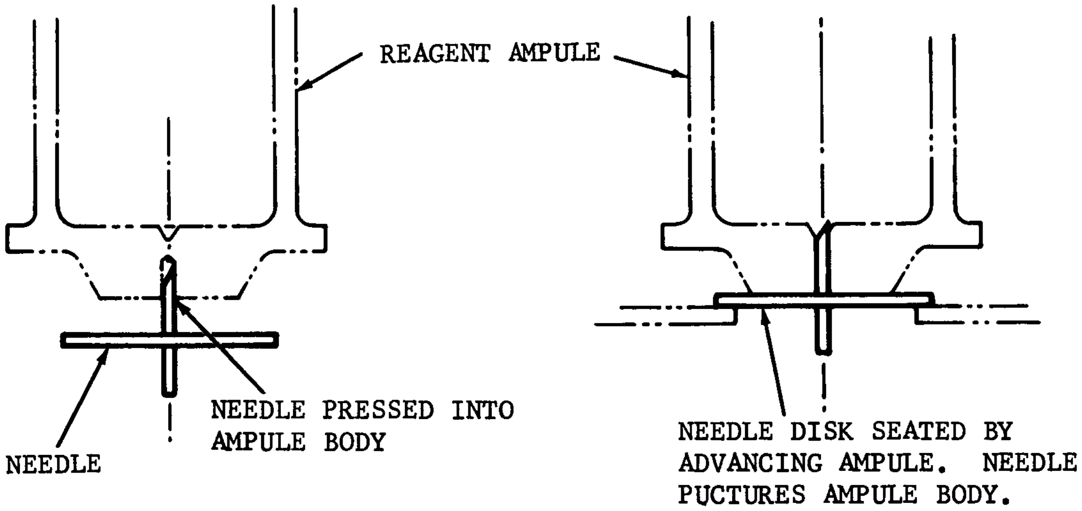

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FIGURE 5.5-18. DISPENSING NEEDLE CONFIGURATION

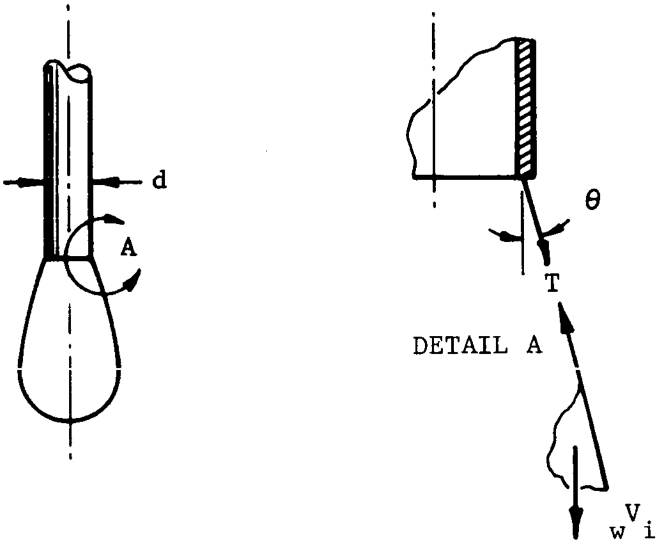

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FIGURE 5.5-19. DROP GEOMETRY

Thus, for a given tube size and tip configuration, the volume must change in proportion to gravity if the drop weight remains constant.

$$\rho_L V_{\oplus} g_{\oplus} = \rho_L V_{o} g_{\mars} \qquad (3)$$

Dividing by ρ_L produces

$$V_{\oplus} g_{\oplus} = V_{\mars} g_{\mars}$$

$$V_{\mars} = V_{\oplus} \frac{g_{\oplus}}{g_{\mars}} \qquad (4)$$

Substituting for the gravitational accelerations of Earth and Mars yields

$$V_{\mars} = 2.62\, V_{\oplus} \qquad (5)$$

If it is assumed that on Earth the volume of one drop is 0.05 cc, using expression (5) indicates that the volume of a single drop on Mars is 0.131 cc. Thus, a drop containing 0.1-milliliter volume is an approximate lower limit. The absolute lower limit must be determined for each liquid and each tube configuration. Thus, the drop size tends to vary linearly with mass density and surface tension and inversely with needle diameter.

A block flow diagram of the operational features of the chemical processor is shown in Figure 5.5-20. The remainder of this paragraph discusses in detail the concepts used to formulate the design point processor. A functional schematic of the processor is presented in Figure 5.5-21. The unit consists of two parallel shafts, oriented vertically. The ampule feed mechanism, chamber, and associated chamber attachments and their feed systems make up the shaft shown on the left. The various drive systems, ampule and attachment wheel mountings, and bulk chemical supply manifold make up the shaft shown on the right.

The upper wheel has provisions for mounting reagent ampules which are delivered from storage to the disk by the internal transport mechanism. In addition, specialized ampules and ampule-shaped detectors may be positioned in the transfer wheel as required. Specialized ampules include (1) the transfer ampule which is used to remove a portion of the liquid from the chamber and transfer it to another point for dispensing, or as temporary storage; and (2) cuvette cells, incorporating optical windows, used to transfer sample solutions to the spectral analyzer and IR spectrophotometers. Detector ampules include barium hydroxide conductivity cell, pH probe, argon β ionization chamber, and β ionization chamber. The units are discussed in detail in Volume II, Paragraph 5.3.

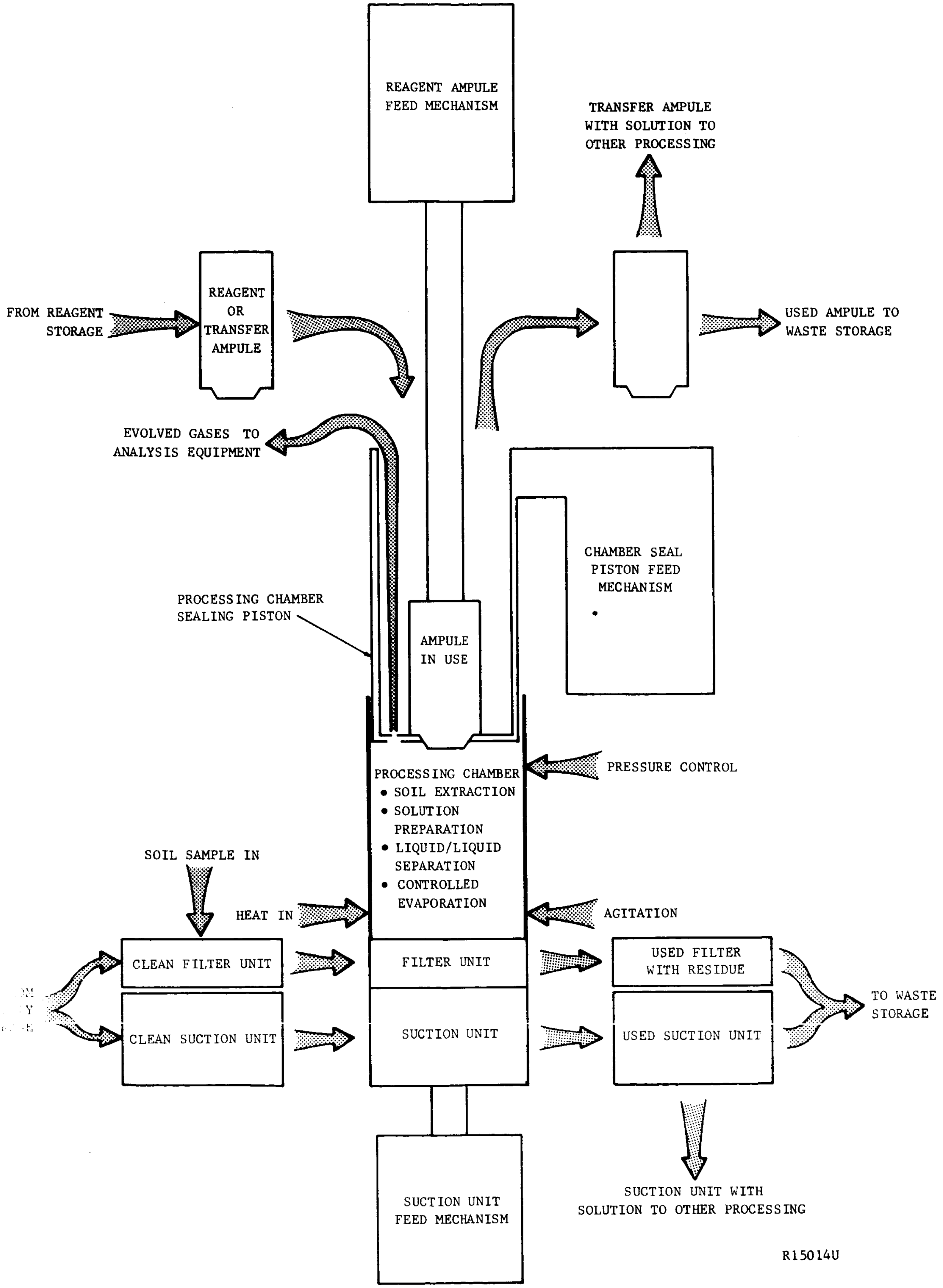
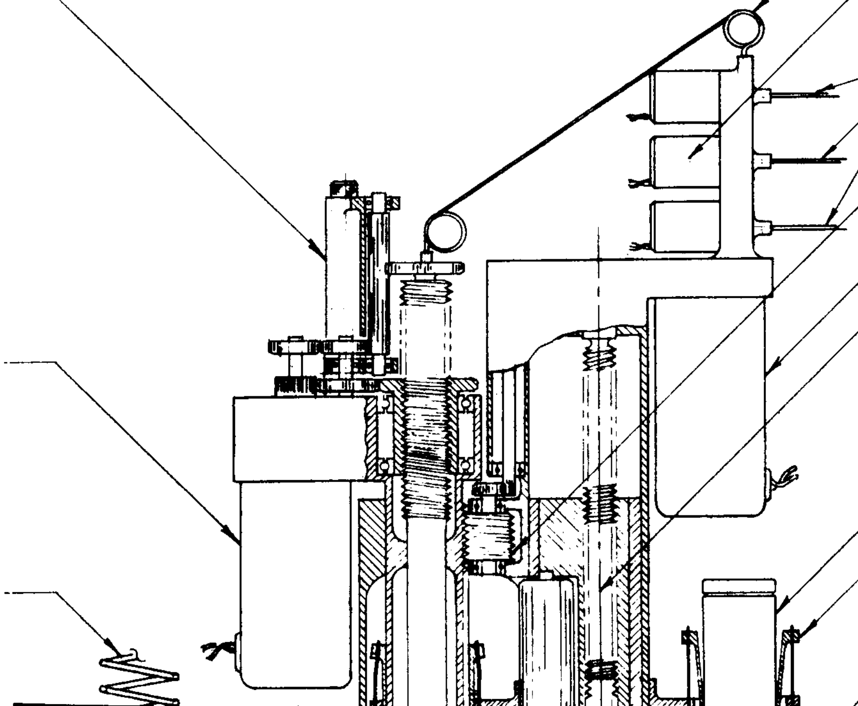
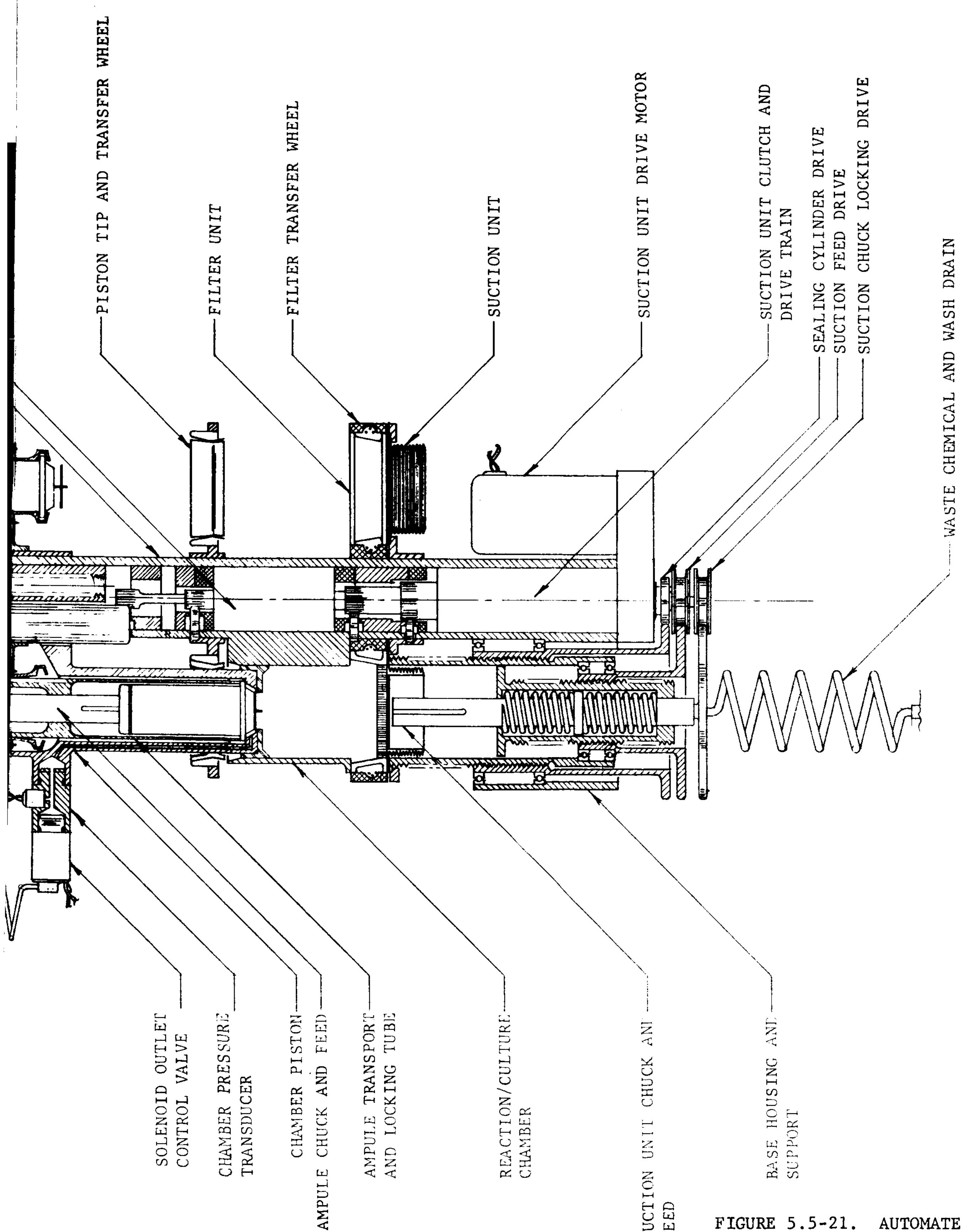


FIGURE 5.5-20. BLOCK FLOW DIAGRAM AUTOMATED CHEMICAL PROCESSOR


FLEXIBLE TUBE
BULK CHEMICAL FEED
BULK CHEMICAL SOLENOID
CONTROL VALVE
AMPULE PISTON FEED
DRIVE AND LOCKING TRAIN
BULK CHEMICAL AND WASH
SUPPLY LINES
FEED DRIVE - AMPULE
TRANSPORT MECHANISM
CHAMBER PISTON
DRIVE MOTOR
FEED DRIVE -
CHAMBER PISTON
AMPULE FEED
DRIVE MOTOR
REAGENT AMPULE
AMPULE HOLDER AND
TRANSFER WHEEL
GASEOUS OUTLET
LINE FOR CHAMBER
BASE HOUSING AND SUPPORT
TRANSFER WHEEL
CLUTCH AND DRIVE TRAIN



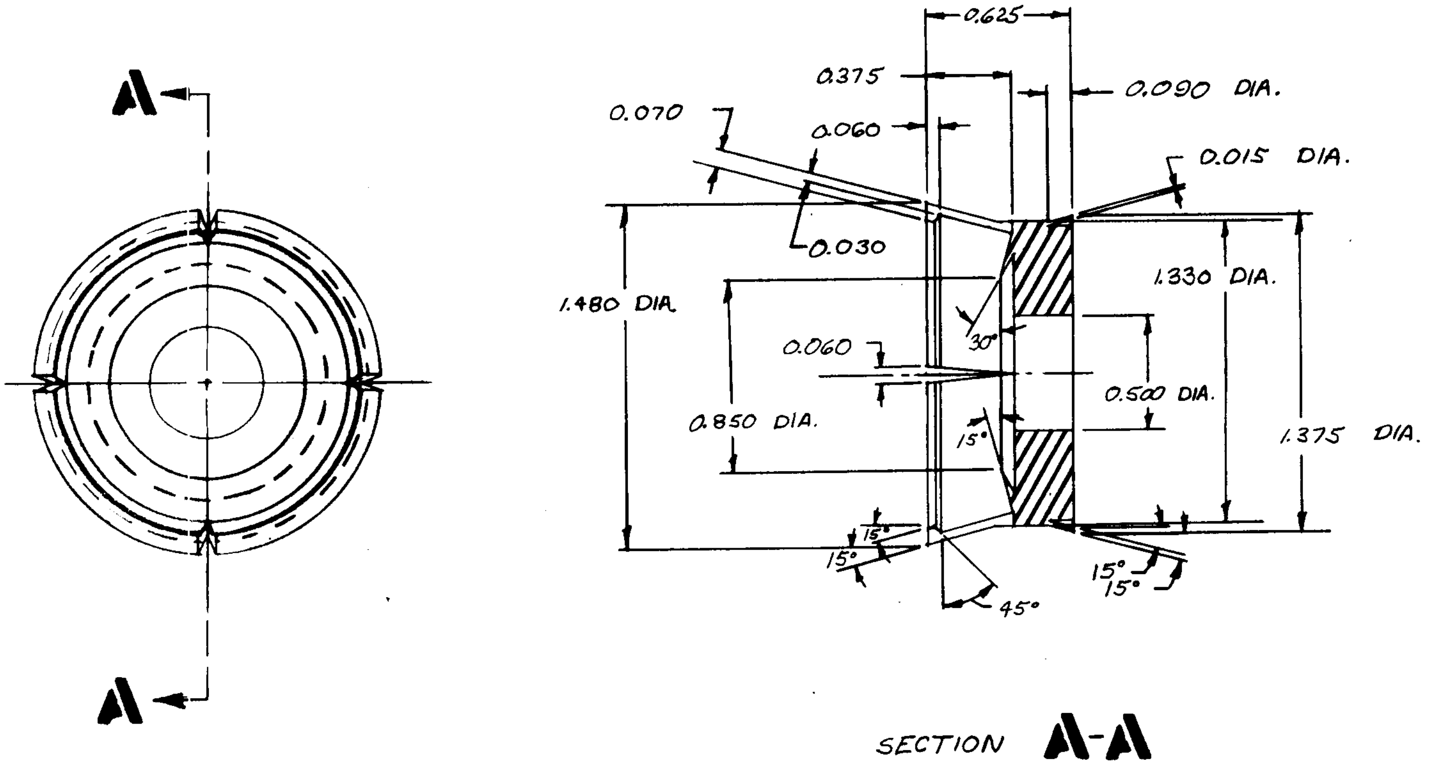
R15015U

FIGURE 5.5-21. AUTOMATED CHEMICAL PROCESSOR/CULTURE CHAMBER

Ampule wheel rotation is accomplished by a pinion shaft driven by the transfer wheel drive train. A concentric shaft collet chuck is used to advance and retract the ampules as required. Piston tips are retained in the transfer wheel just below the ampule storage wheel, and are supplied to the transfer wheel from storage by the internal transport mechanism. A conceptual design for a piston tip is shown in Figure 5.5-22. The tip is engaged by the ampule as it is fed into the processing chamber. Engaging the tip seats the ampule needle and forces the tip into the top of the chamber, thereby sealing the chamber during the chemical process. When the process is completed, the tip is driven along the length of the chamber to remove residue from the chamber walls. The tip is forced into the filter unit and both used tip and used filter are stored as a unit. Filter units are retained in the wheel below the piston tip wheel and are transferred to the transfer wheel from storage by the internal transport mechanism. A conceptual design for one type of filter assembly is shown in Figure 5.5-23. The filter forms the lower wall of the processing chamber and its base. The lower transfer wheel retains suction units, pyrolysis/culture dishes, and α scattering plates. These units are transferred to the transfer wheel by the internal transport mechanism. The suction unit draws reagents through the soil sample and filter to form soil extracts. The drawing process can be modified into a reciprocating motion in which the fluids are drawn through the soil sample in one direction and then in the opposite direction. It may also be used in this fashion as a mixing or stirring unit. The suction unit is a bellows unit grasped by a concentric shaft collet chuck, and advanced and withdrawn by the suction unit drive train located in the base of the right hand column. All used chamber attachments are transferred to storage from their respective transfer wheels by the internal transport mechanism. Gases evolved during the chemical processes are exhausted from the chamber through a solenoid outlet valve and may be directed to the gas chromatographs for analysis.

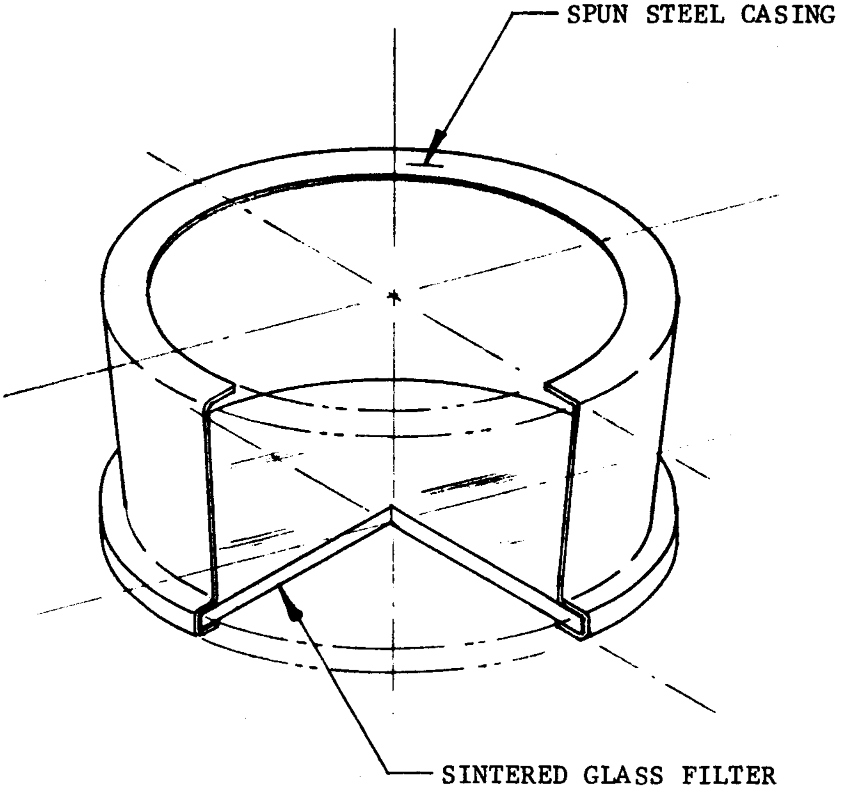
The operational flexibility of the chemical processor is illustrated by describing the steps involved in satisfying the five basic operational requirements:

(1) <u>Soil extraction</u>. A soil sample is supplied to the filter storage container from the weight scale. After the sample is injected into the filter, the filter is transferred into the filter transfer wheel by the transport mechanism. Applicable reagents are placed in the ampule transfer wheel and stepped into place to be grasped by the ampule chuck. The piston tip is engaged by the piston and advanced into the chamber where it effects a closure seal for the chamber. As it enters the chamber, the flared skirt is compressed, thereby retaining the tip in position on the piston. Advancing the



R14898U

FIGURE 5.5-22. PISTON TIP



R15016U

FIGURE 5.5-23. FILTER ASSEMBLY

chamber drive mechanism seats the chamber, filter, and suction tip base into a sealed, integral unit. The ampule feed is advanced, dispensing the reagent as required onto the soil sample. Additional reagents may be added as required. After the necessary reagents have been supplied, the suction cup is withdrawn to filter the sample from the soil extract. The used filter is then stepped clear of the chamber, and the extract prepared for subsequent steps.

(2) Solution Preparation. As an example of this process, it will be assumed that a reagent is required in concentration less than as stored. The placement of attachments is identical to that described above for soil extraction, except that no filter unit is used. The chamber is seated directly on the suction cup unit, and reagent injected into the chamber. Assume that water is the required solvent. Since water is carried only in bulk storage, it would be supplied to an adjacent processor through its manifold. A transfer ampule would be used to take up a supply of water and then be stepped into position in the active chamber. The transfer ampule then can be used to accurately meter the required amount of water into the reagent. If necessary, the reagent can be agitated by reciprocal motion of the suction unit. A second transfer unit can then be used to draw up the revised reagent. The remaining reagent is flushed with water, or solvent and delivered to waste. The chamber and attachments are flushed, dried, the chamber drive reversed to open the chamber, and the used attachments stepped into waste storage by the transport mechanism.

(3) Liquid/Liquid Phase Separation. Experiments 21, 22, and 23 include the requirement that liquid/liquid phase separation be performed. In Experiment 21, for example flavins are extracted from a soil sample with water and sulfuric acid. Since flavins are virtually insoluble in chloroform, the extract is treated with chloroform to remove fluorescent materials. The extract is made basic and photolyzed, thus converting flavins in the extract to lumiflavins. If fluorescence is detected by the spectral analyzer in its

fluorimeter mode, the presence of flavins in the soil is indicated. The removal of fluorescent materials from the extract is accomplished by liquid/liquid phase separation. After a soil extract has been made, chloroform is added and the mixture agitated. After agitation, the mixture is allowed to settle, separating the layers. The The bottom layer is chloroform and is removed by advancing a transfer ampule until the needle is just above the suction unit. The ampule piston is retracted, drawing the chloroform layer into the transfer ampule. A second chamber is used to inject the separated layer into a fluorimeter cuvette, and the cuvette transferred to the spectral analyzer. The use of chloroform as a solvent for luminous materials is repeated until no fluorescence is detected.

(4) Controlled Evaporation. The application of heat under controlled pressure and temperature conditions is required in many of the biological processes. A resistance heater is enclosed within the wall of the processing chamber, and heating is initiated by the computer. Pressure above the mixture is controlled by venting the chamber as required. A thermocouple located at the base of the chamber is used to indicate dryness since the temperature of the liquid will remain at the boiling point until complete dryness is effected.

(5) Growth Process. Evolution of normal and tagged carbon dioxide in Experiments 29, 30, 31, and 32 requires that the processor be used as an incubator to evaluate the ability of Martian soil samples to exhibit growth characteristics. Experiment 29, for example, requires six chambers. Two chambers remain dark and serve as sterile sample for each of two chambers, one lighted and one dark. Soil samples are injected into each of six filters and transferred to the chambers by the transport mechanism. A transfer ampule, containing 10N HCl (premixed by bubbling HCl gas through water in a separate processor) is advanced by the ampule drive, engages a piston tip, and seals all chambers. The chamber is then seated on the suction unit, forming a sealed unit. The two control chambers are heat sterilized and all chambers flushed with CO_2 supplied from bulk

storage through each processor manifold valve. Two chambers are lighted, and controlled temperatures established by operation of the resistance heater contained in each chamber wall. Each chamber is pressurized to ambient CO2 partial pressure with $C^{14}O_2$ and incubation begins. After a preselected incubation period, the HCl is injected onto the samples. The chambers are flushed with nitrogen from the bulk supply and the mixture evaporated to dryness. A β ionization detector replaces the transfer ampule as the chamber seal. After pressurizing the chamber with oxygen from bulk supply, each chamber is heated to combust organic carbon and release fixed C^{14} as $C^{14}O_2$. The chamber cleaning and sterilization process is effected and the used units stepped into storage.

(6) Growth Process Evaluation of Culture Media. Experiment 33 uses the results of the life detection and environmental processes to determine types of culture media to be formulated from Earth originated materials. A separate attachment on each chamber is used to store small culture plates and step them into place in the chamber for injection of media and a small sample of Martian soil. Culture media are mixed and their concentration controlled in separate chambers. A transfer ampule is used to collect the desired media and dispense it on a culture plate positioned in the processor. The transfer ampule needle is advanced to collect a small soil sample from the filter attachment and deposit it in the media. The atmosphere is controlled above the sample and at regular intervals the pH detector lowered into place and readings made. Growth of the sample is monitored by stepping the culture plate over an optical density comparator integrated into the processor housing. Gases evolved from the sample are supplied to the gas chromatograph for analysis.

A laboratory test model of an automatic chemical processor based on the above principles was developed by Aeronutronic under an Independent Research & Development program. A photograph of the early manual model of this processor is shown in Figure 5.5-24. This model was developed to substantiate certain design concepts advanced in this ABL preliminary

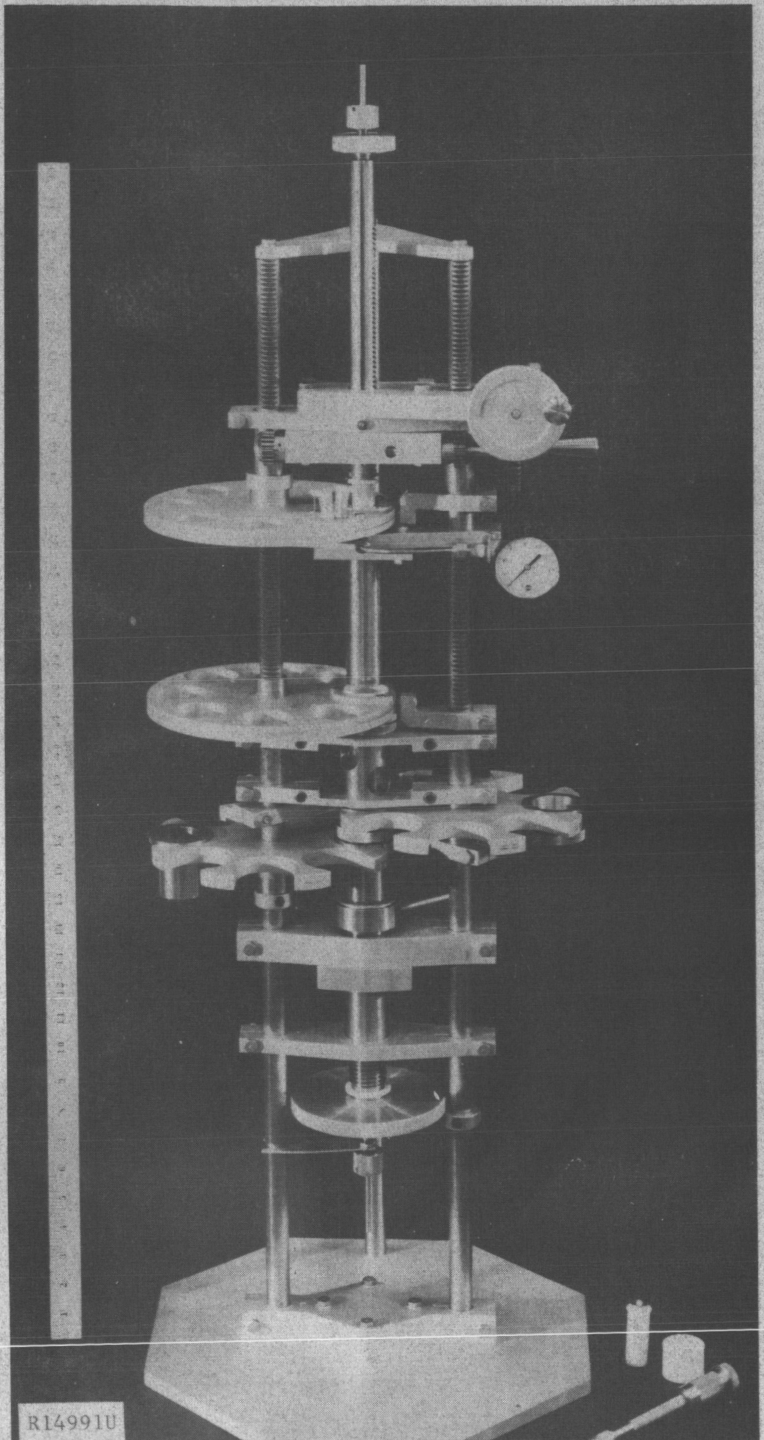


FIGURE 5.2-24. EARLY LABORATORY TEST MODEL
- WET CHEMICAL PROCESSOR

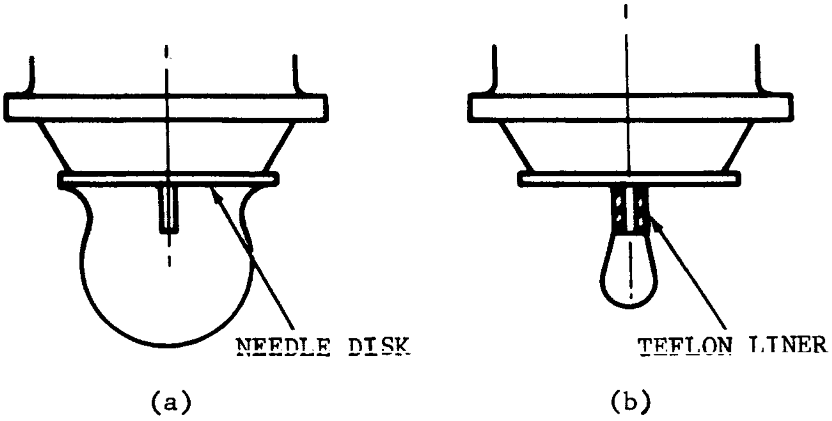
design study. With the exception of the suction units, all processing chamber attachments are similar to those described above. Operational tests conducted by Aeronutronic have established definite feasibility of the following processor concepts.

(1) Reagent ampules utilizing the piston concept for dispensing reagent have been stepped into place, grasped by the chuck, engaged piston tips, and dispensed the enclosed reagents. After dispensing the reagent, the ampule has been withdrawn and transferred back into the ampule storage wheel.

(2) The piston tip has been engaged by the ampule, advanced along the chamber wall, and injected into the filter.

(3) Drop size tests using the ampule needle have been conducted. For water, 68 drops were required to dispense 1 cc. It was assumed in the study that 20 drops would be required on Mars.

(4) Drop size tests using carbon tetrachloride indicated that a modification of the needle design was required. The wetting properties resulted in the liquid adhering to the needle and a large drop forming over the needle disk. See Figure 5.5-25a.



R15017U

FIGURE 5.5-25. DROP GEOMETRY FOR CARBON TETRACHLORIDE

The needle was modified as shown in Figure 5.5-25b by adding a Teflon sleeve around the needle. The drop size became smaller, and the drop count results were more reproducible.

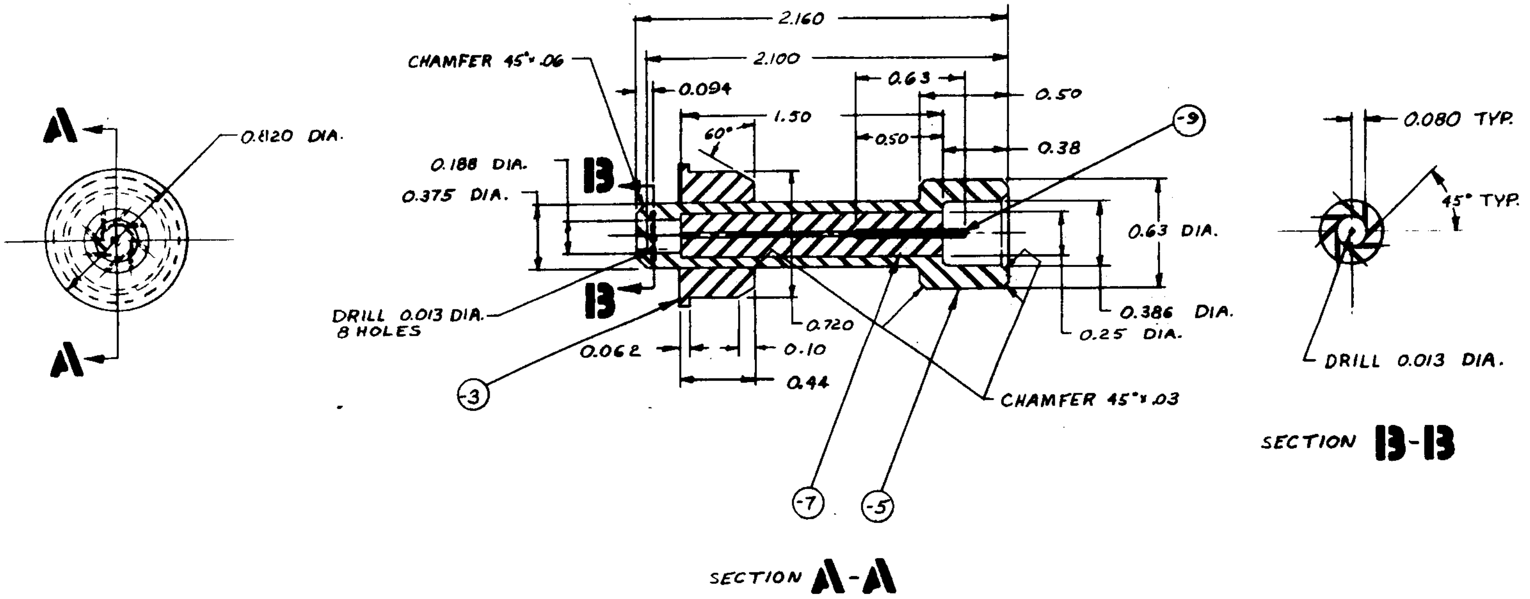
(5) A transfer ampule was developed, using the basic ampule design. Liquids enclosed in the chamber were drawn into the transfer ampule. The transfer ampule was subsequently withdrawn and stepped into the ampule transfer wheel. It was then engaged by the chuck, advanced into the chamber, and its contents dispensed.

(6) A bubbling head was developed using a Teflon body and ampule chuck recess. The head was engaged by the chuck and advanced into the chamber until immersed in liquid. Compressed air from bench supply was delivered to the unit, and the liquid agitated (see Figure 5.5-26).

5.5.6 INTERNAL TRANSPORT MECHANISM

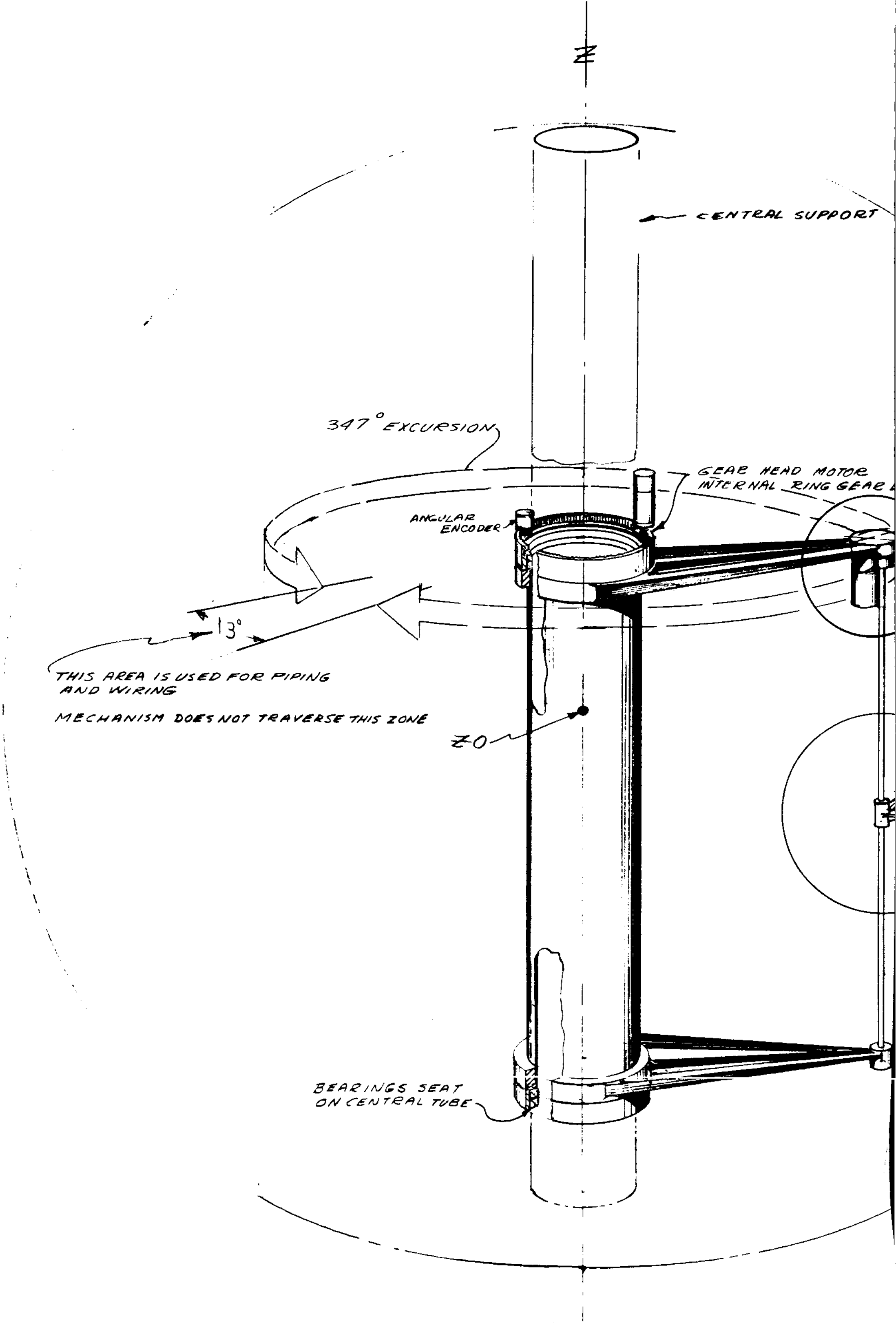
Reagent ampules and processor attachments are transferred from storage to their respective transfer wheels by means of the internal transfer mechanism. It is also used to transfer test samples from the processor to the spectral analyzer, IR spectrophotometer and gas chromatographs, and to return used ampules and attachments to storage from the processor transfer wheels.

A conceptual design for the transport mechanism is shown in Figure 5.5-27. The mechanism elevation system is suspended between two radial arms which are mounted on a ball-bearing torque tube supported by the center spine. The upper arm mount ring includes an internal ring gear driven by a gear-head motor and driving a shaft encoder. The encoder establishes the rotational location of the mechanism. The mechanism serves all processing chambers by traversing an arc of 347 degrees. This allows a pie-shaped segment of 13 degrees for piping and wiring that interconnects the processing chambers and bulk chemical storage with components outside of the transport mechanism clearance envelope. The mechanism arm is elevated by the operation of a ball screw jack powered by a gearhead motor located on the upper arm. Rotary motion of the arm is effected by rotating the slotted guide tube that is concentric with ball screw. The motor drives both the ball screw elevation mechanism and the arm rotary motion by being coupled to a concentric shaft. The clutch permits motor output to be directed to either vertical or rotary motion as required.

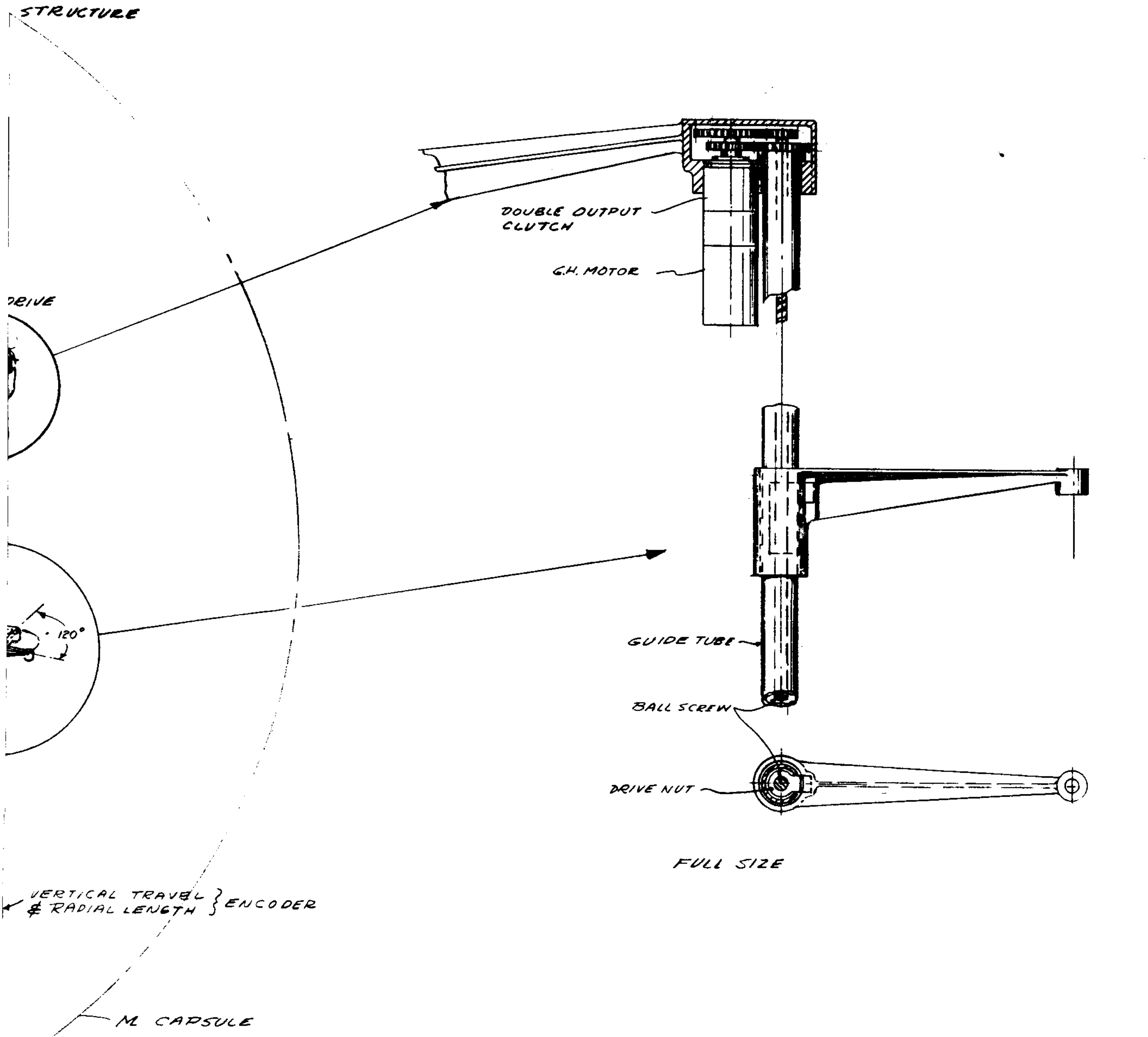


R14899U

FIGURE 5.5-26. WASH AMPULE ASSEMBLY


Z
CENTRAL SUPPORT
347° EXCURSION
GEAR HEAD MOTOR
INTERNAL RING GEAR
ANGULAR ENCODER
13°
THIS AREA IS USED FOR PIPING AND WIRING
MECHANISM DOES NOT TRAVERSE THIS ZONE
Z0
BEARINGS SEAT ON CENTRAL TUBE

1/4 SIZE



R14900U

FIGURE 5.5-27. INTERNAL TRANSPORT MECHANISM

To deliver a reagent ampule the following procedure is used:

(1) Transport mechanism is rotated to preselected angular offset.

(2) Transport arm is elevated into position above desired ampule tray.

(3) Arm is rotated to preset position and lowered to engage ampule.

(4) Arm is rotated to neutral position to remove ampule from storage.

(5) Arm is positioned vertically with ampule opposite desired processor ampule transfer wheel.

(6) Arm is rotated, placing ampule into transfer wheel retainer.

(7) Arm is rotated to neutral position and mechanism secured.

To deliver a processor attachment the following procedure is used:

(1) Attachment tray is rotated until attachment is indexed opposite selected processor.

(2) Transport mechanism is rotated to preselected angular offset.

(3) Transport arm is positioned just above attachment storage.

(4) Arm is rotated to a position above and in line with desired attachment.

(5) Arm is lowered to engage attachment and rotated to index attachment into processor transfer wheel.

(6) Arm is rotated back into neutral position and mechanism secured.

The delivery of a sample cuvette to an analytical instrument is similar to that described above for ampule delivery with the exception that the cuvette is positioned within the instrument by the transport mechanism. Return of reagent ampules and attachments to storage is similar to the procedures described above but generally in the reverse order.

5.6 LABORATORY ASSEMBLY AND CHECKOUT

5.6.1 PRINCIPAL LABORATORY ASSEMBLY AND CHECKOUT OPERATIONS

There are three major considerations that will influence the fabrication, checkout, and assembly of the ABL and its components. These are mechanical cleanliness, chemical contamination, and sterilization. The first has been the primary concern in the fabrication of current generation spacecraft. Sterilization has been of concern in the early lunar spacecraft and is definitely recognized as a stringent requirement for planetary landers. For Mars, an acceptable probability of landing a viable organism has been defined as 10^{-4}. Chemical contamination either by chemical reaction with containers or trace impurities left as a result of imperfect processing or introduced during fabrication and assembly must be carefully assessed and controlled. When it is considered that storage times for ABL supply items can be a maximum of three years, for the system defined in this study, this could become a major quality control consideration. Thus, the philosophy of fabrication and assembly must emphasize these three considerations not only in the terminal stages of assembly, but at all points in the fabrication process, starting with purchased materials and components through fabrication and assembly to terminal sterilization of the completed laboratory and entry vehicle. Since the matter of cleanliness and sterility are difficult to define or to assess quantitatively, definitions for sterile, biologically clean, chemically clean, and mechanically clean were given in Paragraph 5.2 of this Volume for purposes of this study. All purchased items such as raw materials and simple parts must be evaluated for compatibility with the three considerations mentioned previously. For example, the simplest consideration of mechanical cleanliness may demand that surface finishes are smoother than would normally be required from a functional viewpoint to reduce particles produced through wear and to prevent microscopic cracks or crevasses in which material such as grease or skin particles from handling could be lodged. Chemicals will have to be examined for their compatibility with the materials from which the containers are fabricated and the procedures used to fill these containers. To illustrate, a material may easily be shown to be chemically inert to the substance being stored but may still prove to be unsatisfactory for long term storage because of its permeability. Since permeability will increase as the material thickness decreases, this could become a significant parameter for an ABL payload since ultra-light construction is employed wherever possible. In filling a container with a chemical, the inclusion of simple atmospheric gases can cause oxidation and other processes to take place with a resultant change in the quality of the reagent. From the sterility viewpoint, not only must acceptable procedures for reducing contamination by viable organisms be developed, but also methods for assessing the effectiveness of these procedures must be developed. The sterility achieved in terminal sterilization of the flight spacecraft will not be directly ascertained through direct inspection methods but must be inferred through control specimens and a complete historical record of the handling and conditions undergone in the fabrication and assembly process. This will impose a much more stringent set of inspection and quality control procedures than is ordinarily expected in the fabrication and assembly of previous spacecraft, as well as intensive training for the shop personnel and technicians in the use of these procedures.

Two types of components will be encountered in fabricating and assembling the ABL in terms of sterilization. In this discussion, these are designated* type A for those which are compatible with dry heat sterilization and type B for those which are not. Examples of type B are ampules containing certain kinds of growth media and propellants such as hydrazine which borders on unstable dissociation at these temperatures. Thus, other methods of sterilization must be utilized and these components added after sterilization or protected during sterilization. Propellants or chemicals stored in bulk containers are most easily added by sterile insertion techniques since they are fluids and may be pumped in through sterile piping. Component assemblies such as reagents stored in ampules are virtually impossible to install by sterile insertion techniques because of the many interfaces and boundaries which must be opened and exposed. A technique which appears to be more promising for this type of component is to sterilize and subencapsulate these components individually and provide thermal isolation during terminal dry heat sterilization to limit the temperature at the critical component to a safe value. To illustrate the two types of components, Figure 5.6-1 shows the basic elements of fabrication and assembly for a typical reagent ampule and storage unit. Figure 5.6-2 shows the elements for fabrication and assembly for the same kind of unit which must be thermally isolated during terminal sterilization. Figure 5.6-3 illustrates the details of the thermally isolated unit to indicate the method employed to guarantee no contamination inside the subencapsulation boundary. The concept illustrated here uses a basic ampule storage unit with the additional feature of a cold plate coolant system in the walls. All the hardware items are dry heat sterilized to the same program as the terminal brake cycle while inside the sterile assembly chamber. All assembly tools are also included. The reagent or growth media is either filtered through a sufficiently fine filter to remove all organisms or, if possible, it is sterilized by an appropriate steam sterilization process. It is then filled into the ampule through a sterile interface. In some instances, the filled and sealed ampule can be sterilized by exposure in live steam at only 121°C for 15 minutes. The fully assembled ampule storage unit is then inserted inside the subencapsulation boundary which is insulated. The unit is then sealed by welding the outer skin boundary and may be subjected to a helium leak test before removing it from the sterile assembly chamber. From this point, it can be handled in the same manner as a type A component. During terminal sterilization, the outer surface achieves sterilization temperatures while the cold plate coolant

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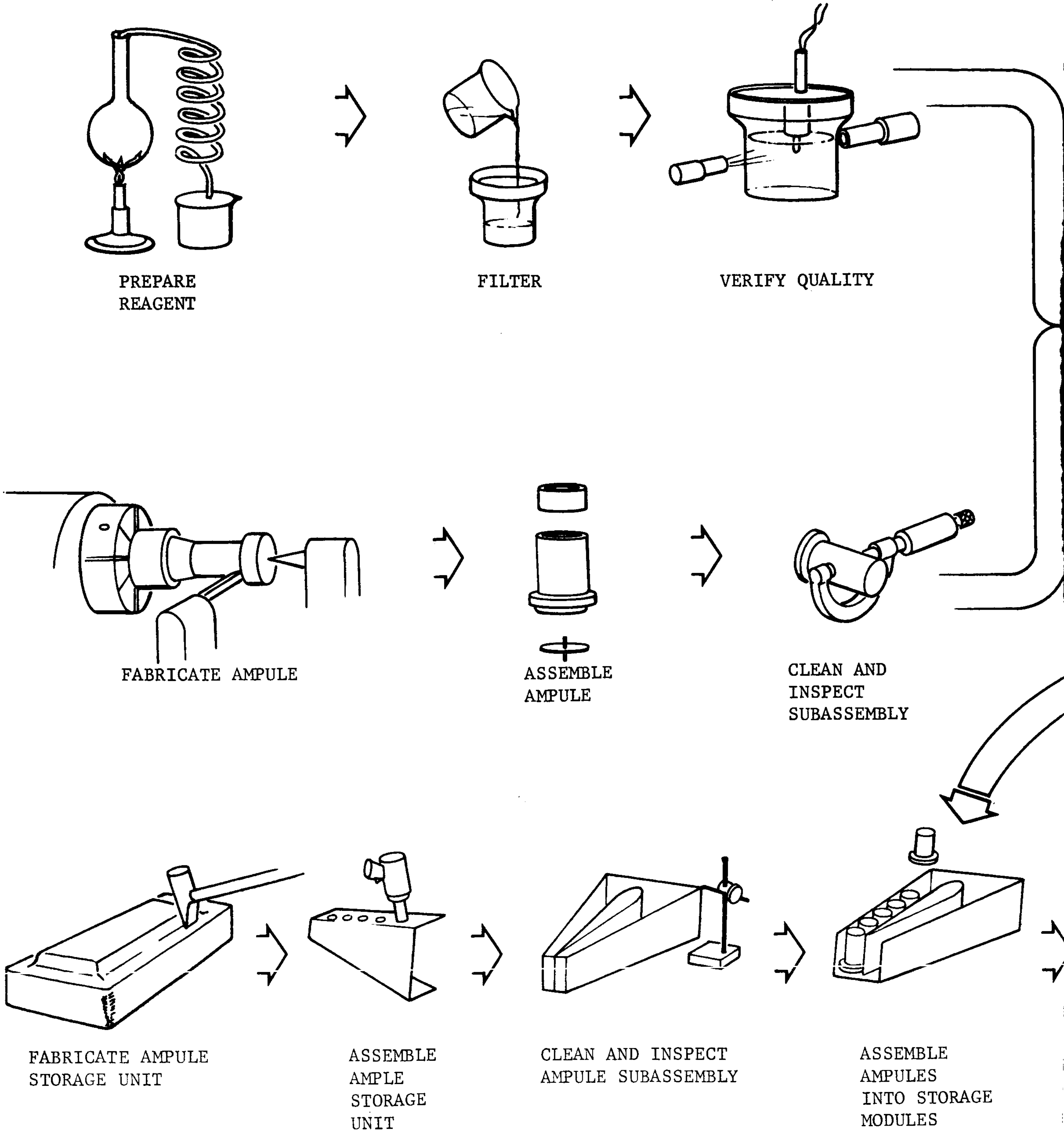
*In Paragraph 5.7.1, these components are categorized into sterilization classes conforming with current NASA sterilization compatibility requirement. Type A corresponds to classes I and II. Type B corresponds to class III.


PREPARE REAGENT
FILTER
VERIFY QUALITY
FABRICATE AMPULE
ASSEMBLE AMPULE
CLEAN AND INSPECT SUBASSEMBLY
FABRICATE AMPULE STORAGE UNIT
ASSEMBLE AMPLE STORAGE UNIT
CLEAN AND INSPECT AMPULE SUBASSEMBLY
ASSEMBLE AMPULES INTO STORAGE MODULES

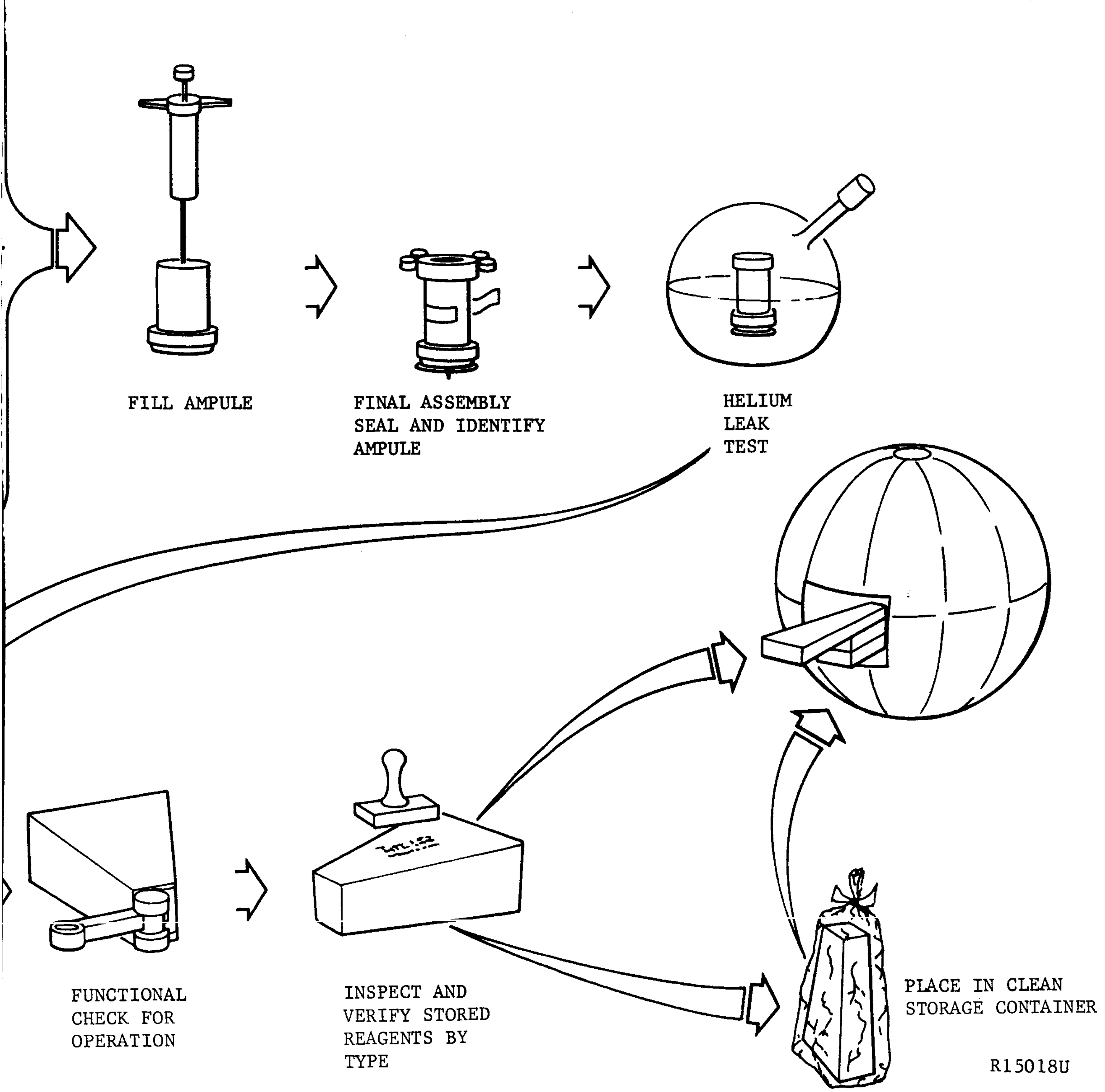


FIGURE 5.6-1. TERMINAL DRY HEAT STERILIZABLE AMPULE STORAGE COMPONENTS AND ASSEMBLY PROCEDURE

maintains a safe temperature inside. Since all the material inside the outer boundary has been previously sterilized, it is not necessary for the insulation to achieve sterilization temperatures. In order to open the subencapsulation boundary later when the reagents must be used, it is only necessary to cut the outer shell boundary and allow the springs to draw it back out of the way. A material which is available under the trade name of "Pyrofuze" is ideally suited to this application. The material is aluminum with a coating of palladium. When heated locally to approximately 600°C, an exothermic alloying reaction takes place between the palladium and the aluminum at a temperature of 2800°C. The reaction is initiated by heat alone and requires no oxygen since it is not an oxidation process and evolves no gases. The residual material is in the form of fine globules of an aluminum-palladium alloy. Since the reaction reaches a temperature about twice that to melt aluminum, a ribbon of material can effectively cut through a thin aluminum shell by melting or vaporizing it. It should be pointed out that mechanical systems designed with this material can be made to eliminate the need for pyrotechnic squibs and actuators, although at some penalty in terms of weight.

All assembly and checkout functions will be performed in a class 100 vertical laminar flow clean room to minimize the biological load that is associated with joining surfaces. Thus, the only parts to be fabricated under shop conditions are detailed machined parts, formed parts, and welded or brazed assemblies, i.e., simple parts.* After the simple parts are fabricated and cleaned by normal shop procedures such as acid pickling, etc., they must be subjected to further cleaning and sterilization which may include ethylene oxide washes and baking. The ABL preliminary design, as developed in this study, is approaching a size which makes it necessary to carefully assess the permissible physical limits of a vertical laminar flow clean room. Functional testing of the ABL mast used to deploy some of the experiments and the remote sampling system will require a minimum ceiling height of 15 feet. This feature creates the need to evaluate the design against possible facility limits and the testing requirements. Mast deployment tests may necessarily be performed in a horizontal attitude to avoid having operators upwind from the ABL assembly.

The RTG power supply is the final component assembled into the ABL payload because it contains a radioactive source. Although it produces primarily β radiation which is easily shielded, it is still desirable to install it as late in the assembly procedure as possible. Another reason for delaying installation is that the RTG must operate continuously under load and also produces a large amount of heat which must be dissipated. Figure 5.6-4 illustrates the final assembly of the RTG power supply into the ABL. There

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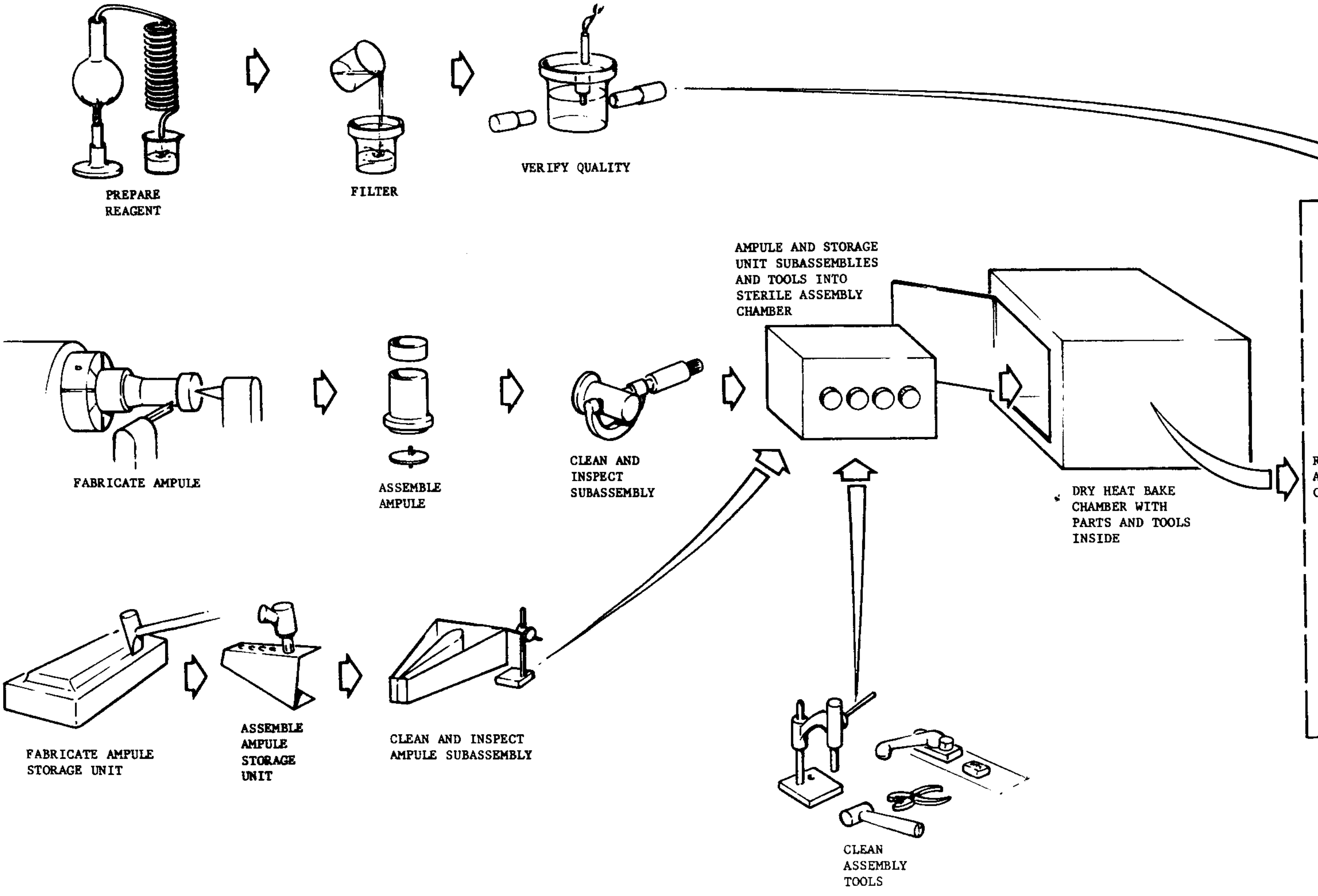
*Simple and complex parts are defined in Paragraph 5.7.1 in accordance with the terminology of current NASA sterilization policy statements.


PREPARE REAGENT
FILTER
VERIFY QUALITY
FABRICATE AMPULE
ASSEMBLE AMPULE
CLEAN AND INSPECT SUBASSEMBLY
AMPULE AND STORAGE UNIT SUBASSEMBLIES AND TOOLS INTO STERILE ASSEMBLY CHAMBER
DRY HEAT BAKE CHAMBER WITH PARTS AND TOOLS INSIDE
FABRICATE AMPULE STORAGE UNIT
ASSEMBLE AMPULE STORAGE UNIT
CLEAN AND INSPECT AMPULE SUBASSEMBLY
CLEAN ASSEMBLY TOOLS

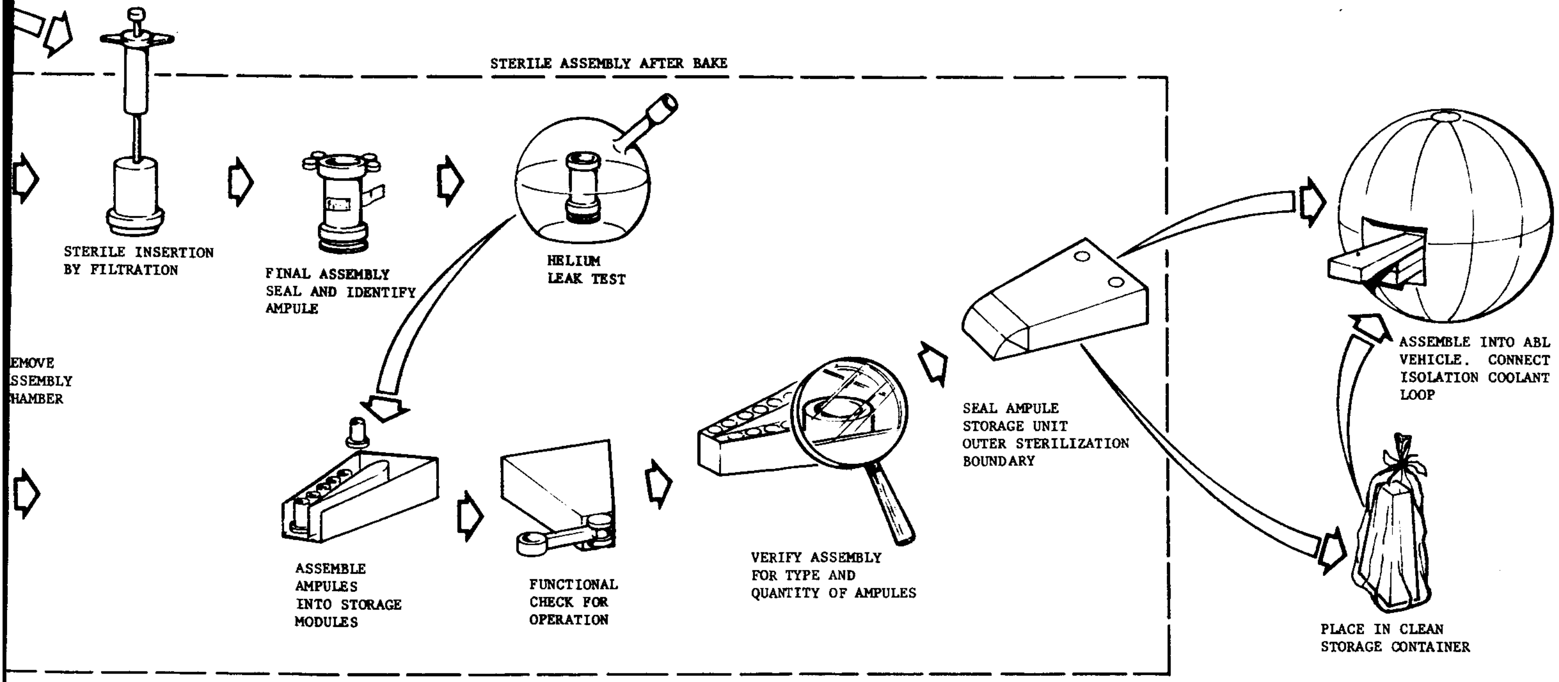
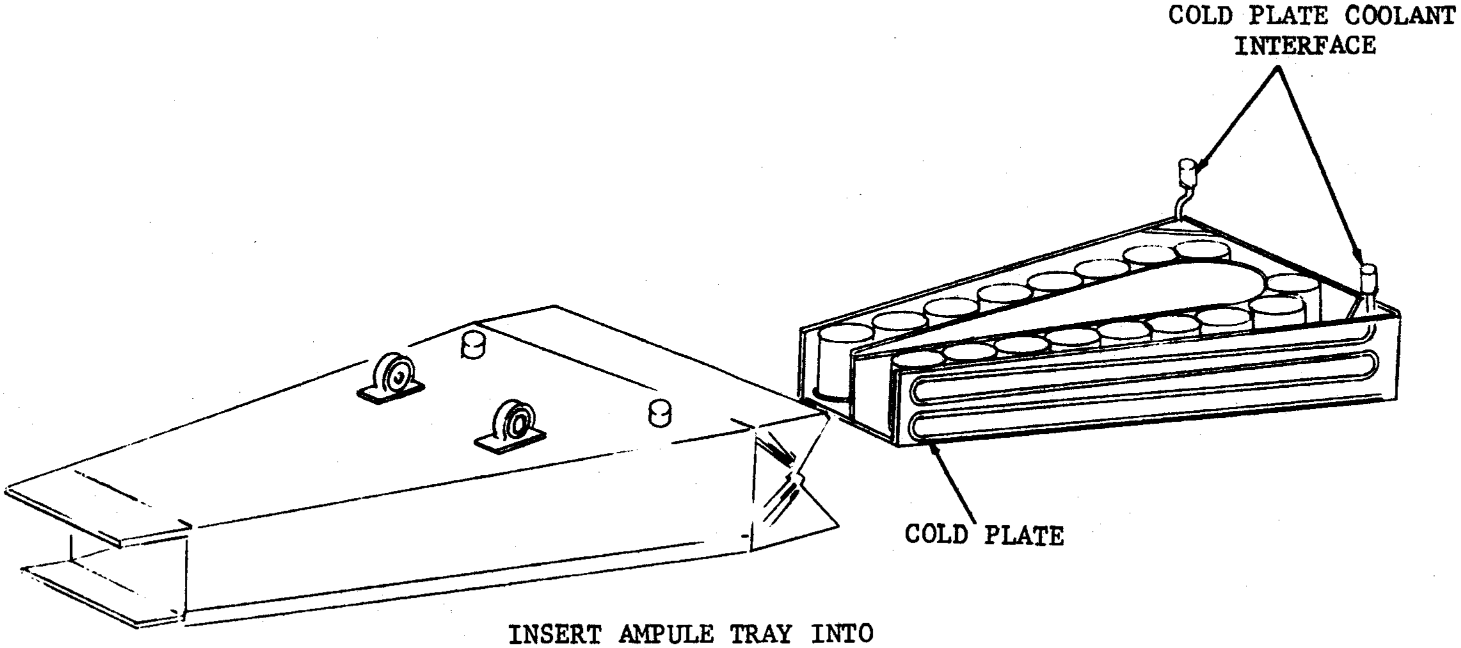
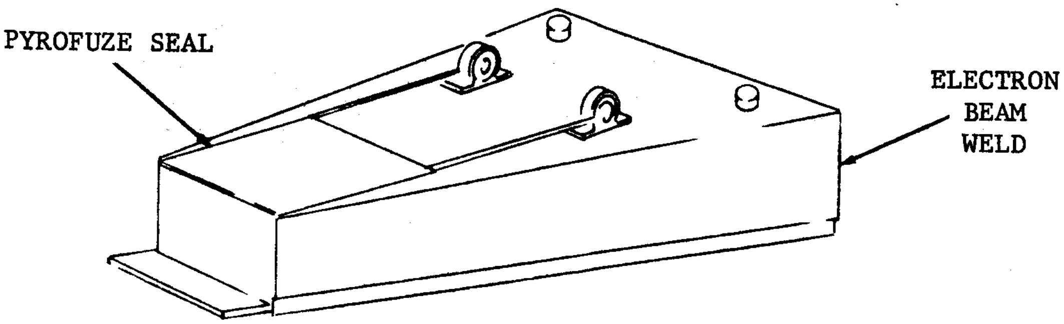


FIGURE 5.6-2. FABRICATION AND ASSEMBLY OF AMPULE STORAGE UNIT FOR THERMAL ISOLATION

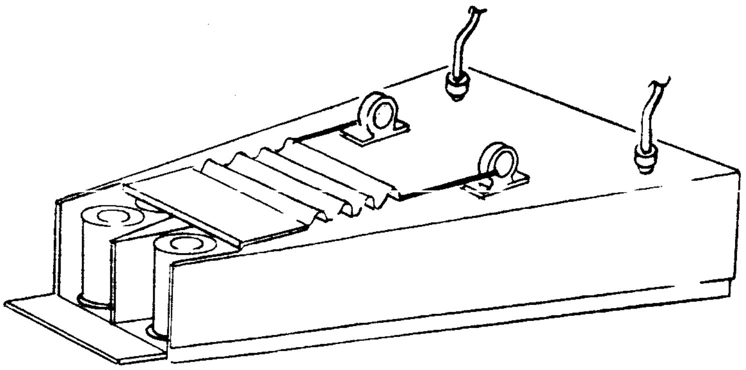
[redacted]



INSERT AMPULE TRAY INTO CONTAINER



SEAL CONTAINER & INSTALL IN SPACECRAFT



AFTER STERLIZATION CYCLING, STOP COOLANT FLOW, OPEN CONTAINER WITH PYROFUZE

R15020U

FIGURE 5.6-3. THERMAL ISOLATION AMPULE STORAGE UNIT

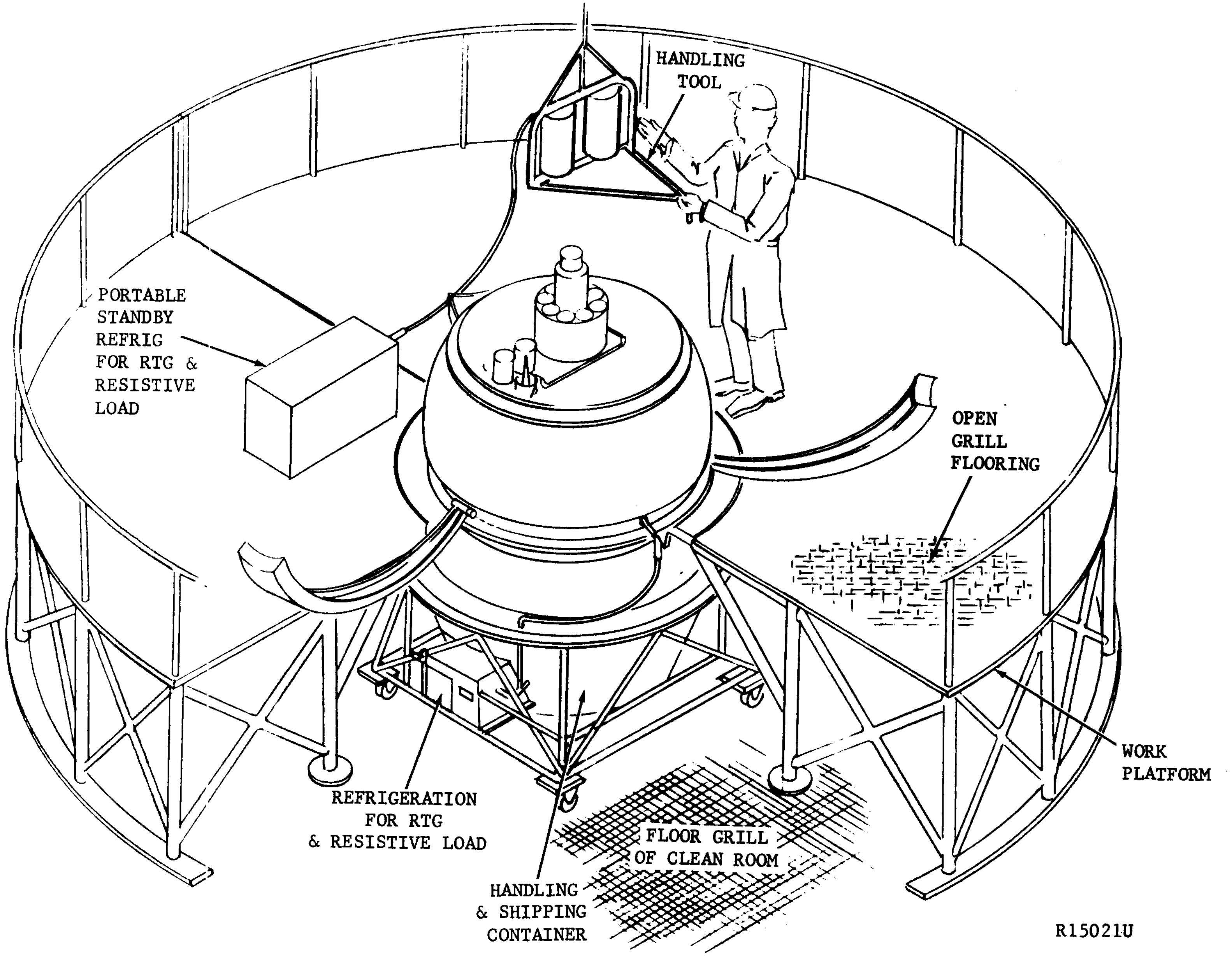


FIGURE 5.6-4. RTG ASSEMBLY

are several features which should be noted. The floor of the work stand must be an open mesh or expanded metal in order to prevent interference with the vertical laminar flow of air which would defeat the operation of the clean room. For this same reason, the handling and shipping container is shown directly below the ABL. The RTG is connected to a portable refrigeration unit and resistive load to maintain its temperature at a safe operating point. Since the cold junction of the RTG is at 500°F, it will be necessary to use a handling tool to guide the power supply into position on the structure. After the unit has been installed, the standby refrigeration unit is disconnected and connections are made to the refrigeration unit mounted on the lower half of the handling and shipping container. During this time; the coolant loop which allows the RTG to be rejected into the stored water supply of the ABL is operative. The heat sink capacity is such as to allow an hour to complete the folding of the legs and securing of the ABL for insertion in the lower half of the handling container. Sufficient length of line from the handling fixture to the ABL for coolant transfer between the refrigeration unit and the RTG power supply is provided to allow freedom of movement when the ABL is removed later. The final installation of the handling and shipping container are shown in Figure 5.6-5. Continuous monitoring of the refrigeration unit operation and internal temperature of the laboratory will be required as long as the unit is in the container.

5.6.2 LAUNCH, BOOST, AND INTERPLANETARY OPERATIONS

The prelaunch preparations are initiated some time before launch with the terminal dry heat sterilization cycle. All the components and tools required to assemble the final entry vehicle and its payload within the sterilization shield are introduced into the sterilization oven as shown in Figure 5.6-6. After sterilization, sterile assembly of the various components into the sterilization shield is accomplished. As each step of the assembly proceeds, functional and circuit continuity checks are performed on such items as power supplies, squibs, and actuators. The internal temperature and pressure of the ABL are continuously monitored with automatic monitoring equipment. There are several points at which the refrigeration loop for the RTG power supply must be interrupted in order to connect each stage of the thermal control system. These are when the entry vehicle aft closure and the sterilization shield aft closure and the sterilization sheild aft closure is installed. Thus, one hour limits are imposed on these operations because of the heat sink capacity of the internal water storage. Sealing of the sterilization shield is accomplished with an automatic seam welder by rotating the assembled payload on the sterilization shield support turntable. The payload can now be transferred to a dolly for transport to boost vehicle. A portable refrigeration unit must again be supplied to cool the RTG power supply.

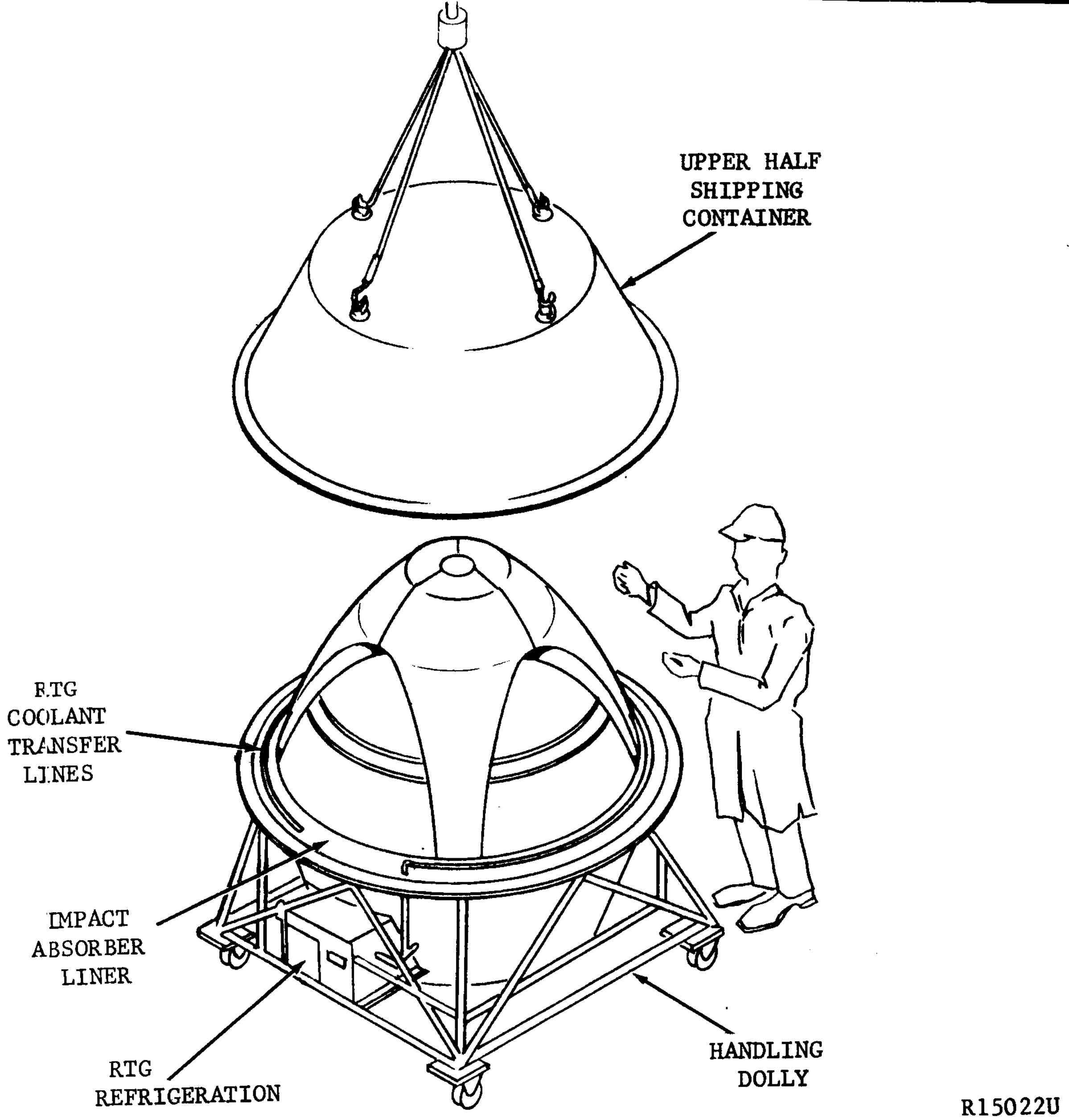


FIGURE 5-6.5. ABL LANDER PAYLOAD SHIPPING AND HANDLING CONTAINER

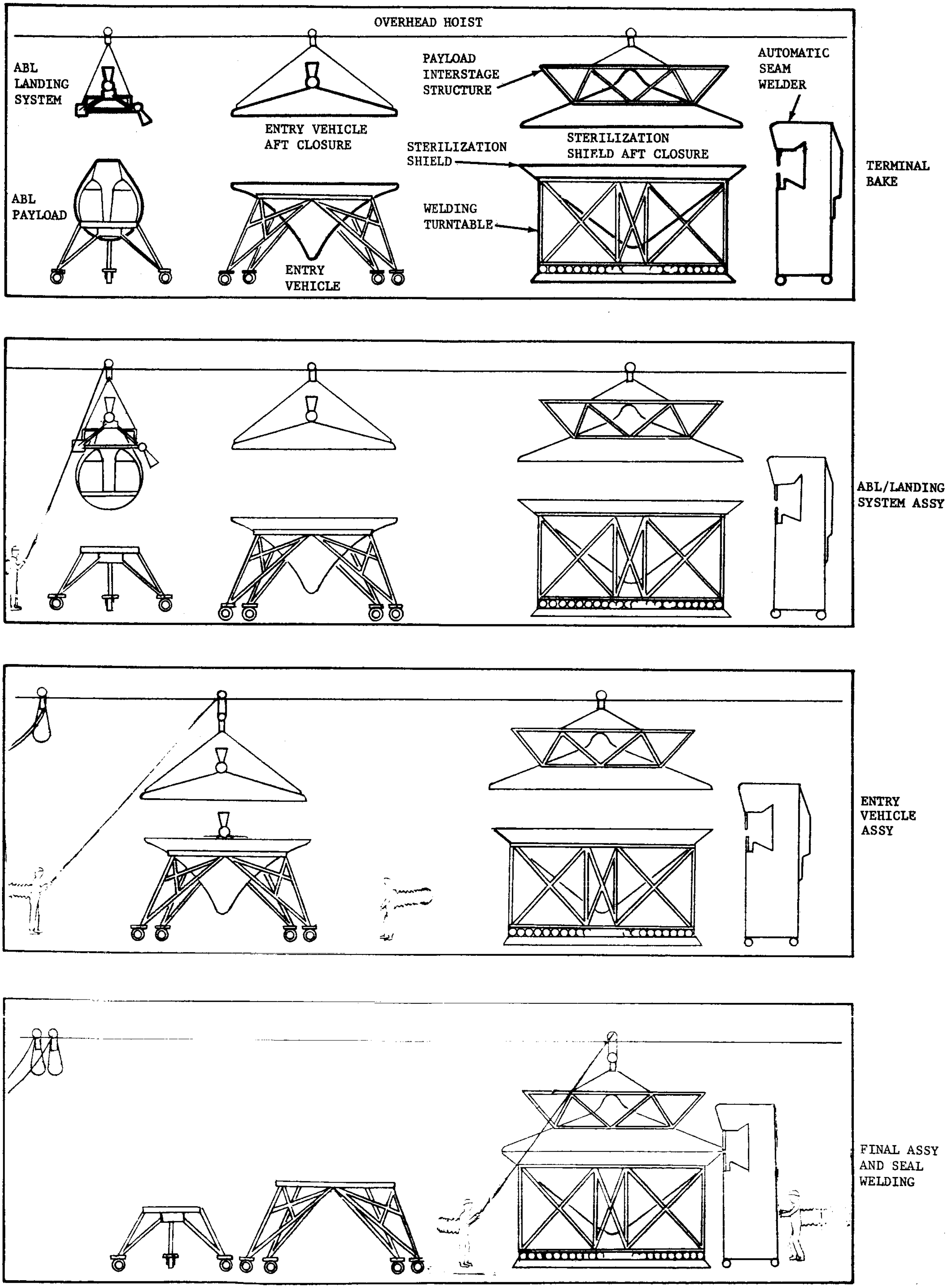


FIGURE 5-6.6. ABL PAYLOAD AND ENTRY VEHICLE FINAL ASSEMBLY SEQUENCE

Figure 5.6-7 shows all the payload components assembled in the gantry payload assembly area which can be sealed off and operated as a clean room. The entry vehicle in its sterilization shield is installed first. Figure 5.6-8 shows the orbiter/bus being installed on top of the entry vehicle. Figure 5.6-9 shows the exit heatshield being brought into position. Before final closure is made the portable refrigeration unit is disconnected and a water boiling unit is connected which will provide the RTG power supply cooling during countdown and launch. Figure 5.6-10 shows the final launch configuration for the ABL system.

After launch and the ABL system has separated from the booster, the thermal control system is transferred from the water boiling system to a closed loop system using a space radiator located in the aft closure of the sterilization shield. During the transit time of the transfer trajectory the ABL is in a standby mode with only the thermal control system active.

After the communications link has been established and an Earth command is received verifying that the communication link is established, the laboratory is free to perform subsequent reorientations until communications is established. Since the entire ABL is free to rotate within the leg support structure, it can be put into a rotational mode which would allow Earth-based receivers to detect a maximum signal. Since the fan beam used allows Earth to receive for three hours out of each day, this backup mode of orientation would require at least one day per attempt. Immediately after receiving the communications verification command, the ABL will deploy its on-site sampler and proceed to execute the experiments as they were phased in the analysis of Paragraph 4.3 or until altered by Earth command. The panoramic visual and infrared scan would be accomplished at the earliest possible time after initiating the full scientific mode and relayed to Earth for evaluation and preliminary selection of promising remote sampling sites for more detailed examination. After two weeks, the core hole drilling is initiated for an hour each day until the desired depth is attained and high resolution scans are performed on which to base the selection of the first remote sampling site. Consideration of other promising sample sites will also be made so that the transport cables might be deployed to maximum advantage for future use. At the end of 30 days, the remote sampler transport cables are deployed and rigged. The instructions for sampler deployment to the first remote site are stored in the ABL control center. Power to operate the remote sampler originates within the ABL and is transmitted to the sampler along with control commands through an auxiliary wire deployed as the sampler is transported along the wire.

The above description covers the major sequence of surface operations for the ABL except for engineering functions such as thermal control, internal atmospheric control, and component failure detection. All of these functions are performed automatically unless commanded otherwise. Dangerous operating conditions and incipient equipment failure are sensed and relayed to Earth. Two levels of failure signals will indicate when conditions are approaching a level where caution should be exercised and when component failure occurs.

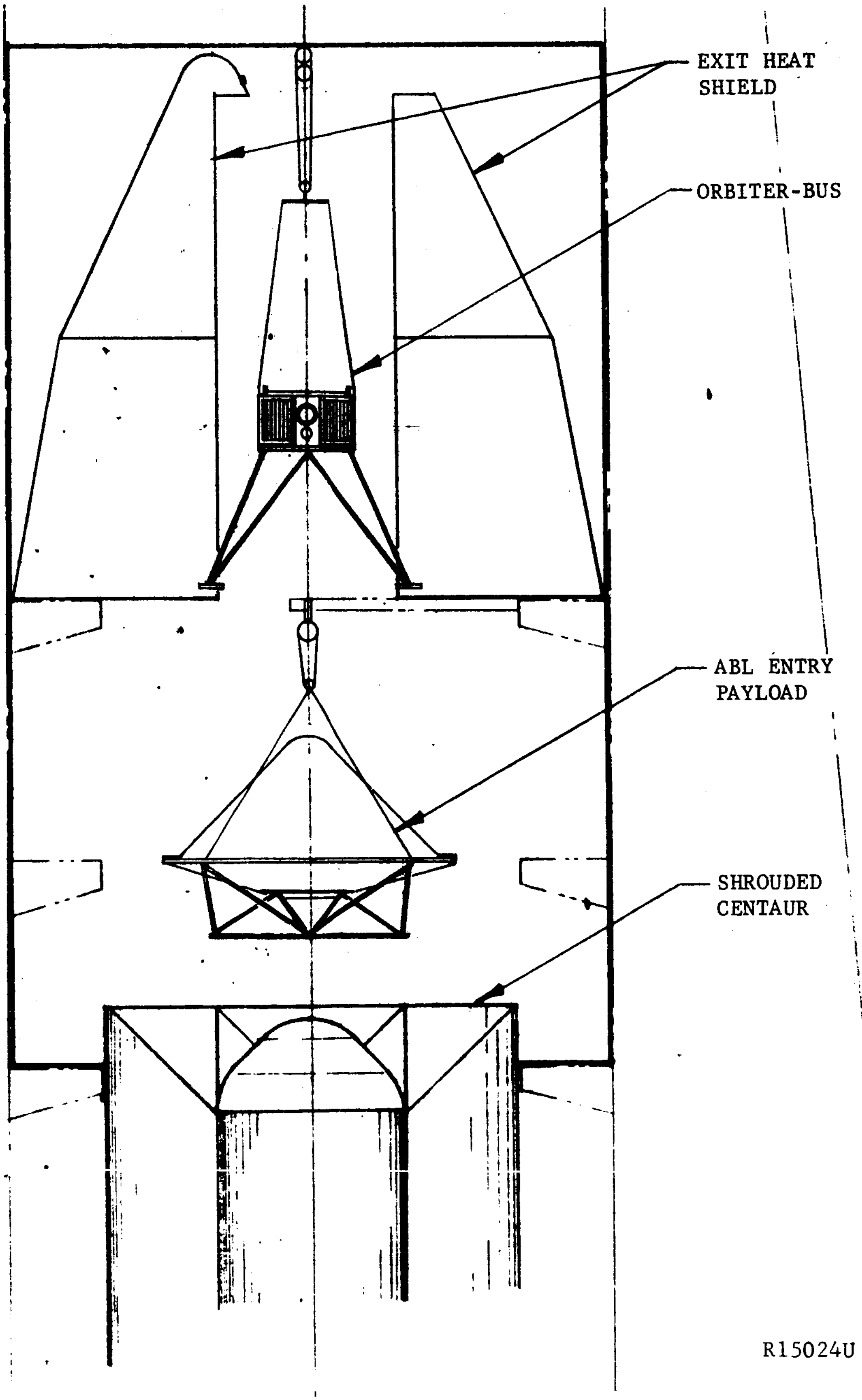


FIGURE 5-6.7. TOTAL PAYLOAD/BOOSTER MATING OPERATION

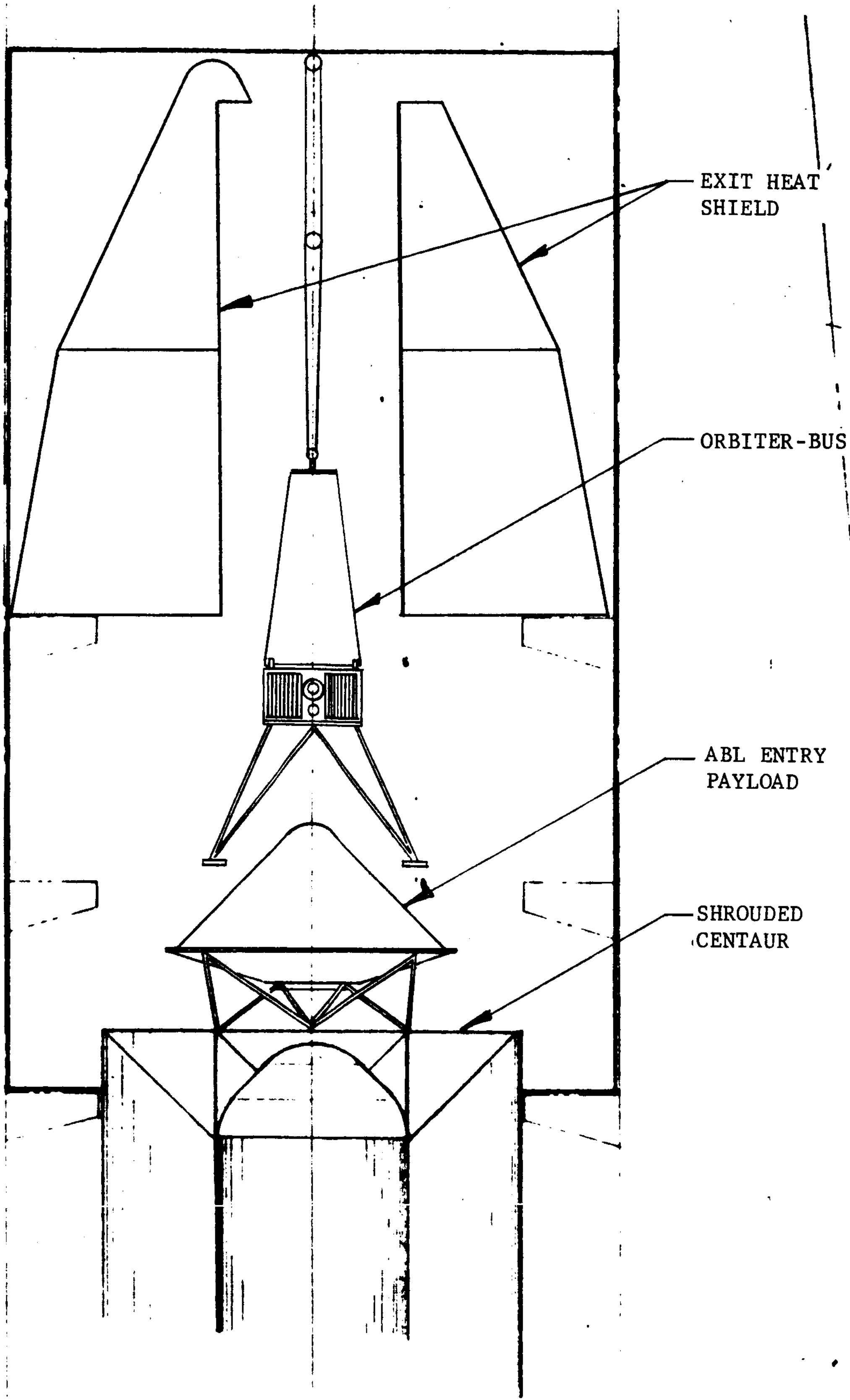


FIGURE 5-6.8. ABL/ENTRY PAYLOAD MATED

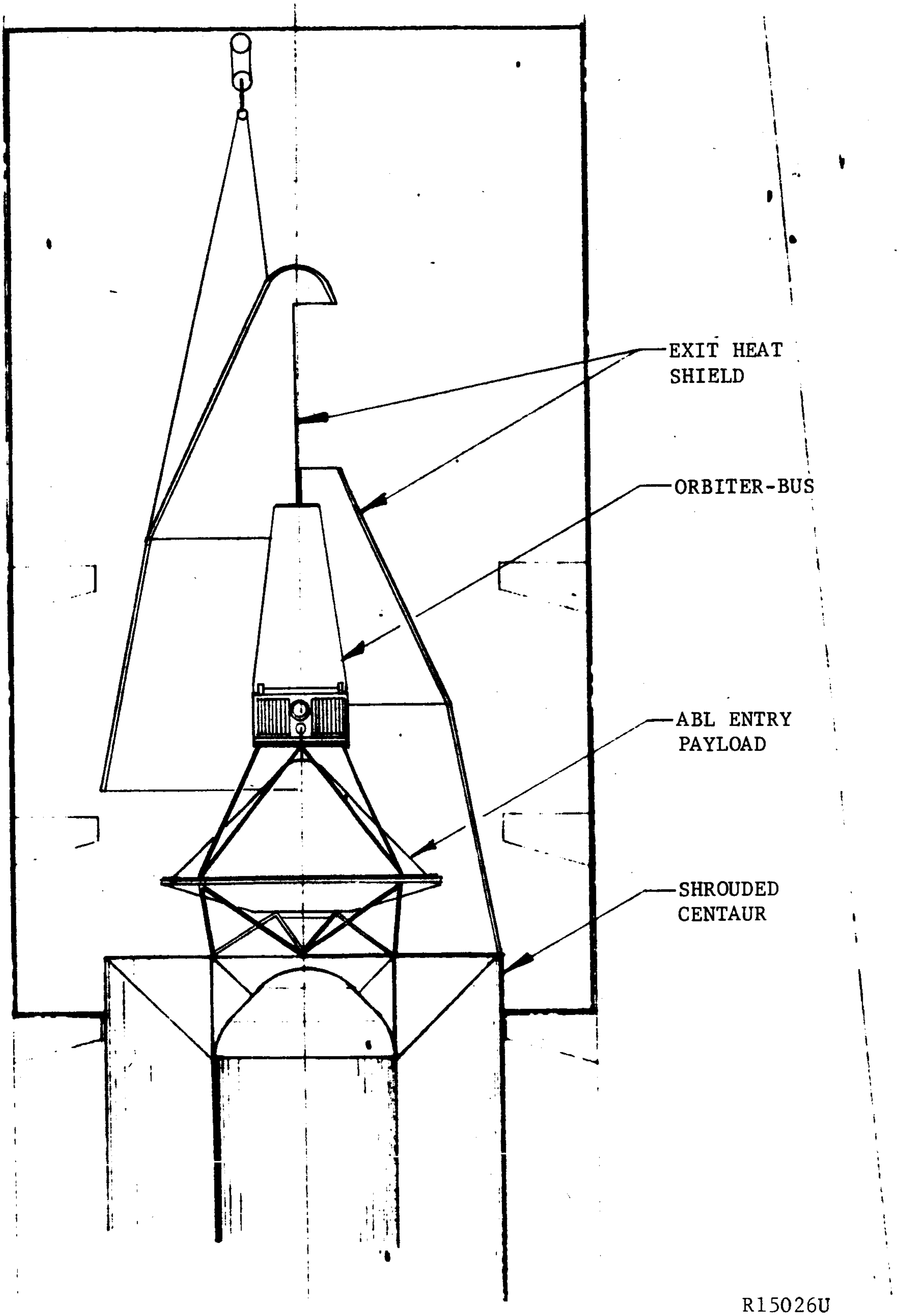


FIGURE 5-6.9. ORBITER BUS MATED AND SHROUD INSTALLATION

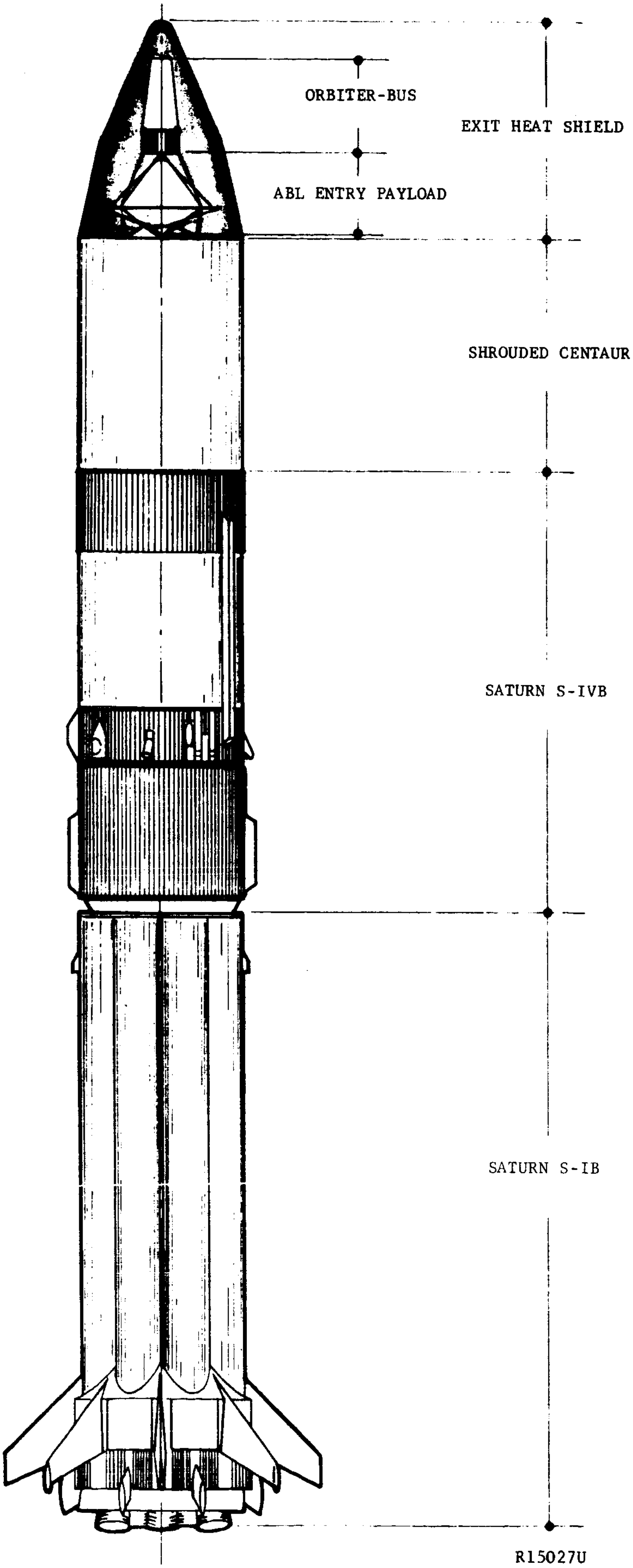


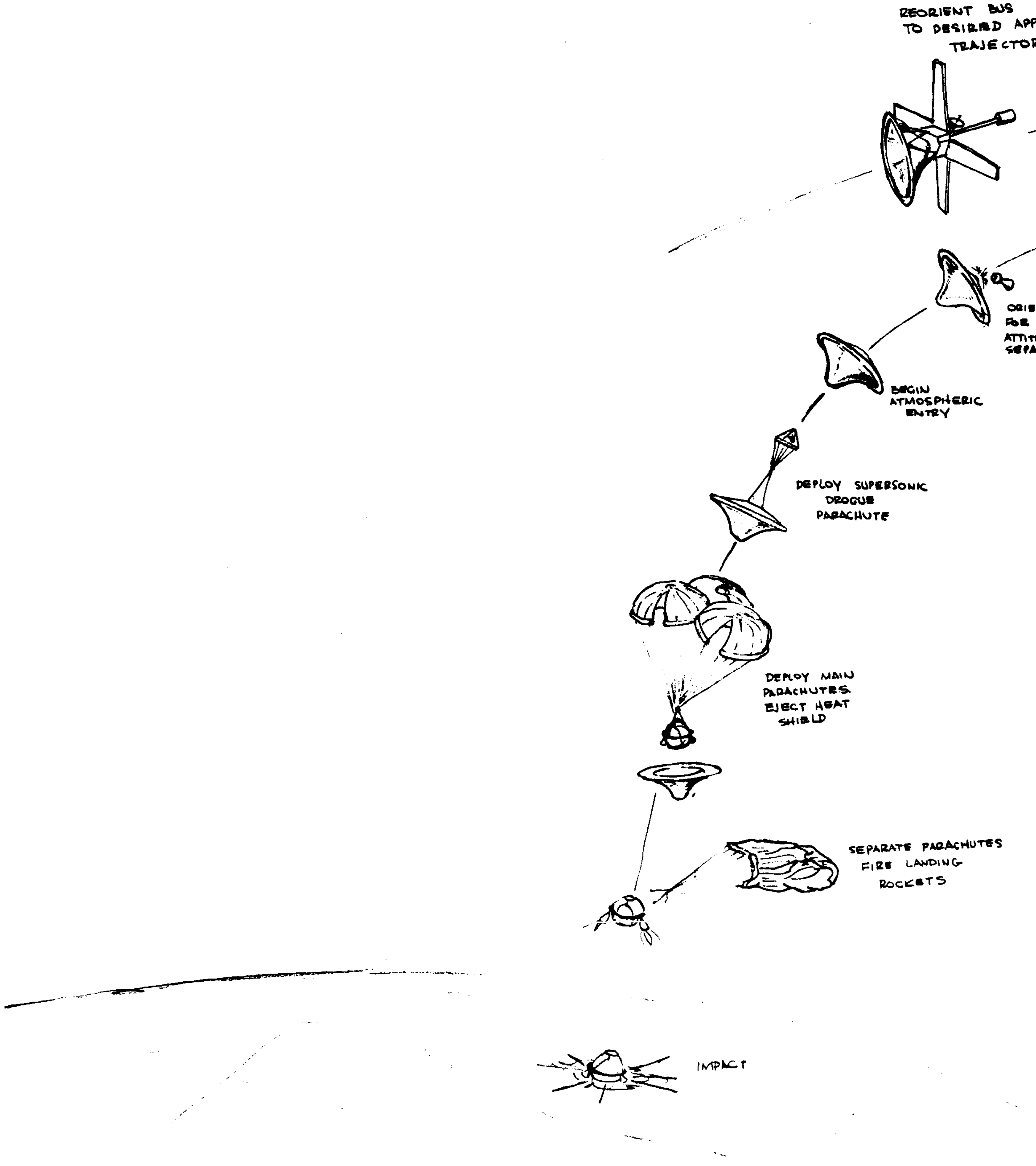
FIGURE 5-6.10. ABL-CLASS VOYAGER PAYLOAD ON SATURN Ib - SHROUDED CENTAUR

5.6.3 LANDER SEPARATION, ENTRY, AND LANDING OPERATIONS

Prior to Mars encounter the sterilization heatshield is opened so that the entry vehicle can be separated. For the mounting configuration shown in Figure 5.6-10, the sterilization shield closure must be ejected. For a piece of structure of this size it is necessary to eject it with enough differential velocity that it will continue in a flyby orbit without drifting near either the entry vehicle or the orbiter/bus. It is assumed, to illustrate this sequence, that the bus is put into orbit about Mars to serve as a relay communications link for the ABL. The orbit will be selected in accordance with requirements to make its lifetime compatible with prevention of planetary contamination. The complete entry sequence is illustrated in Figure 5.6-11 for a soft landing. If an impact limiter is used in a hard landing mode, the terminal retro just prior to touchdown can be eliminated. Separation of the entry vehicle requires an orientation maneuver by the orbiter/bus. After separation the entry vehicle is oriented for retro boost required to place it in the entry trajectory. It is then reoriented for entry with attitude control being used up to parachute deployment. At some point between deployment of the supersonic drogue and the main parachute deployment, the entry heatshield is discarded to reduce the weight decelerated by the main parachutes. This also simplifies the erection of the laboratory after landing. If a terminal retro is used, a velocity vector sensing system must be employed to eliminate or minimize wind drift at touchdown.

5.6.4 LABORATORY ERECTION AND SURFACE OPERATIONS

The details of the laboratory erection sequence are discussed in Paragraph 5.5.1. The sample deployment system was discussed in Paragraph 5.5.2. However, it is appropriate to summarize the surface operations of the ABL to give a more comprehensive presentation of the surface operations for ABL. Figure 5.6-12A and 5.6-12B shows the major operational events for the first 30 days. After landing it is assumed that the ABL can come to rest in any attitude and erect itself. For this reason the legs when folded terminate to form a conical shape at the top of the ABL. This will bias the terminal position away from being exactly upside down. As the legs deploy they will rotate the laboratory to an erect position. A sensor to detect the local vertical then drives a servo mechanism to level the laboratory by adjusting the legs with respect to each other. After erection and leveling, the mast is deployed carrying the environmental and macroimaging systems with it. The macroimaging system then goes into a sun track mode for the first day of operation to determine the final orientation required for the high gain antenna. At the end of the first day the laboratory is rotated in its leg structure to achieve final orientation and establish communications through the high gain antenna.


REORIENT BUS
TO DESIRED APP
TRAJECTOR
ORIE
FOR
ATTIT
SEPA
BEGIN
ATMOSPHERIC
ENTRY
DEPLOY SUPERSONIC
DROGUE
PARACHUTE
DEPLOY MAIN
PARACHUTES.
EJECT HEAT
SHIELD
SEPARATE PARACHUTES
FIRE LANDING
ROCKETS
IMPACT

5-137-1

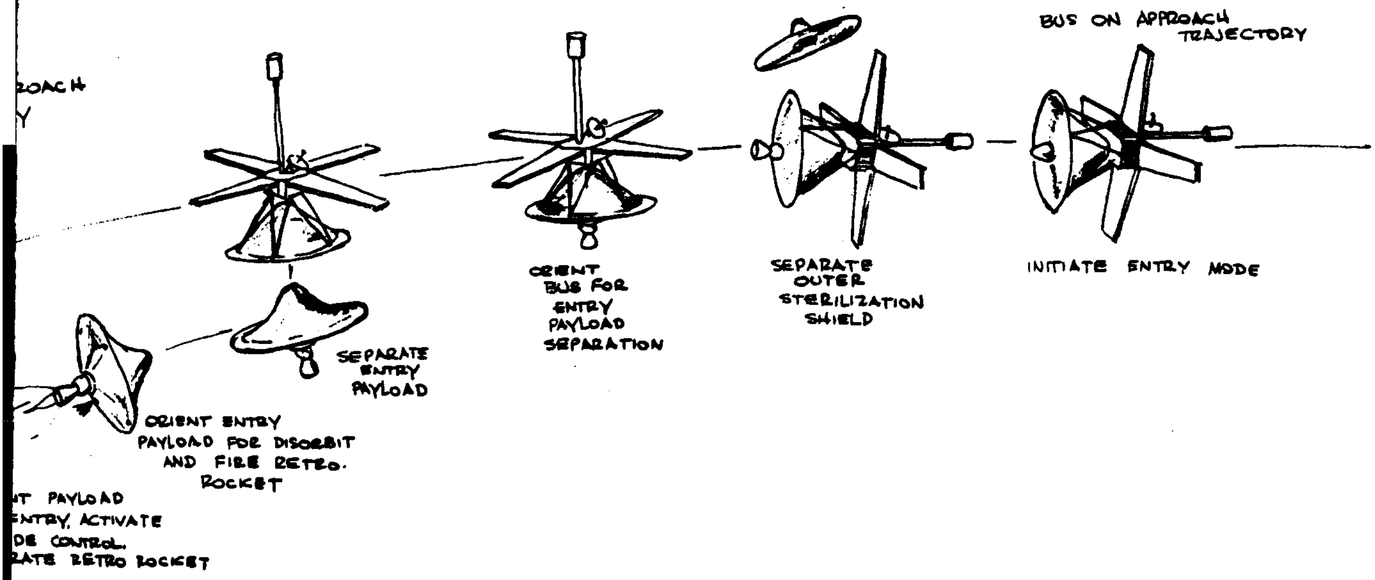


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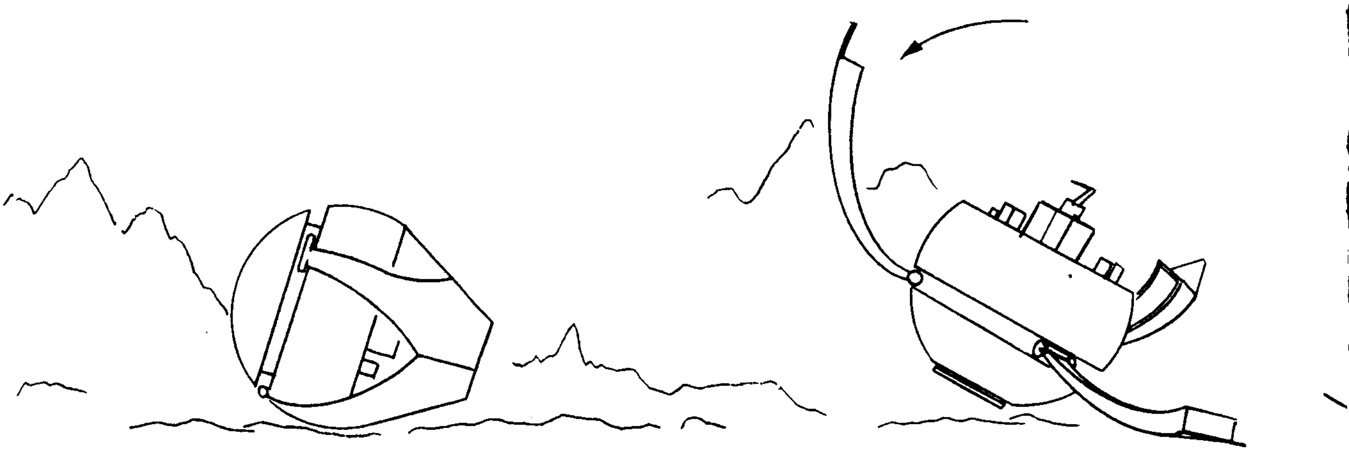
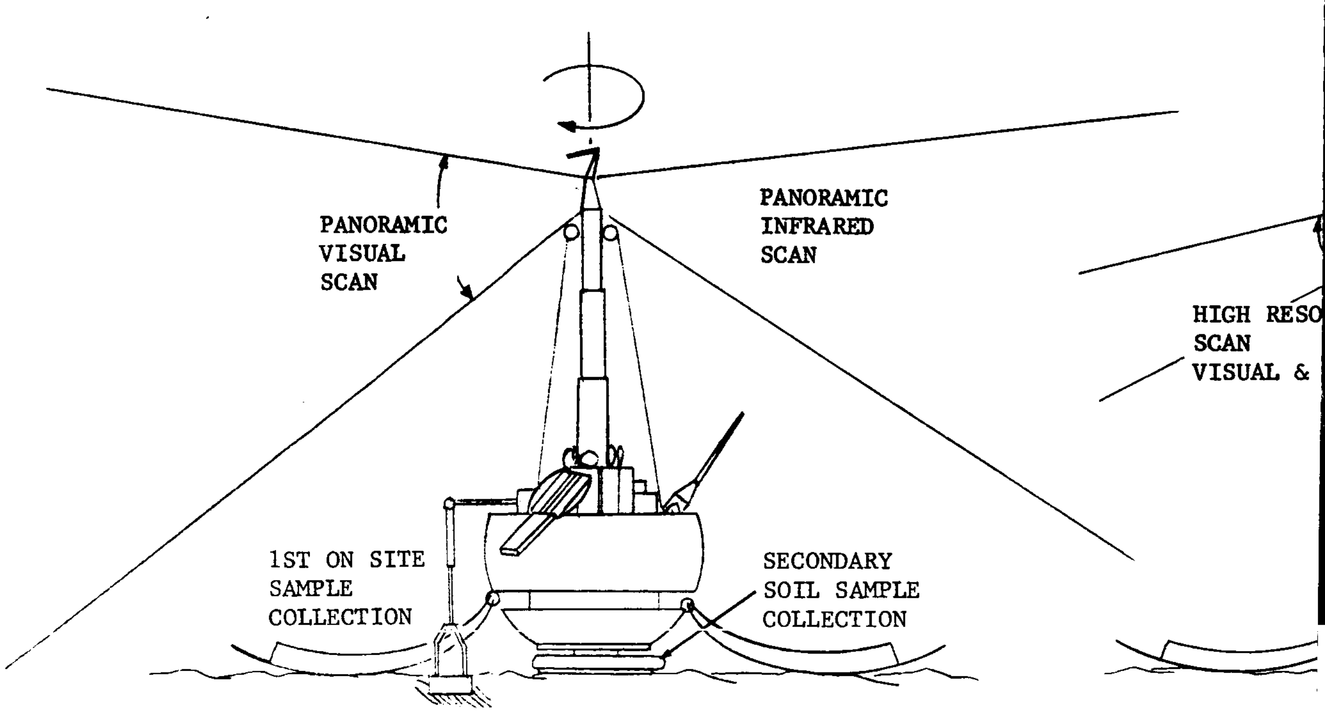
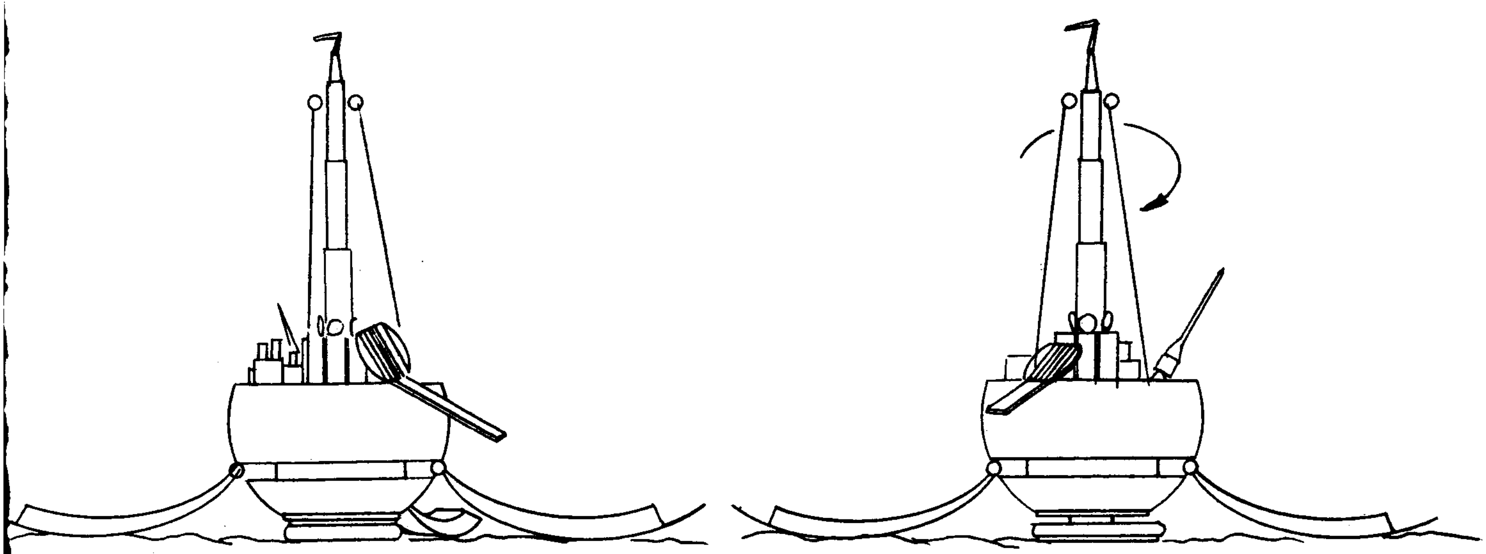
FIGURE 5.6-11. LANDING SEQUENCE



AFTER IMPACT

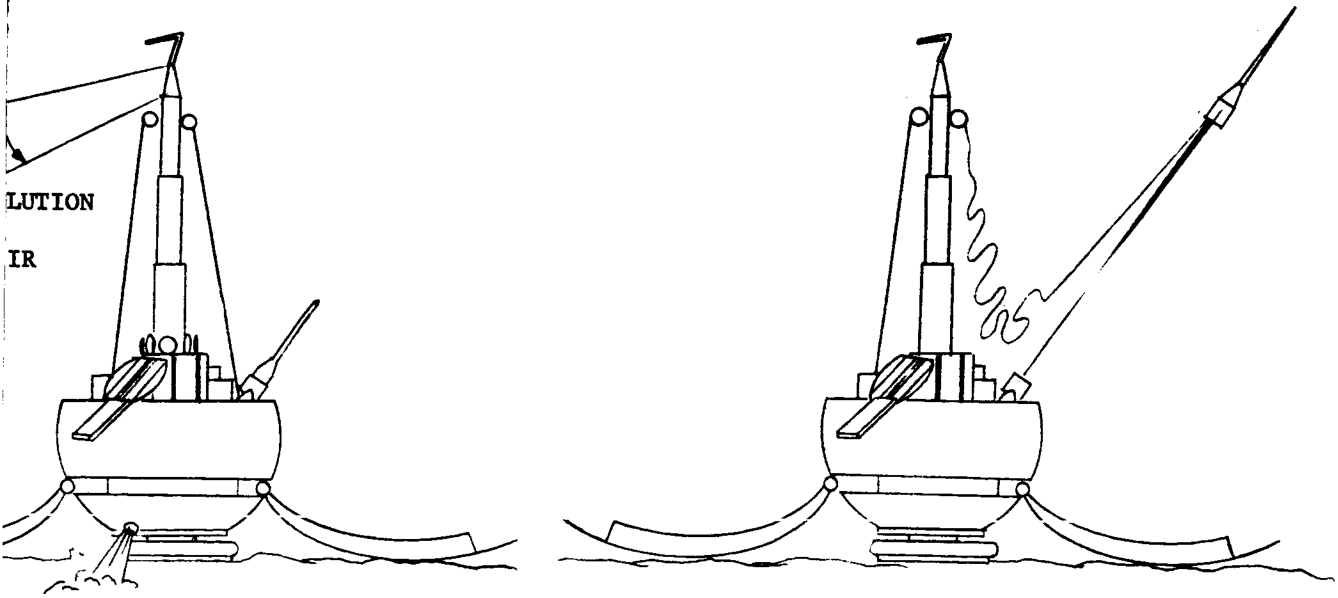
ERECTION - LEGS DEPLOYED





LEVELED AND MAST
EXTENDED IN SUN TRACK
MODE
START ENVIRONMENTAL
MEASUREMENTS

LABORATORY ROTATED
TO PROVIDE FINAL
HIGH GAIN ANTENNA ORIENTATION
END OF FIRST DAY

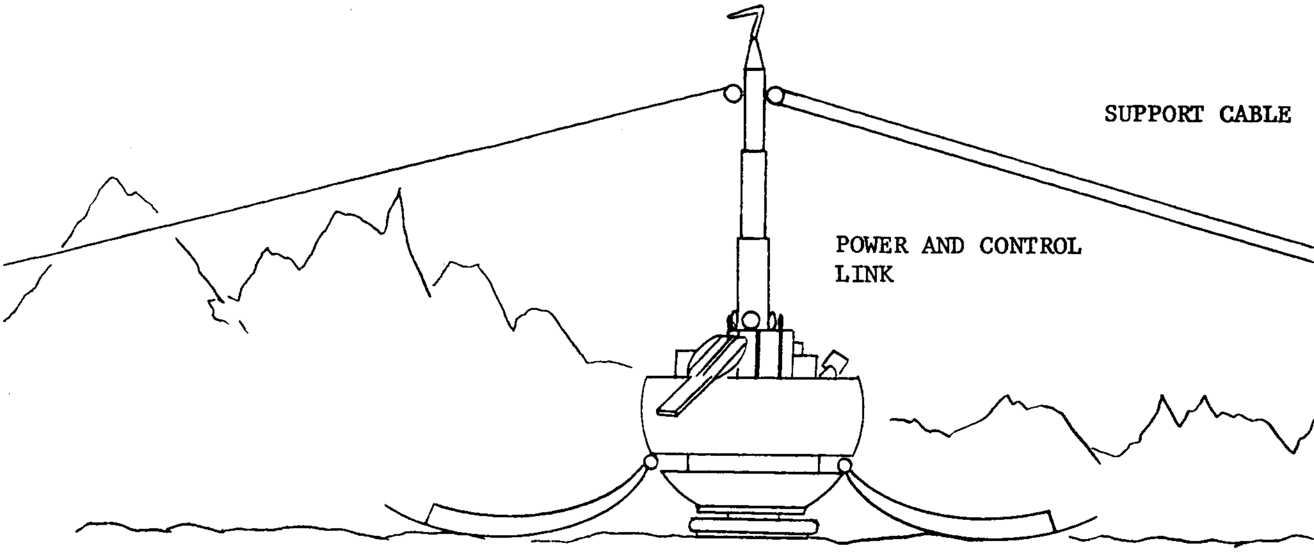


13TH TO 21ST DAY
DRILL CORE HOLE
CONTINUE EXPERIMENTAL
PROCESSING

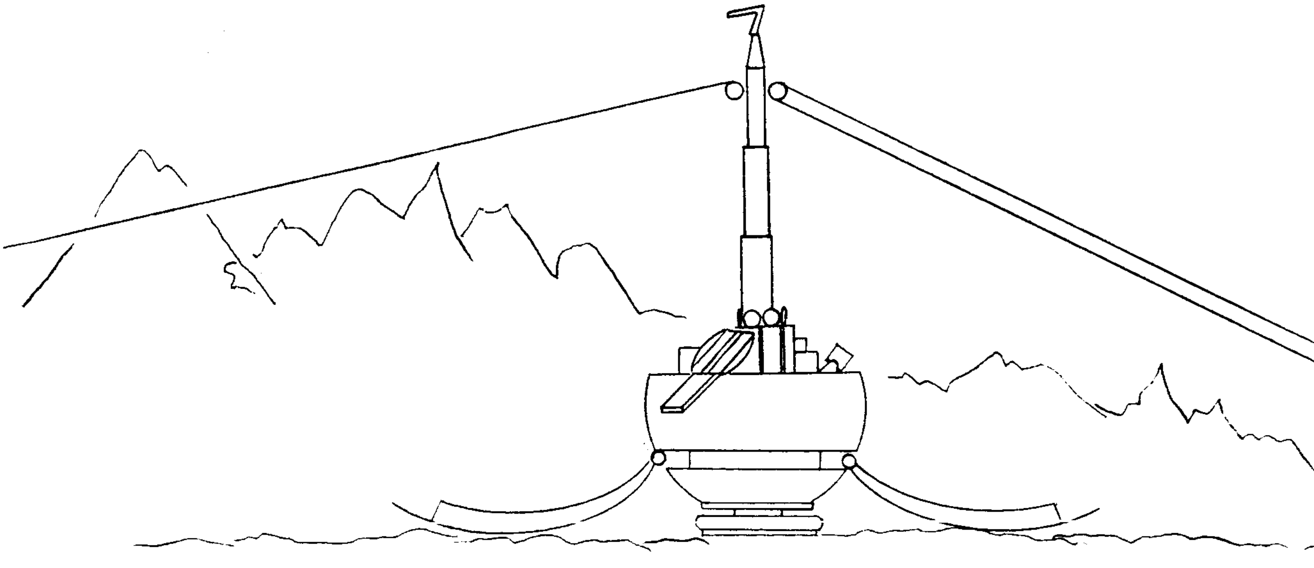
30TH DAY
DEPLOY REMOTE
SAMPLER LINES

R15028U

FIGURE 5.6-12A. ABL LANDED PAYLOAD ERECTION AND OPERATIONAL SEQUENCE

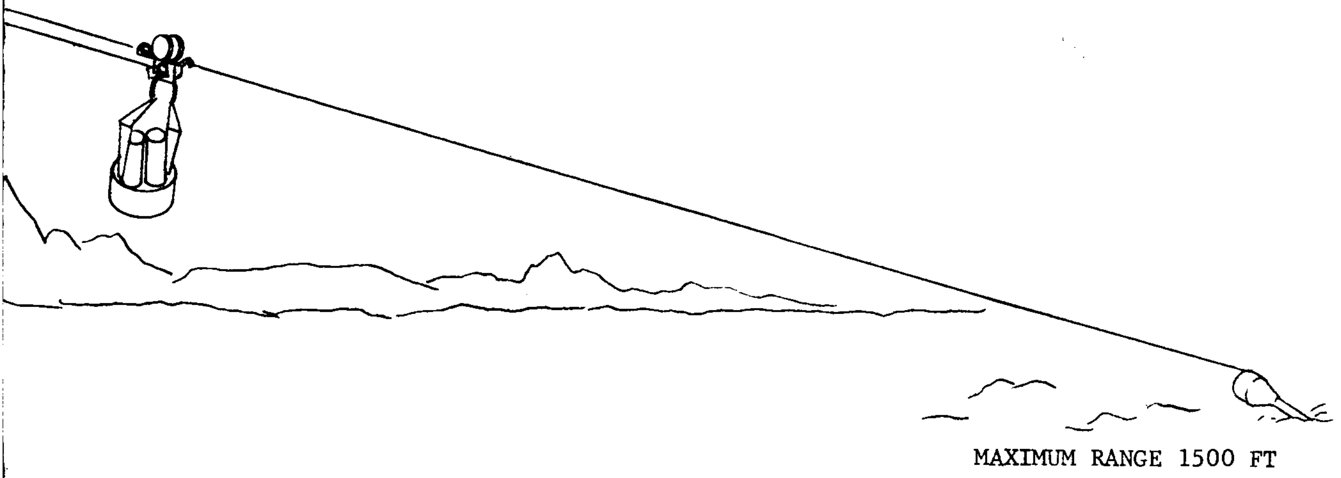


REMOTE SAMPLER DEPLOYED TO
SELECTED REMOTE SITE AT 50 DAY INTERVALS
POWER AND CONTROL SUPPLIED FROM LABORATORY



TO ATTAIN SURFACE RELAX TENSION
IN WIRES UNTIL CONTACT IS SENSED TO
RETURN SAMPLER RETENSION
SUPPORT CABLES

TO RETURN SAMPLER RE-TENSION
SUPPORT CABLES



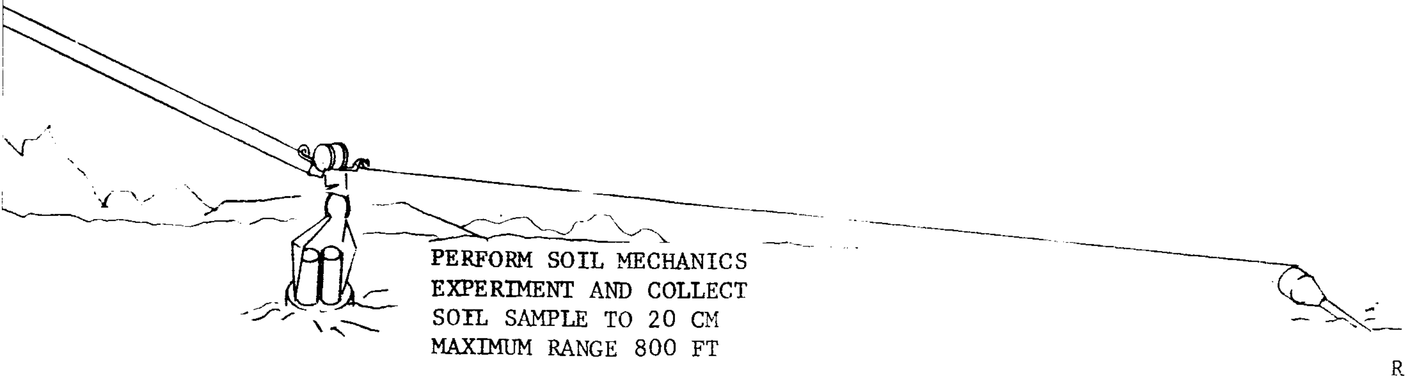


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FIGURE 5.6-12B. TROLLEY SAMPLER DEPLOYMENT SEQUENCE

5.7 STERILIZATION STUDIES

5.7.1 GENERAL

a. Introduction. The sterility of the ABL will depend on the effective application of contamination control procedures during the course of manufacture and testing and on the effectiveness of a terminal sterilization heat soak in dry nitrogen for 24 hours at $135^\circ {}^{+2}_{-0}{}^\circ C$. ABL sterility will also depend upon the effectiveness of the packaging and the procedures developed to prevent recontamination after the terminal sterilization process has been applied. The sterilization studies performed in connection with the ABL study have not been directly concerned with the biological aspects of sterilization but only with the effects which sterilization and decontamination efforts may have on the performance of materials, components, and subsystems, i.e., the engineering aspects of sterilization.

A basic objective in the ABL design effort has been the elimination, wherever possible, of components which are known or suspected of being incompatible with the recommended thermal sterilization conditions.(1-5). This objective has been discussed in Paragraph 5.3.3 and will be described further in subsequent paragraphs. While every effort has been made to select components which are compatible with sterilization requirements, the state of sterilization technology is such that all necessary components cannot be positively categorized. In anticipation of the discovery that a few yet unidentified useful components may require less severe sterilization treatments, it has been assumed that some small portion of the components sterilized by acceptable alternate procedures(1) will be protected during terminal sterilization by thermal isolation.

b. Objectives. The ABL sterilization studies have been directed toward three separate objectives:

(1) An analysis of the essentially ABL-peculiar subsystems developed or identified in the preliminary design, identification of subsystems common to all planetary-impacting spacecraft (sterilizability of some of these subsystems has been given a much a much more thorough evaluation in other NASA and JPL studies, Paragraph 5.7.2, than would have been possible in the present study).

(2) From the design point case, the development of recommendations for a sterilization program in subsequent design and testing work.

(3) Several ABL-peculiar components of important life detection experiments have been explored for critical sterilization compatibility problems.

c. Technical Discussion

(1) Selection of Parts and Materials for Preliminary Design.

(a) Use of Qualified Parts and Tested Parts. NASA has supported a major effort to establish catalogs of components qualified for various types of space exploration missions and to measure the extent of degradation and the modes of failure of essential spacecraft components, materials, and subsystems.(6,7) Table 5.7-I presents a partial listing of these programs. Only a few categories have definitive specifications of parts, components, or subsystems, and these have been well defined and considerable data on them accumulated. Where these data have been available, they have been used in selecting designs compatible with use in the ABL. The philosophy used in the design has emphasized use of the most satisfactory combination of design approach and reliable parts and to match and assemble them with all possible care. The systems and subsystems have been chosen to be as invulnerable as possible to internal failure either in the components themselves or in the interfaces between them.

The development of a catalog of parts and subsystems qualified for use in ABL has not yet been accomplished. Of course, it is too early in the development cycle for detailed specifications of performance to have been identified. To the extent that the general performance characteristics have been established in this study, categories of suitable materials and components are described in the following paragraphs.

The environments involved in both contamination control and the terminal sterilization impose additional stresses, over and above those of the mission profile, on the materials, components, interfaces and subsystems. It is expected that many of the piece parts, materials, and components required in the construction of the ABL will have specifications sufficiently similar to those used in the development of parts lists qualified by NASA centers for planetary-impacting spacecraft use that components from these lists will be satisfactory for use in the ABL. It is clear, however, that an enormous amount of qualification testing remains to be done.

Table 5.7-II lists the major systems of the ABL and Table 5.7-III principal subsystems. Considering expected advances in the state of the art by the time these subsystems are required in construction, many of the sterilization compatibility class assignments will change. It is not particularly useful at this point to identify the various instruments, processing equipment, or subsystems as being compatible with sterilization, for in fact, insufficient evidence is at hand to support any assertion made in this respect. The classification exercise described in Paragraph 5.7.2 is for the purpose of identifying potential sterilization critical items.

TABLE 5.7-I

COMPONENTS, MATERIALS, AND DEVICES NOW UNDER ADVANCED DEVELOPMENT FOR USE IN STERILIZABLE SPACECRAFT

Radio-Transparent Shroud
Thermoelectric Cooling System
Potting Compounds for Planetary Spacecraft
Structures
Actuator
High Temperature Photocathode Image Dissector
Inertial Sensors
Gas Chromatograph
Miniature Electronic Optical Image Detector
Reed Capacitor
Sensors
Capsule Scientific Instrument Buffer
Cabling and Packaging Materials
Battery
Parachute
Solid Propulsion Units
Liquid Propulsion Units
Electrical Connectors
Thermal Contact Surface
Pyrotechnics
Electronic Components
Polymers
Electronic Modules
Organic Scintillation Crystals
Inorganic Scintillation Crystals
Optical Coupling Materials
High Impact Quartz Crystal
Solar Cells
Packaging
Tape Recorder
Magnetic Core Buffer
Photomultipliers
Solid-state Radiation Detectors
Geiger Mueller Tubes
Plastics and Elastomeric Materials
Slow-scan Vidicon

TABLE 5.7-II

MAJOR SYSTEMS INCLUDED IN THE ABL

System	Function
Structure	Provides for laboratory erection and orientation. Provides structural support and orientation for other systems. Provide mechanisms required to maintain overall laboratory environments.
Biological Barrier	Provides means for maintaining sterility.
Landing	Provides control over the entry* and landing of the ABL on the planet's surface.
Sample Collection and Grading	Provides for experiment deployment. Provides for sample collection, pulverization, and grading.
Chemical and Growth Processing	Provides processing equipment. Provides internal transport mechanisms for solids, liquids, and gases. Provides waste control and storage.
Instruments	Provides data acquisition sensors including specific environmental maintenance and sample control sensors.
Command and Control	Provides communications, both internal and external. Provides for experiment and engineering function programming. Provides data processing equipment.
Power	Provides primary power. Provides secondary power. Provides power distribution and regulation.

* In this category only does the function include the entry vehicle as well as the ABL landed payload. This was done to assure that no critical sterilization interfaces were overlooked. The entry vehicle sterilization problem in itself was not a principal concern of this study.

TABLE 5.7-III

PRINCIPAL SUBSYSTEMS OF THE ABL

Structure

Subsystem

- Thermal control system
  - Heat exchangers, heat transfer fluid, and distribution pumps and piping system.
  - RTG radiation fin and thermal isolation system.
  - Sterilization thermal isolation system.
  - Heat sinks and reservoirs.
  - Temperature regulator system.

- Telescoping Mast System

- Planetary Atmosphere Processing Train

- Legs and Orientation System

- Shell, bulkheads, and trusses

- Various mechanical systems
  - gear trains and housings
  - clutches and housings
  - shaft drive mechanisms
  - pulleys, cables, and winches
  - indexing, latching, and locking mechanisms.

Biological Barrier

Subsystem

- Packaging
- Shroud and Seals
- Explosive Bolts and Inflight Disconnect System

TABLE 5.7-III (Continued)

Landing

Subsystem
Entry Body
Aft Cover
Retro Motors
Fuel reservoir
Squib valves
Impact Limiter System
Limit
Separation System
Attitude Control System
Inflight Disconnect System
Explosive Bolts and Squib Valves
Retardation System
Cut-off fitting
Reefing line cutters
Parachute, lines, and swivel
Drogue mortar
Power supply and regulators

Sample Collection and Grading

Subsystem	Experiment
Soil Pulverizer	12,15,16,18-33
Pneumatic Soil Grader	12,15,19-33
Soil Probe Nos. 1, 2	8,14
Core Drill	9,10
Atmospheric Dust Collector	3, 33
Soil Sampler and Deployment Mechanism	11-16, 18-33
Aerosol Dust Sampler, mode 1	
Aerosol Dust Sampler, mode 2	
Surface Soil Sampler, mode 1	
Surface Soil Sampler, mode 2	
Surface Soil Sampler, mode 3	
Encapsulator	
Soil Sample Storage	

TABLE 5.7-III (Continued)

Chemical and Growth Processing

Subsystem	Experiment
Separator Scale	12,13,15,16,18-33
Chemical Processor	15,19-28, 29-32, 16,33
Soil Gas Exchange Chamber	17, 29-32
Culture Evaluation Processor	33
Dialyzer	24, 25, 26, 27
Reagent Supply Storage	15, 17, 19-33
Waste Storage	13, 15, 16, 18-33
Atmospheric Circulation Pump	17
Vacuum Ion Pump	22, 23, 33
Vacuum Fore Pump	7, 14, 17, 22, 23, 33

Instruments

Instrument or Detector	Experiment
Atmospheric Parameters Sensors Resistance wire thermoter Pitot tube head Aneroid barometer Hot wire anemometer	1
Gold Film Aluminum Oxide Water Vapor Detector	2
Microphone with Acoustic Resonator	3
Microphone with Acoustic Reflectors	4
B and γ-ray Pulse Height Counter	6
Core Hole Traversing Sonde Resonant tank circuit (Q measurement) Electrical potential bridge circuit Resistance wire thermometer Al_2O_3/gold film H_2O vapor detector Modified Michelson interferometer γ-ray soil density scattering analyzer	9, 10, 11
Soil Mechanics Apparatus	-
Optical Motion Detector	34
Optical Density Comparator	33

TABLE 5.7-III (continued)

Instruments

Instrument or Detector	Experiment
Macroimaging System (TV)	35
Infrared Radiometer	35
Solar Radiation Spectrum Analyzer	5
pH meter	15, 33
$Ba(OH)_2$ Conductivity Cell (CO_2 Detector)	30
β-ionization Counter	17, 29, 31, 32, 33
Gas Chromatograph No. 1 (Atmospheric and Soil gas analysis)	7, 14, 17, 33
Gas Chromotograph No. 2 (Amino acid)	18, 19
Gas Chromatograph No. 3 (Nonsaponifiable Lipids)	22, 33
Gas Chromatograph No. 4 (Saponifiable Lipids)	23, 33
Gas Chromatograph No. 5 (Macromolecules)	27
α-ray scattering Analyzer	13, 15
Infrared Spectrophotometer	28
Spectral Analyzer U.V. Spectrophotometer Visible Spectrophotometer Fluorimeter Polarimeter	16,20,21,24,25,26,33
Mass Spectrometer	7,14,17 ,22,23,27,33
Argon Ionization Detector	16

TABLE 5.7-III (Continued)

Command and Control

Subsystem

- Electrical harness and connectors
- Data Automation System
- Pneumatic Controls
- Solenoid Valves
- Servo Motors
- Electric Drive Motors
- Radiometer
- RF Shielding

- Diagnostic Instrumentation Subsystem
  - Temperature sensors
  - Accelerometer
  - Pressure sensor transducers
  - Sun sensor
  - Ablation sensor and converter
  - Vertical sensor

- Internal Communications System
  - Electrical harness
  - Switches
  - Relays
  - Control electronics module
  - Recorders and Memory devices

- External communications systems
  - Transmitters
  - Amplifiers
  - Receivers
  - Antenna
  - Antenna deployment system
  - Transponders

- Miscellaneous Mechanical Systems
  - Gear train and housings
  - Clutches and housings
  - Shaft drive mechanisms
  - Pulleys, cables, and winches
  - Indexing, latching, and locking mechanisms

- Miscellaneous electrical power control devices such as switches, relays

TABLE 5.7-III (Continued)

Power

Subsystem
Radioisotope Thermoelectric Generator (RTG)
Electrochemical Batteries
Insulated Power Distribution Harness
Pyrotechnic Systems
Voltage Regulation System

For purposes of discussing the work required to prepare lists of qualified parts for use in design and manufacturing, the qualification concept is divided into several classes(1)of part types. In discussing some of the design problems which will be encountered in the course of development of the ABL, the following definitions of the several classes of parts will be used.

Class I: A simple or complex part which is compatible with all sequences of the environments anticipated from the time of receipt from a vendor to the completion of the mission several years later. In addition, it is compatible with the NASA thermal sterilization compatibility test conditions(1,5). Among the anticipated environments for certain parts are those involved in resterilization on the planet. They may be salvaged from a lander which has been contaminated subsequent to the 24-hour terminal sterilization(1) soak at 135°C.

Class IA: A simple or complex part which is compatible with all of the environments involved in the qualification of Class I parts except for the ethylene-oxide decontamination compatibility environment at 40°C.(22)

Class IB: A Class IA part which is not compatible with either of the ethylene-oxide decontamination compatibility conditions.

Class II: A simple or complex part which is compatible with all of the sequences of environments involved in the qualification of Class I parts, except for the thermal sterilization compatibility test conditions involving three separate and distinct 36-hour soaks at 145°C. A Class II part is compatible with the 24-hour terminal sterilization soak at 135°C, any necessary decontamination treatments involving either liquid or gaseous sterilant or exposure to either higher or lower temperatures(4,23), and any resterilization procedures required in the accomplishment of the mission or in salvaging(1) components from an accidentally contaminated lander.

Class IIA: A Class II part which is not compatible with the ethylene-oxide decontamination compatibility conditions at 40°C(9).

Class IIB: A Class II part which is not compatible with either of the ethylene-oxide decontamination compatibility conditions.

Class IIC: A Class II part which cannot be salvaged from an accidentally contaminated lander.

Class III: A simple or complex part which is not compatible with the 24-hour terminal sterilization heat soak but is compatible with all other anticipated environments including those required to maintain presterilization contamination control, those required to render the part sterile, and those to maintain sterility. As a result of environments experienced during the course of fabrication, assembly, and storage, this part is internally sterile at the time of its attachment to the spacecraft assembly. It may or may not be salvageable.

(b) Review of Unqualified Items on a Parts, Materials, and Interfaces Basis. The cost of parts qualification for any particular application is often great. In the course of design, particular attention was given to the use of parts having the maximum amount of available qualification information. To obtain a uniform degree of assurance that parts and materials used are reliable and compatible with sterilization, they would be purchased in accordance with a specification designed to describe fully the requisite conditions of manufacture and performance. Parts must be purchased from a qualified vendor and suitable quality control tests must be performed to assure that the parts meet specification. When standard commercial parts from a controlled process can be purchased on a continuing basis, they should be chosen for performance and life testing if in other respects they meet the specification. The specific NASA requirements NPC-200, (10,11,12) and the preliminary design of the ABL has been predicated on their application in the manufacturing phase of the ABL program.

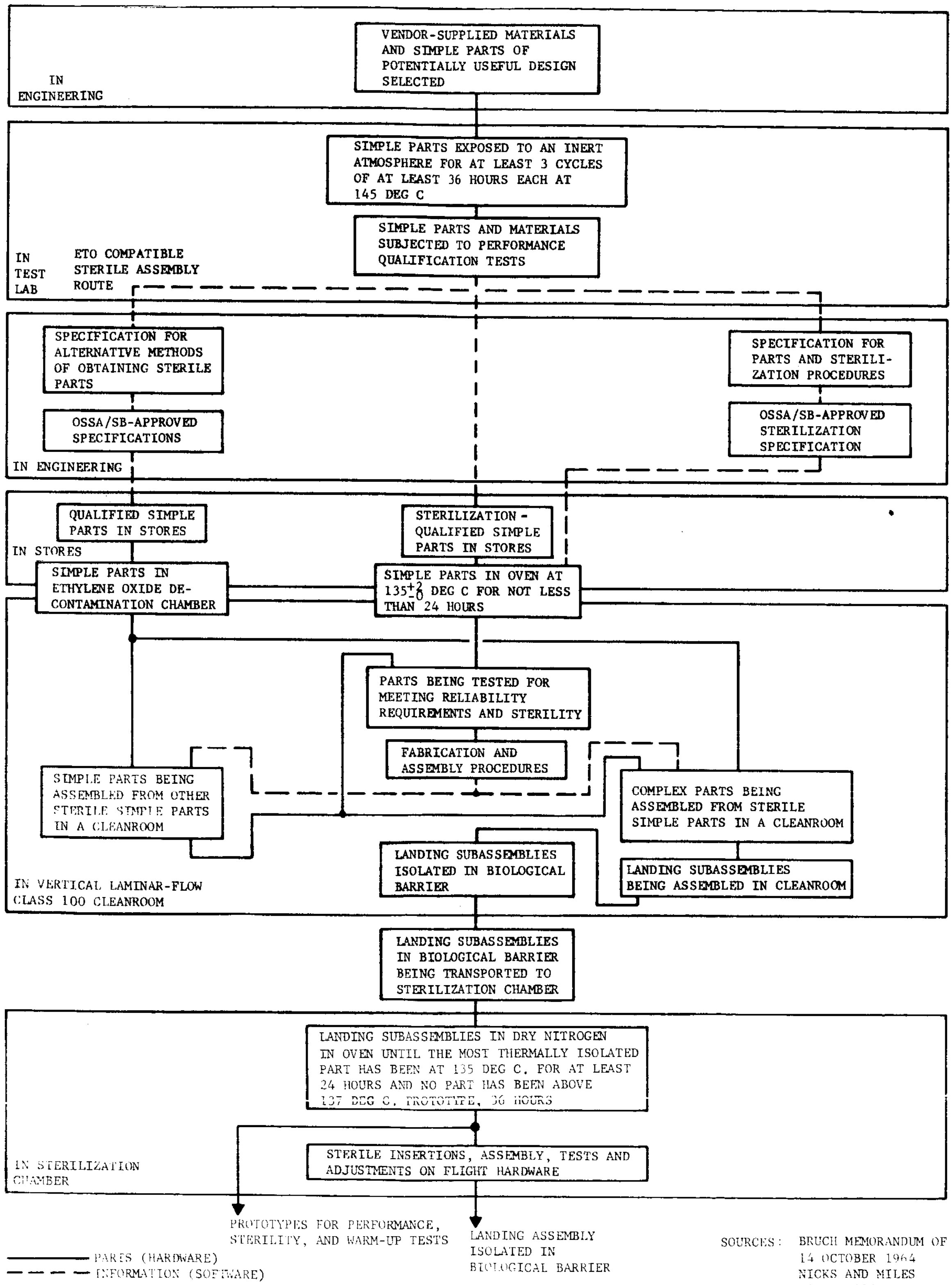
(2) Design Implications in Sterile Manufacture, Terminal Sterilization, Sterility Maintenance, Resterilization, and Repair.

(a) The Course of Design and Construction. The course of design and construction of a sterile ABL-type payload is shown in Figure 5.7-1. The present study program has involved only the first step, "select vendor-supplied materials and simple parts," and a consideration of information developed "in test lab" for a few of these materials and simple parts.

Simple parts include those parts for which the reliability can be thoroughly and practically demonstrated and whose sterility is not subject to question. Included are hook-up wire, resistors, fasteners, O-rings, and other piece parts that are not capable of being assembled or disassembled in the process of ABL manufacture. Materials such as structural or other plastics, adhesives, potting compounds, lubricants, conformal coating materials, elastomers, sealants, solder, and solder fluxes which are to be sterilized before they are used in higher levels of assembly, resemble simple parts in the procedures by which they are to be handled.

Complex parts are built-up subassemblies whose reliability and/or sterility cannot be thoroughly demonstrated either because of size, complexity, heterogeneity, cost, or other reason and include electronic black boxes, printed circuit cards, batteries, gyros, motors, solenoids, relays, propulsion units, photomultiplier tubes, and built-up structures which involve faying surfaces, rivets, composite materials, or other structure, that might entrap organisms, whether or not they are capable of being assembled or disassembled during the manufacture of the capsule.

The flow diagram of Figure 5.7-2 shows the steps required to identify the critical sterilization compatibility problems associated with obtaining a



SOURCES: BRUCH MEMORANDUM OF 14 OCTOBER 1964
NICKS AND MILES COSPAR 1965 PAPER

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FIGURE 5.7-1. COURSE OF DESIGN AND CONSTRUCTION OF A STERILE PAYLOAD

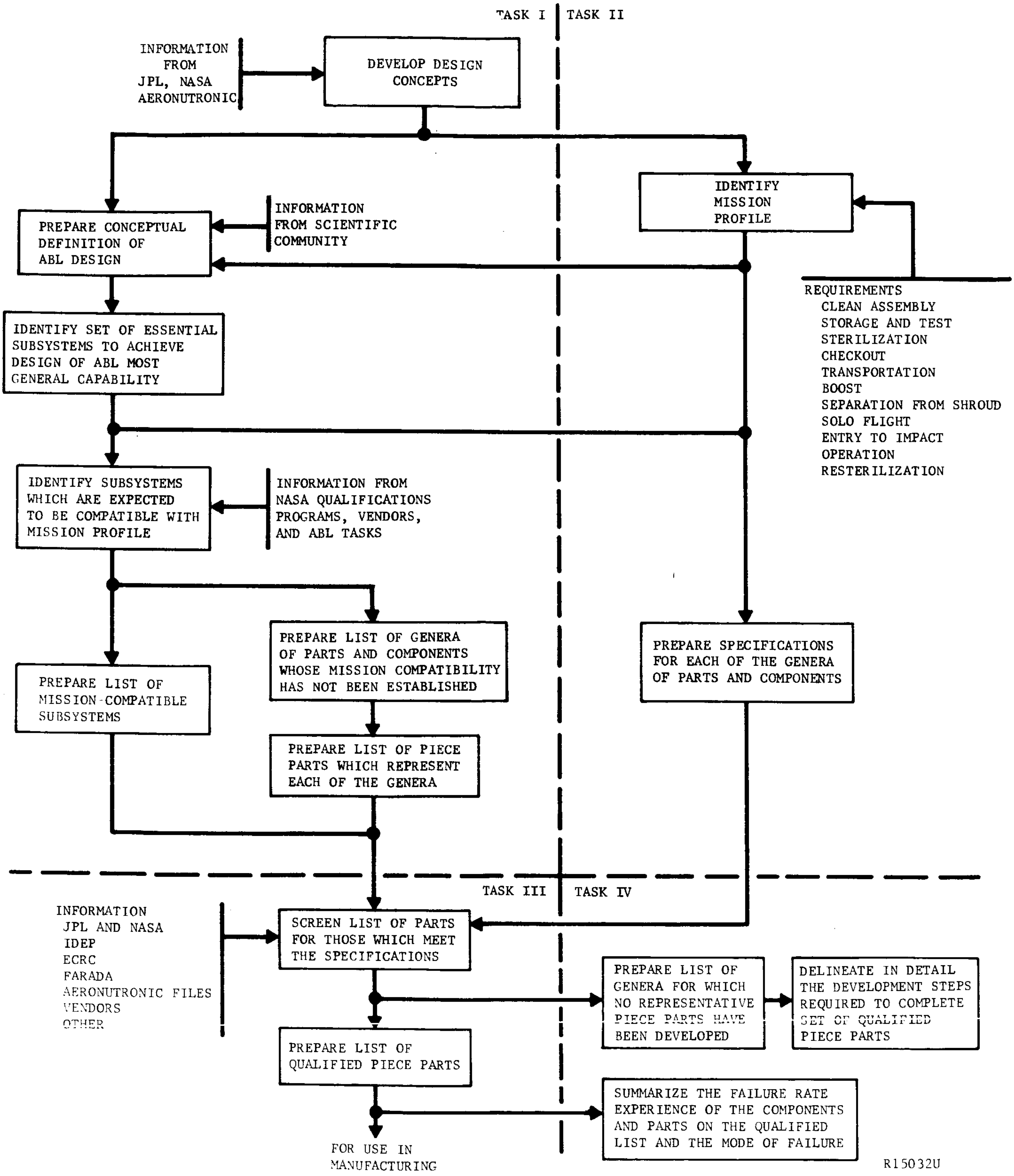

FIGURE 5.7-2. COURSE OF DEVELOPMENT OF STERILIZATION QUALIFIED PARTS LIST

suitable complement of materials and simple parts from which an ABL will be constructed. In Task I, of the Figure 5.7-2, the design concept for the ABL was developed to reflect the mission, payload-weight restrictions, interface relationships, and other constraints. Designs for an ABL and its principal subsystems were developed; these subsystems are listed in Table 5.7-III. Several of these subsystems have already been recognized by NASA as representing potentially critical sterilization compatibility problems. Some, such as electrochemical batteries, tape recorders, and solid propellants are the subjects of continuing intensive advanced development activities (see Table 5.7-I). The sterilization compatibility of these subsystems may be regarded as largely beyond the scope of the present study. The data search effort for the subsystems was restricted to assessment of the expected contributions from current NASA advanced development activity to the availability of appropriate subsystems for the ABL mission.

The tests in the NASA programs are generally applied to a sufficient number of replicate parts to provide statistical significance in the results. The relevance of the test results to a particular application in the ABL must be established for each case, however. This is even more important in extrapolating data from sources other than NASA, e.g., IDEP (Interservice Data Exchange Program), to anticipated performance of a part in an ABL application.

(b) Specific Implications for ABL Design. In accordance with NASA quality requirements(10,11) and requirements outlined in the current NASA sterilization procedures document(1), the methods for selection and qualification of parts, as well as their sequence of assembly and sterilization have been defined. Figure 5.7-1 shows the sequence of applying these methods.

In the actual assembly of the ABL, no particular distinction will be made between Class I and Class II items. Class IIA and IIB items, however, must not be exposed to any gaseous ethylene-oxide contamination processes. The assembly of Class III items represents a different matter; these items must be protected from the total exposure to the terminal sterilization process. Some may survive a shorter exposure to the temperatures involved in which case a suitable internally sterilized thermal resistance can be used to isolate them. Others will have a maximum temperature at which they can be exposed. Local cooling will then be required. Others can be maintained at suitable temperatures with the use of thermoelectric devices. The choice of particular thermal isolation techniques for Class III devices has not yet been established.

In the terminal sterilization chamber,(3) the entry vehicle, including the ABL, will be assembled into a rigid biological barrier of suitable material. The outer surface of this barrier will become contaminated immediately when the assembly is removed from the sterilization chamber.

The details of this barrier and its interface with both the orbiter and the entry vehicle were not a concern of this study and have not been specified in sufficient detail to define the sterilization compatibility problems that may be involved. The manufacturing sequence must be predicated on the assumption that testing, adjusting, and repair of the landers and the capsule would not be permitted once the biological barrier has been sealed. A certain amount of electrical testing will of course be permitted. One of the areas of difficulty foreseen in the final assembly is the possible need to incorporate rocket propellants for retromotors after terminal sterilization, or their thermal isolation during this operation.

Class 100 clean work benches in a cleanroom of lower rating may be used where it is appropriate to do so. Once the assembly gets so large that people must climb over it or inside it, the contamination control advantage of the laminar-flow cleanroom evaporates. To keep usefulness in line with costs, the ABL design contemplates the final assembly of the largest parts to be made in enclosures providing absolute(13) separation of the operator from the spacecraft, possibly through protective garb on the operator. This absolute separation represents an inconvenience, and, possibly, a critical sterilization problem.

The resistance to heat transfer in the insulation used to protect certain components and in the structure of typical spacecraft was discussed by Tenney, et al.(14,15,16) The proposed use of the waste heat from the RTG primary power supply to heat the ABL internally during sterilization will substantially reduce the thermal gradients within the assembly compared to those discussed by Tenney. The temperature rise required in most components also will be less than that required in Tenney's model. To the extent that the dimensions of parts change with temperature, a thermal gradient as well as an elevated temperature can change alignments, tightness of fits, stress, and ratio of stress to yield strength. This latter property can be of critical importance in hermetically sealed containers enclosing liquids which have either both an appreciable coefficient of thermal expansion or increase of vapor pressure with temperature. Thermal control of the ABL during sterilization is discussed in Paragraph 5.3.3.

Material incompatibilities express themselves in two ways. The materials can undergo a significant change in properties independent of other materials in their environment. They can also interact with these other materials. The latter type of incompatibility is often difficult to predict, usually because the possible interactions among materials used in the design have not been previously explored. On the other hand, much data are available on the effect of temperature on specific materials. Fewer problems are expected in specific material-temperature incompatibilities, in the subsequent steps of detailed design, than in the interactions between materials at elevated temperatures. A substantial amount of exploratory work on compatibility of various materials and electronic components with the ethylene oxide decontamination conditions has been done.(17 through 24) This work will provide a useful basis of selection of candidate parts and materials for qualification.

The compatibility of various materials and electronic components with the NASA thermal sterilization compatibility test conditions has been the subject of several very intensive investigations.(25,26,27,28,29) Again the results of these studies will provide guidance in the selection of candidate parts and components.

The potential incompatibilities among several materials under the conditions of either the terminal sterilization or the thermal sterilization compatibility test conditions may be large. The work discussed in Paragraph 5.7.4 found several incompatibilities derived from interactions among several materials exposed to the terminal sterilization conditions while in contact. The incompatibilities can appear as excessive pressure, as loss of strength or fracture, dissolution, chemical action, or corrosion, to name but a few possibilities.

(c) Other Requirements for Sterility Assurance. All assembly of subsystems and systems will be performed in an environment which is compatible with effective control over the rate of accumulation of viable microorganisms on the assembly. Because the documentation is so essential to the certification of sterility,(12) the careful definition of manufacturing and quality control procedures, their monitoring, and the training of people to perform them is imperative if the objectives of sterility and reliability are to be attained.

The fabrication and assembly of complex parts will be performed by suitably garbed personnel in a Class 100 vertical laminar-flow cleanroom.(3,8, 12, 13, 30, 31, 32, 33, 34, 35) The resulting assembly is amenable to sterilization under the conditions of the qualification test environment defined in Figure 5.7-3. It can be assembled in a less clean environment and thoroughly cleaned before introduction into the cleanroom for assembly as a simple part. Subsequent operations in the cleanroom may require that some parts and assemblies be decontaminated through exposure to liquid and/or gaseous sterilants, to sterilizing doses of radiation, or to temperatures above 135°C (see Figure 5.7-3). The ABL preliminary design has considered that components and subsystems be exposed to one or several decontamination environments during the course of fabrication and assembly. Among the additional environments are the following:

(1) 121°C for 15 minutes in an atmosphere of saturated steam (most applicable for surfaces and aqueous suspensions or solutions).

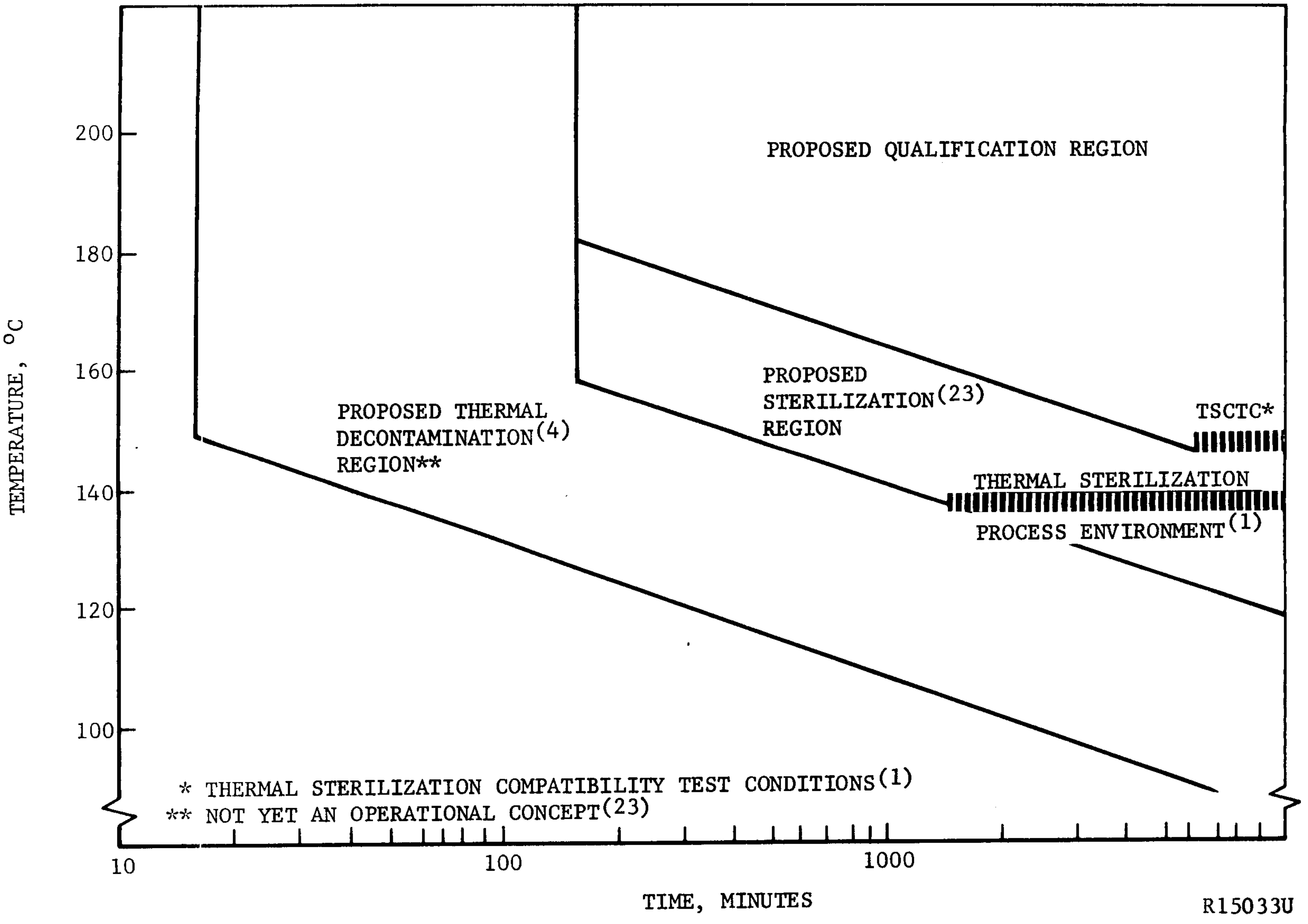

FIGURE 5.7-3. TIME-TEMPERATURE TRADE-OFF FOR THERMAL STERILIZATION OR DECONTAMINATION IN AN INERT GAS ENVIRONMENT

(2) One of the NASA-specified ethylene-oxide decontamination procedures.

(3) Certain other surface decontamination procedures developed specifically for a particular contamination reduction application.

A basic objective in the ABL design has been the elimination, wherever possible, of components which are incompatible with the thermal sterilization compatibility test conditions. Several components of particularly interesting life-detection experiments appear to be incompatible with these conditions. Rather than eliminate these experiments at this early date before sterilization compatibility was firmly determined, attempts to find alternative design solutions were made. Characteristically, too little quantitative information is now at hand to say just which of these components will ultimately be suitable for use in the design. If any of the required components are ultimately sterilized internally by a procedure less thermally severe than the terminal cycle, these components then must be isolated thermally from the rest of the ABL during the terminal sterilization heat soak. The temperature sensitive components can be thermally isolated by mounting them on, or surrounding them with, cold plate heat exchangers. The component and cold plates are sterilized by other than high temperatures and enveloped in a protective structure. During sterilization, coolant is provided to the cold plate heat exchanges to maintain the critical components within acceptable temperature limits. The outside of the protective structure is maintained at the required sterilization temperature by the normal sterilization treatment.

An example of an item which currently appears to require sterilization by the method of 121°C wet stream autoclaving for 15 minutes is the cellophane membrane used in the dialysis process. Subsequent protection for this membrane during dry heat bake sterilization can be achieved with thermal isolation as described above. Another case is ampule storage of Earth originated growth media which tests have indicated is degraded by the terminal sterilization cycle. A detailed description of the method that can be employed to implement thermal isolation for ampule storage is given in Paragraph 5.6.1 of this volume.

The design of the ABL as well as the analysis and evaluation of expected in-service performance has presumed that each part will be totally inaccessible for maintainence or for making adjustment subsequent to the start of the terminal sterilization process. It is assumed that all components of the lander will be sealed in a biological barrier and that this barrier can have a direct effect on the stress or thermal histories experienced by the parts during the terminal sterilization. These barriers can occasionally lead to chemical incompatibilities unless this possibility is given proper consideration in design. The barrier has been considered to be fabricated of a suitable rigid metal or polymeric material compatible with the terminal sterilization process, although further consideration should be given to flexible laminates(36) for certain portions of the barrier. It has been anticipated that the biological barrier will be in place containing the entry vehicle and the ABL when they emerge from the terminal sterilization process. The barrier will be separated from the lander assembly prior to initiation of the entry sequence without introducing any viable contamination into the lander or having any likelihood of impacting the planet itself.

Even before the terminal sterilization process, sterility maintenance will play an important role in preserving internal sterility in Class III parts. All components and materials used in fabrication will be monitored with respect to contamination and will be subjected to further contamination control procedures. Means of contamination reduction will be implemented whenever possible.

The design has considered that after terminal sterilization of the ABL, parts will not be replaced. Checkout from this point will be concerned with conformance of the flight model with specification and not with verification of design. Caging mechanisms may be monitored for release and internal thermal environment or pressure, e.g., may be monitored by means compatible with the preservation of sterility. Those instruments which would necessarily be deployed uncaged in order to make a meaningful check of performance will be designed in such a way that data of adequate assurance are derivable from tests on prototypes.

The ABL has provision in its design for resterilization of those subsystems required(1) to permit recycling of experimental instruments. When experiments are repeated for confirmation or to measure seasonal changes, there must be assurance that the results are not affected by previous use of the equipment. These requirements have been identified in the detailed experimental procedures developed in Appendix 5, Volume VI.

One of the design requirements for planetary impacting spacecraft is that both the payload and the protective barrier be compatible with terrestrial repair operations involving resterilization, salvage of components, and decontamination with ethylene oxide. Though no use of poststerilization repair is contemplated in the design of the ABL, the compatibility requirement has been recognized in the designs chosen.

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5.7.2 EVALUATION OF STERILIZABILITY OF ABL FROM ANALYSIS OF PRELIMINARY DESIGN

a. Introduction. While the biological problems in sterilization are significant in the overall sense, this evaluation has been restricted to problems in designing a reliable ABL. This reliability is affected by specified environmental conditions, designed to produce sterility, imposed during the course of assembly.

The ABL instrument complement and the major noninstrument components have been defined in Table 5.7-III. They range from ABL peculiar items to items of very broad applicability in aerospace hardware. The evaluation has been centered on the ABL peculiar items. Other than among the consumables, there was no point including sterilization incompatible items in a design point case study if they were known to be incompatible. Thus, the significant and perhaps difficult incompatibility problems, if any, will be identified on the first iteration of proof testing, following the detailed design and specification of parts and functions. This has been true in the overall NASA program as described by Nicks and Miles.(1) Hall, Miles, Bruch, and Tarver(2) have observed that "based on results to date, no reason has been found to believe that a full complement of heat-sterilizable hardware will not be available when needed." This observation applies, of course, to the parts not peculiar to ABL.

All generic parts considered for use in the design point case ABL are either conceptually capable of passing the proof tests, subject to a few design iterations, or they are fundamentally similar to those now under study and redesign in other NASA programs. These component parts proof tests have been defined in the recent paper by Nicks and Miles(1) and included exposures to both the thermal sterilization compatibility test conditions and to the compatibility test conditions for ethylene oxide decontamination.(3) The proof testing and redesign effort in the NASA program to define sterilization compatible parts is at a current level of 100 man years per year.(1) The status of various portions of this program will be discussed in terms of the prognosis for early availability of satisfactory components.

The consumables are all ABL peculiar and are listed in Table 5.7-IV. They are associated largely with one particular piece of equipment, the chemical processor. They tend to be experiment rather than equipment-dependent. The sterilization compatibility limitations of a particular set of consumables does not really limit the applicability of the ABL concept but rather the sterilizability of the components of particular experiments. Improvements in sterilization compatibility should be directed more at the experimental procedure than at the equipment. One important exception is the container for consumables. The container is a part of the ABL rather than of the experiment complement.

TABLE 5.7-IV

CONSUMABLES

Ampule-Packaged Materials	Category	Sterilizability Class
Gases (mixtures will be prepared as required)		
Argon	a	I
Carbon Dioxide	a	I
Carbon Dioxide (C^{14}-tagged)	b	I
Helium	b	I
Hydrogen Chloride	b	I
Nitrogen	a	I
Oxygen	a	I
Sulfur Dioxide	a	I
Liquids (pure)		
d-2-Butanol (99.5°C bp)	a	I
Carbon Tetrachloride (76.75°C bp)	a	I
Chloroform (61.2°C bp)	a	I
Dimethyl Formamide (153°C bp)	a	I
Ethylene Oxide (10°C bp)	b	I
Water (100°C bp)	a	I
Liquids (binary solutions)		
Ether-Acetone, 2:1	a	I
Ethyl Acetate-Acetic Acid, 4:1	b	I
EDTA (ethylene diamine tetraacetic acid)-Water	b	I
Sodium Chloride-Water, 1%	a	I
Sodium Hydroxide-Water, 0.5 N	b	I
Sodium Hydroxide-Water, 1 N	b	I
Hydrochloric Acid-Water, 10 N	b	I
Sulfuric Acid-Water, 1 N	b	I

TABLE 5.7-IV (Continued)

Ampule-Packaged Materials	Category	Sterilizability Class
Liquids (chemically defined multicomponent solutions)		
Neutral Buffer Solution, 0.001 M	b	I
Neutral Buffer Solution, 0.002 M	b	I
Liquids (vaguely defined multicomponent solutions)		
Culture Media	c	III
Formaldehyde (C^{14}-tagged) substrate	c	III
Glucose-U (C^{14}-tagged) substrate	c	III
Petroleum Ether	a	I
Solvent for Cleaning	a	I
Sulfur Substrate (S^{35}-tagged)	b	III
Solids		
Thiocarbocyanine Dye	b	I
Agar	c	III

Films	Category	Sterilizability Class
Dialysis Membrane	b	I
Filter Membrane	b	I

Other	Category	Sterilizability Class
Piston Tips	a	I
Ampules	a	I

b. Objective. The objective of this, and the continuing, evaluation of the design is the early recognition of technical problems arising from the sterilization requirement. A subsidiary objective is the continual development of alternative materials and designs for specific functions in order to reduce the total number of proof test-redesign iterations eventually required.

c. Technical Discussion

(1) Consumables. Table 5.7-IV has assigned the consumables to three categories, (a) those apparently compatible with terminal sterilization and long poststerilization storage, (b) those which may be compatible after a few proof test design iterations, and (c) those which in their present concept are incompatible. None of the consumables involved in the nominal complement of experiments would be resterilized in the course of the ABL mission and none would be deliberately exposed to any decontaminant.

In assigning sterilization compatibility classifications to the species of consumables, judgments have been used in lieu of specific proof test data on the design involved. The limitations of this procedure have been recognized. For example, the classification of the growth media, and possibly other items, may eventually be changed as the result of proof tests or of work not yet contemplated. An intensive study of the chemistry of growth media degradation at the sterilization temperature might result in an upgrading of specific types of media, e.g., simple solutions for photosynthetic experiments. On the other hand, some growth media will require a prohibitively large effort to develop a satisfactory formulation.

To cope with the Class III consumables, effort must be expended either to devise specific thermal isolation techniques compatible with the overall ABL weight and other restrictions or to upgrade these consumables to Class I. The first effort is equipment oriented and the second experiment oriented. Because of the requirement for experiment flexibility, the greater emphasis has been placed on the first alternative.

The development of suitable containers involves obvious steps of iterative design and is not really a part of sterilization except in the first proof test in which the fundamental compatibility of the materials is verified or the failure mode identified. In Paragraph 5.7.4 of this volume, the first iteration proof test of the container showed an unacceptable failure rate in the Viton B closure.

(2) Major Noninstrument Components. Major noninstrument components are listed in Table 5.7-III. Many are generically similar to those under development in the NASA program. Because of the satisfactory prognosis(2) that these items will be available in a sterilization compatible form when

required, it will be sufficient to summarize briefly the current status of the NASA program.(1) To date, no results have been available on several types of components. Only components for which proof test data are available will be discussed, and the instrument and noninstrument components will be discussed together:

(a) Structure. The thermal sterilization compatibility test requirement has not reduced the range of materials available to the design though it has reduced the range of configurations in which they can be used.(4,5,6,7)

(b) High Temperature Photocathode Image Dissector. Some revision of the manufacturing procedures may be required.(1)

(c) Gyroscope. Revised design now under test.(1)

(d) Reed Capacitor Modulator. Prognosis looks good. Further tests are underway.(1)

(e) Battery. Program is being revised to broaden concept of the battery function.(8)

(f) Propellant. Program is being expanded to develop new alternatives.(9,10,11,12,13)

(g) Pyrotechnic Devices. Sterilization compatible design now available.(14)

(h) Electronic Components. Only a few types have completed proof tests but many appear to be satisfactory.(15,16)

(i) Polymers. Half of those put on proof test have passed. The other have not yet completed the tests.(1)

(j) Scintillation Crystals. Some sterilization compatible forms have been identified.(1)

(k) Optical Coupling Crystals. Sterilization compatible forms have been identified.

(l) Parachute Materials. "Nomex" has been found to be satisfactory.(17)

(m) Tape Recorder. The prognosis is very good though the final proof test results are not yet in.(1)

(n) Photomultiplier Tubes. The results of the first design tests were unsatisfactory and the revised designs are to be tested.(1)

(o) Solid State Radiation Detectors. One type has been found to be satisfactory while the others are to be redesigned.(1)

(p) Geiger-Müller Tubes. Sterilization compatible forms are now available.(1)

(q) Buffer Memories. Sterilization compatible forms are now available.(1)

(r) Biological Barriers. The hermetically sealed metal can appears to be preferable to the flexible bag type of protector.(1)

Even though the particular sterilization-compatible components sought in each of the NASA programs becomes available, incorporation into the ABL proof test model will require superficial changes and will constitute an additional compatibility challenge. Even at this late stage of development, evaluation of sterilizibility can uncover new problems which must be dealt with.

Three major noninstrument components are not ABL peculiar, are not covered in the current NASA program, and have a greater likelihood of having inherent compatibility problems than do the majority of the noninstrument components. These three are discussed in the following paragraphs.

The design point case impact limiters would be constructed of bonded balsa wood sections. The components of the limiter are compatible with the terminal sterilization procedure under certain restrictions. The required design alternatives may be found in methods of preparing and sealing the balsa wood or in substitution of materials. The important modes of failure would be splitting, unbonding, and loss of compression strength. The problems would not likely appear before proof tests of the ABL.

The design point case inflight disconnect systems require only heat compatible materials. Because the overall effectiveness of the sterilization program depends upon the reliability of the disconnection, first of the bacteriological barrier and then the orbiter bus from the lander, critical sterilization compatibility problems cannot be tolerated. Alternative designs must be carried along throughout the design and testing program.

The design point case drogue mortar is less likely to have sterilization compatibility problems than was the parachute tested in the NASA program. As with all complex parts involving many materials, its overall sterilization compatibility is not completely obvious.

Among the ABL peculiar noninstrument components are five requiring early attention to allow for the expected design iteration needed to obtain sterilization compatibility. These are discussed in the following paragraphs.

The expected sterilization induced dimensional instabilities have been accommodated in the design of the separator scale. On the mission, cleaning, decontamination, and resterilization may be required. Early laboratory confirmation of the compatibility of the design and materials with this type of usage is essential.

The chemical processor is one of the most complicated items in the ABL equipment complement. It contains enough parts, materials, and interfaces that analysis alone cannot answer adequately, questions of sterilization compatibility. The mechanical seals, bearings, and alignments will contain most of the compatibility problems, if any. The effect, on the materials and interfaces selected, of the repeated usage, interspersed with various types of cleaning and resterilization, are not predictable in advance of laboratory tests.

The culture evaluation processor employs not only new mechanisms to handle culture plates but also to control the atmosphere over them during incubation. The solid medium is dispensed into the plates as a viscous liquid. The compatibility of this equipment with cleaning and resterilization can only be established through testing and iterative design of hardware and procedures for using it.

The cellophane dialyzer membrane tested in Task 13 was found to be incompatible with sterilization. Development of alternative materials for dialysis should include consideration of gel filtration and equipment suitable for this filtration technique. Further development and selection of dialyzing membrane materials is, however, required before any basic sterilization incompatibility of membrane technique is established.

The vacuum fore pump involves tight seals. Small dimensional changes leading to leakage could prevent effective performance of the vacuum ion pump and the mass spectrometer. Though sterilization compatible design appears feasible, confirmatory testing should be scheduled early.

(3) Instruments. Most of the fundamental components of the ABL design point case instrument complement are included in the NASA program to develop sterilizable hardware. Admittedly, the ABL will use modifications of the hardware tested by NASA. The fundamental parts of the components will, however, be the same. Four of the ABL design point case instruments not listed in Table 5.7-I are sufficiently complicated in possible modes of failure to deserve discussion here. The configuration and design used in the design point case study appear to be compatible with sterilization.

(a) Microphone and Reflector. Though the materials used in the construction of this instrument present no compatibility problems in themselves over and above those common to many electrical devices, the relationship between frequency response and signal attenuation and the sterilization process effects cannot be estimated from knowledge at hand. It may be negligible or easily controlled through alternative designs.

(b) pH Meter. The pH electrode for the proposed application is only marginally compatible with sterilization even under less severe conditions than those of the terminal sterilization process. Typically, neutral water attacks glass surfaces and, equally typically, glass electrodes must be stored in neutral water. The variability in performance of pH electrodes sterilized for use in the ABL cannot be estimated from present knowledge.

(c) Carbon Dioxide Detector. The design point case model of this instrument involves a solution of barium hydroxide enclosed in a TFE Teflon ampule. Characteristically, Teflon is more permeable to carbon dioxide than to most other gases. This permeability through all of the conditions encountered during assembly and sterilization may affect the background or baseline signal from the detector. Sterilization may very well change the permeability.

(d) Mass Spectrometer. As with the chemical processor, this instrument contains enough materials and interfaces to make its overall sterilization compatibility less than obvious. Sterilization compatible materials and designs were used in the development of the design point case model but this is not sufficient to assure sterilization compatibility in so complex a part.

Similar observations can be made about many of the other more complicated instruments. These four are typical and illustrate the role of judgment in the assignment of parts and components to various sterilizability classes in the design point case.

(4) Other Observations About the Sterilizability of the Design Point Case ABL. Except in a few cases among the consumables, no difficulty is experienced in selecting either materials or configurations of materials which are obviously compatible with the sterilization compatibility test conditions. Historically, however, as more and more materials are arranged together in intricate designs with high reliability requirements, incompatibilities are uncovered. For the purpose of a design point case analysis, little laboratory testing is appropriate; enough data is at hand. As detailed designs are developed, an increasing number of choices among materials with special properties are required. Some of these are easily made and affect only the part involved. Others have effects which can permeate an entire subsystem. It is for this reason that the laboratory proof testing of sterilization compatibility will coincide with the breadboard phase of design development.

d. References

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5.7.3 CONCLUSIONS AND RECOMMENDATIONS FOR THE DESIGN POINT SYSTEM

a. Introduction. In evaluating the sterilization compatibility of the ABL, attention has focused on compatibility of ABL peculiar materials, parts, instruments, experimental techniques, and even of experimental objectives. Some of the items included in the design point case study are admittedly marginal with respect to sterilization compatibility.

Sterilization compatibility at the instrument, technique, and experimental objective level of complexity has a time dimension. This time dimension has been taken into consideration in including these marginal items in the design point case. The conclusions and recommendations are directed primarily to the ABL portion of the capsule. No unique requirements for electronic components appeared in the design.

b. Conclusions. The selection of materials for simple parts does not present a significant obstacle to the design of the ABL. The principal problems arise at the complex part and subsystem levels where several materials are employed together in close or intimate contact. Yet, the available evidence supports the belief that the construction and launching of a sterile ABL is technically feasible within the time span considered.

Most of the required sterilization-sensitive components are not basically peculiar to the ABL. The functions to be performed by them are common to a wide variety of aerospace missions. Table 5.7-I lists many of the ABL components which fall into this category. The solution of the technological problems basic to many of these components is not readily apparent. By the time that hardware in these functions is required, however, the technological problems will have been solved if solution is feasible, whether within the context of ABL or not. Otherwise, the function will have been necessarily redefined in other terms. Once a solution to the functional design problem is at hand, there are no critical problems requiring extensive research apparent in the interfaces between any of these components and the other components of the ABL.

Among the ABL peculiar materials, components, and subsystems, the critical sterilization compatibility problems lie almost entirely within the growth and chemical processing system. The parts of greatest concern require specific materials, such as dialysis membrane, which may be fundamentally incompatible with the temperatures involved in sterilization. Solutions lie in development or identification of alternative materials or in the redefinition of technique. For example, dialysis through a semipermeable membrane is not the only method of separation of large molecules and colloids from small molecules.

Sterilization compatible materials and designs have been developed by which to build the reagent containers. Though insufficient evidence is available to claim that one single design will suffice for all reagents, only a few items in the reagent complement require special consideration from the compatibility standpoint. The more significant design effort must be placed in the development of reliable assembly techniques for the design finally chosen. No problems, as such, are expected in this development.

What critical sterilization problems peculiar to ABL there are, at this point in design, pertain to the growth media. To develop the scientific basis on which to interpret growth observation in media sterilized at 135°C, let alone 145°C, may require more effort than is justified when a feasible alternative exists. This alternative is the thermal isolation of temperature-sensitive components during the terminal sterilization process provided that they are internally sterile and protected from recontamination at the start of this process. This alternative has been adopted in the design point case study.

Subsequent iterations of the design effort to develop further detail and to explore alternative experiment complements will doubtless uncover difficult design problems arising from the sterilization compatibility requirements. It is not useful to do more than point out this truism at this stage in the design study.

c. Recommendations. These recommendations are directed first to the development of a documentation format through which the sterility of the flight model of the ABL can be certified when the time comes. Second, they are directed to the smooth integration of provisions for sterilization requirements into those of good manufacturing practice. These provisions pertain to compatibility testing, contamination control, and documentation. Finally, they are directed to specific potential compatibility problems found in the evaluation of the design point case.

(1) Certification of Sterility. This will be based on an evaluation of the set of documents developed along the course of development, manufacturing, storage, and transporting the ABL to the gantry. For a particular spacecraft, the opportunity to observe and record a critical fact about sterilization, sterility, or contamination cannot be retrieved once lost. It is therefore necessary to define carefully and early the documentation eventually required and to provide for its continuous development in an orderly and systematic manner. It is recommended that development of this format be based on systems engineering techniques and that it be started early. This documentation will include at least the following items.

(a) Definition of requirements for selecting and and training personnel.

(b) Definition of appropriate manufacturing, storage, and transportation facilities.

(c) Sterilization oriented clauses in parts specifications, manufacturing procedures, testing procedures, and training course documents.

(d) Definition of contamination control procedures.

  (1) Microbiological procedures and proof of effectiveness.

  (2) Decontamination and sterilization procedures and proof of effectiveness.

  (3) Audits of the manufacturing application of these procedures.

(e) Excerpts from manufacturing records, purchasing records, quality control records, test reports, and perhaps even personnel assignment records as they are developed.

(2) Continuing Evaluation. Evaluation of the sterilizability of the ABL current design implies a continuing development of a sound technological basis for this evaluation. This basis is fed into the design in the next iteration. It is recommended that the continuing evaluation be formalized as a contractor sterilization control group with responsibilities for:

(a) Providing the design and test groups with up-to-date information from NASA and JPL, from outside sources, and from the literature on compatibility problems and their resolution.

(b) Providing information on new materials and simple parts which are compatible with the thermal sterilization compatibility test conditions. This responsibility will require both laboratory tests and vendor surveys.

(c) Providing short-term compatibility tests on simple parts or materials, when these tests will materially aid the design effort.

(d) Identifying needs for development of materials, parts, or sources of supply well in advance of the time required.

(e) Providing for orderly development of techniques for use in fabrication, sterilization, monitoring, assembly, and testing when the technique can affect sterility.

(f) Providing the requisite support in microbiology.

(3) Compatibility Tests. Several short-term compatibility tests are recommended to probe certain interesting materials, simple parts, design approaches, and equipment operation sequences for modes of failure and relationship of the thermal sterilization environment to failure mode. For the following items in this category, it is recommended that post-sterilization performance tests be started early:

(a) Dialysis materials and techniques.

(b) Ampules filled with a large variety of likely liquid reagents.

(c) Glass electrodes.

(d) Packaging materials and designs.

(e) Propellant reservoir materials.

(f) Gold film/aluminum oxide water vapor detector.

(g) Vacuum fore pump.

(h) Microphone and resonator.

(i) Impact/Limiter.

(j) The solid medium preparation and dispensing subsystem.

(k) The reagent dispenser, filter, and suction subsystem of the chemical processor.

5.7.4 STERILIZATION COMPATIBILITY TESTING STUDIES

a. Introduction. An initial objective in the study of the ABL was to choose materials and subsystems compatible with the NASA-prescribed(1) sterilization qualification of three separate and distinct 36-hour periods at 145°C while immersed in an atmosphere of dry nitrogen. Some of the materials involved in the customary application of life detection approaches appear to have marginal compatibility with this sterilization requirement. This does not automatically limit the sterilization compatibility of the approach, however, rather it points to a need for further study and development of the technique. This study has indicated some of the parameters associated with failure of some materials commonly used in life-detecting experiments.

b. Methods. The materials listed in Table 5.7-V were selected for study because they are common components of several life detection techniques and were considered likely to be incompatible with heat sterilization. The strategy chosen was to test components (reagents and materials in containers) in the presence of contemplated packaging materials with interface areas approximating those expected in an ABL. These materials were examined from the standpoint of visual and functional changes arising from only terminal heat sterilization and subsequent storage. No attempt was made to identify the factors involved in failure. Neither the mode of failure nor the useful life of materials or systems was considered.

Table 5.7-VI shows the environmental conditions to which the materials were exposed. The table also indicates the nature of the experimental controls (standard temperature). The environmental conditions included storage at room temperature for 5 months, following a 24-hour treatment at 135°C and 145°C. The separate specimens of each material were subjected to 135°C and 145°C and to various other materials in a package. Among these, other materials were solutes, solvents, Teflon coupons, and tantalum coupons in various combinations in glass containers.

After sterilization and storage, as required by the experimental plan, changes in color, turbidity, solubility, conductivity, pH, and oxidation-reduction potential of the test materials were noted. Changes in the packaging materials were also recorded. In addition, the ability of the tested materials to perform functionally was ascertained.

Table 5.7-VII lists the categories of materials studied and the tests which were applied to each. Table 5.7-VIII presents the numbers of specimens prepared and tested. When the early tests showed a gross incompatibility of a material with the sterilization procedure, no further testing was carried out. The test procedures are outlined in detail in Paragraph 10.2.3.

TABLE 5.7-V

MATERIALS AND AMOUNT IN THE PACKAGES

Code No.	Material	Amount in Package
a	Sabouraud Liquid Medium	10 ml
a'	Sabouraud Liquid Medium Solids (dry)	1 g
b	Fluid Thioglycollate Medium	10 ml
b'	Fluid Thioglycollate Medium Solids (dry)	1 g
c	Trypticase Soy Broth	10 ml
c'	Trypticase Soy Broth Solids (dry)	1 g
d	M8-type Medium	10 ml
d'	M8-type Medium Solids (dry)	1 g
e	M9-type Medium	10 ml
e'	M9-type Medium Solids (dry)	1 g
A	Water	10 ml
B	60% Perchloric Acid	10 ml
C	Silicotungstate, Anhydrous	1.008 g
D	Silicotungstate Solvent	10 ml
E	Silicotungstate Reagent	10 ml
F	Ammonium Molybdate, Anhydrous	0.50 g
G	Ammonium Molybdate Solvent	10 ml
H	Ammonium Molybdate Reagent	10 ml
I	Concentrated Sulfuric Acid	0.195 ml
J	Ethanol, 99.5%	9.55 ml
K	Alcholic Sulfuric Acid Reagent	9.75 ml
L	Dowex-50 W Ion-Exchange Resin	5 g
M	Water for Suspending Ion-Exchange Resin	10 ml
N	Dowex-50 W in Water	10 ml
O	Dye	0.067 g
P	Water	10 ml
Q	Dye Reagent	10 ml
R	Dialysis Membrane	6 in.
S	Water	10 ml
T	Dialysis Membrane in Water	10 ml
U	Stannous Chloride, Anhydrous	0.175 g
V	Stannous Chloride Solvent	12.5 ml
W	Stannous Chloride Stock Solution	5 ml
X	Sulfuric Acid, 1 N	12.5 ml

TABLE 5.7-VI

DEFINITIONS* OF PACKAGES AND EXPOSURES USED IN TASK 13

Packages** Exposure Code Number ***	Material Code Number****																																	
	a	a'	b	b'	c	c'	d	d'	e	e'	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
1	X		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	X
3	X		X		X		X		X		X	X			X						X			X									X	X
4											X	X			X			X			X			X						X			X	X
5											X	X			X			X			X			X			X			X			X	X
6	X		X		X		X		X																									
7											X	X			X			X			X			X						X			X	X
8	X		X		X		X		X		X	X			X			X			X			X			X			X			X	X
9											X	X			X						X			X									X	X
10														X			X			X			X			X			X			X		
11														X			X			X			X			X			X			X		
12														X			X						X			X						X		
13		X		X		X		X		X			X			X			X			X			X			X			X			
14		X		X		X		X		X			X			X			X			X			X			X			X			
15		X		X		X		X		X			X			X									X						X			

* Only the X's in the array represent experimental combinations actually used.

** All packages were prepared in triplicate to permit the tests to be performed after each of two different periods of poststerilization storage and to allow for loss of specimens through breakage.

*** The package-exposure code numbers have the following significances:

1. Standard ***** temperature, no coupons
2. 135°C, no coupons
3. 145°C, no coupons
4. Standard temperature, Teflon coupon
5. 135°C, Teflon coupon
6. 145°C, Teflon coupon
7. Standard temperature, Teflon and tantalum coupons
8. 135°C, Teflon and tantalum coupons
9. 145°C, Teflon and tantalum coupons
10. Standard temperature, no coupons
11. 135°C, no coupons
12. 145°C, no coupons
13. Standard temperature, Teflon coupon
14. 135°C, Teflon coupon
15. 145°C, Teflon coupon

**** The materials code is defined in Table 5.7-V.

***** For water, the dialysis membrane, and the components of the growth media the standard temperature exposure was 15 minutes at 121°C. For all other materials there was no exposure to any elevated temperature.

TABLE 5.7-VIII

NUMBER OF SPECIMENS PREPARED AND TESTED

Category of Materials	Number of Materials in Category	Number of Types of Tests Performed on Packages of Materials	Tested Immediately						Tested after 5 Months					
			Controls			Heated			Controls			Heated		
			No Coupons	Teflon Coupons	Teflon and Tantalum	No Coupons	Teflon Coupons	Teflon and Tantalum	No Coupons	Teflon Coupons	Teflon and Tantalum	No Coupons	Teflon Coupons	Teflon and Tantalum
Growth Media	5	7	53	53	53	53	53	53	53	53	53	53	53	53
Water	1	5	1	1	1	2	2	2	2	2	2	3	3	3
Perchloric Acid	1	3	1	1	1	2	2	2	2	2	2	3	3	3
Phosphate Reagents	4	5	8	10	5	14	14	9	16	20	10	23	28	13
Thiocarbocyanine Dye	1	5	2	2	1	3	5	1	4	4	2	4	6	2
Ion-Exchange Resin	1	4	3	3	3	3	3	1	4	5	5	5	5	2
Dialysis Membrane	1	3	3	3	1	3	3	1	3	3	2	3	3	2

TABLE 5.7-VII

TESTS APPLIED TO MATERIALS IN PACKAGES

Category of Material	Tests							
	Color and Appearance	Turbidity	pH	Oxidation-Reduction Potential	Conductivity	Packaging Materials Appearance	Capacity to Perform Function	Solubility
Growth Media	X	X	X	X		X	X	X
Water	X	X			X	X	X	
Perchloric Acid	X	X				X	X	
Phosphate Reagents	X	X				X	X	X
Thiocarbocyanine Dye	X	X				X	X	X
Ion-Exchange Resin	X					X	X	
Dialysis Membrane	X					X	X	

c. Results. A detailed description of the observations is presented in Paragraph 10.2.3. In brief, the essential findings of this sterilization compatibility testing program were as described in the following paragraphs.

(1) Growth Media. Exposure of the growth media to 135 or 145°C generally produces an adverse effect on their ability to support microorganism growth. However, this effect was not uniformly applicable to all of the species tested. Some of the thermally treated complex media promoted good growth for some species. In some cases, the growth-suppressing effects observed immediately after the 24-hour thermal exposure decreased with storage. The fluid thioglycollate medium was degraded not only by the thermal treatment, but also by storage, since fresh control medium supported growth of species of organisms, whereas in tests after 5 months of storage, this medium supported growth of only two species. In the case of the other four media, 5 months of room-temperature storage did not produce a significant effect on their ability to support growth.

The thermal treatment produced sediment in all of the media studied and the color of the media, containing sugar and/or protein derivatives (whether as dry powder or in solution) was altered. In addition, changes in pH and oxidation-reduction potential of these media were noted and, in the absence of buffering agents, the media containing large amounts of organic materials became very acid.

In a few instances, a suggestion of growth inhibition caused by the Teflon was observed.

(2) Phosphate Reagents. Because most of the phosphate reagents are used in excess in the assay procedure for inorganic phosphate(2), a large amount of deterioration can occur before assay sensitivity is effected. At least one of the configurations of each of the reagents survived both the thermal treatment and the subsequent storage well enough to permit accurate assays to be made with the thermally treated material. In solution, the ammonium molybdate reagent was completely destroyed by the thermal treatment and in the hydrate form the stannous chloride crystals changed color. The thermal treatment changed the ease with which most of the dry forms of the reagents went into solution. The concentrated sulfuric acid extracted a dark-colored material from the closure.

(3) Water. The effects of the thermal treatments on water were limited to a slight increase in conductivity in the presence of Teflon and a slight attack of the walls of the borosilicate glass tube. The capacity of the water to perform in the phosphate assay was unaffected.

(4) Ion-Exchange Resin. The capacity of the ion-exchange resin was unaffected by the thermal treatment and the subsequent storage. The color of the resin was changed and when the thermal treatment was carried out on an aqueous suspension of the resin, the water became colored.

(5) Dialysis Membrane. Thermal treatment of the dialysis membrane caused it to turn brown in color and become crisp in texture. When suspended in water during the thermal treatment, it remained colorless, but readily disintegrated under mechanical stress. However, sterilization at 121°C for a period less than 60 minutes was not deleterious. This particular test does not imply that all dialysis membranes are incompatible with the thermal treatments at 135°C. Other dialysis membrane materials might well prove to be more satisfactory.

(6) Thiocarbocyanine. In the form of a dry powder, the 24-hour treatments at 135 and 145°C changed the ease of solution of the dye in water. The visible absorption spectrum of the heated dye was not different from that of the unheated material and when it was dissolved and mixed with ribonuclease, the expected changes in the absorption spectrum readily occurred. Aqueous solutions of the dye were completely decolored by the thermal treatments.

(7) Perchloric Acid. The perchloric acid was not affected by the thermal treatments or the subsequent storage.

(8) Packaging Materials. Tantalum was not attacked by any of the materials tested. While Teflon was not attached, it did appear to affect the growth-supporting capacity of some of the media and the conductivity of the water with which it was packaged. This effect may have been due to impurities in the Teflon rather than to the Teflon itself. The borosilicate glass tubes were attacked(3) by neutral water. The Viton B component of the closure on the packages suffered a large compression set during the thermal treatment.

The hydrogen chloride over the acid stannous chloride solution permeated the Teflon liner of the closure and destroyed an aluminum foil component beyond it.

Tantalum was chosen for simulations of the metallic component of the container-dispenser when it was found that perchloric acid dissolved pure nickel which, for other considerations, was considered to be the metal of choice for this application.

d. References

(1) Bruch, C. W., Memorandum to all Biosciences Program Office Contractors Concerned with the Science of Experiments and the Development of Appropriate Instruments for the Detection of Extraterrestrial Life, dated 14 October 1964.

(2) Martin, J. B., and Doty, D. M., "Determination of Inorganic Phosphate," Anal. Chem. 21(8), 1964.

(3) Holland, L., The Properties of Glass Surfaces, New York: John Wiley and Sons, Inc., 1964.

SECTION 6

LABORATORY SUPPORTING SUBSYSTEMS AND INTERFACE STUDIES

6.1 MISSION AND VEHICLE SYSTEM CONSTRAINTS

The design point ABL landed payload configuration developed in the studies described in the preceding section was used as the basis for the studies of supporting subsystems and entry vehicle interface studies described in this section. The same criteria relative to mission and design constraints identified in Paragraph 5.2 apply to these studies as well. In some of the analyses, it was necessary to develop more specific criteria, as, for example, the assumptions concerning the surface environment parameters required in the thermal control analyses in Paragraph 6.5. Where this was necessary, the latest information in the established literature, or from recognized sources working in the field, was employed. No attempt was made, however, to anticipate what conclusions might be reached from currently tentative experimental data. Where additional assumptions or criteria are used, they are clearly identified either in the section in which the analysis was performed or in a supporting section in Volume VI, Technical Appendix.

While the design point case evaluated was designated as a 1975 mission opportunity, the analyses in this section frequently were of a parametric nature, and where they were time (epoch) sensitive they included this effect. Generally, a time period of 1970-1980 was employed in these cases.

The ABL payload/entry vehicle interface studies reported in Paragraph 6.6 were initiated prior to the completion of the preliminary design study so that final weights for the design point case were not available. The correct payload sphere size was used for these studies, but a round-number weight of 1,000 pounds was employed. (The actual payload final weight, as reported in Paragraph 5.4, was 1,186 pounds.) This difference has only a nominal effect on the absolute values in Paragraph 6.6 and essentially no effect on the relative merits of the several approaches studies.

6.2 COMMUNICATION AND CONTROL STUDIES

6.2.1 GENERAL

This paragraph presents the communication and control system analyses completed as part of the ABL interface studies. The principal parameters affecting the ABL telecommunication system design are outlined, and the overall ABL mission communication and control problem is discussed. A detailed Direct Link telecommunications analysis is presented for both telemetry and command links, along with plots of the maximum bit rate capability achievable during a Martian year for the 1970 decade.

A similar detailed Orbiter Relay Link telecommunications analysis is also presented. A comparative evaluation of Direct versus Relay communications and control is derived from an enumeration of the performance characteristics of each mode of operation. As a supplement to the primary studies, a Remote Sampler communications analysis is also included.

The conclusions reached in the various analyses culminate in a description of the selected design point Telecommunications System for ABL. Supporting data describing Earth-Mars communication geometry and telecommunication transmitter implementation are presented in Appendices 11 and 12 of Volume VI.

6.2.2 PRINCIPAL PARAMETERS AFFECTING TELECOMMUNICATION SYSTEM DESIGN

a. General. The ABL mission presents a formidable task for the communications and control systems. The desirability of operating throughout a complete cycle of Mars seasons creates a need for communicating over longer interplanetary distances and under more adverse conditions than has been encountered on previous interplanetary programs. Voyager and current ABL studies have established such factors as the communication geometry between Mars landing sites and Earth or an orbiting communications relay.(1,2) Frequencies and durations of communication opportunities have been established as functions of time, lander latitude, and relay orbit elements. This information is mandatory for communication system design. However, much additional information is required before a concept can be selected. Specifically, the assumptions and constraints governing implementation of the various concepts (such as ABL/Earth direct links or orbital relays) must be identified, as must the details of the telecommunication systems for the various proposed concepts. Before proceeding with an account of these assumptions and constraints and the detailed communication and control system studies, certain general considerations pertinent to the overall communication aspects of the ABL mission will be discussed.

Payload considerations will obviously have a significant bearing on the desirability of employing an orbital relay, especially if the desired orbital elements are in conflict with the attainment of a desired landing site. Evaluation of orbital accuracy requirements will also be a factor, as will the alteration of the orbital elements with time by perturbative influences. Antenna directing problems will have major importance. A crucial part of the practicality of an orbital relay rests in the capability of orienting antennas to communicate both with the Martian surface and with Earth. In view of the relative proximity of the relay to Mars, the former problem may not be overly severe. The latter problem is substantially more difficult than has been encountered in previous interplanetary experience. The use of celestial objects for attitude references is complicated by the fact that, for the long periods of operation required, it may be difficult to select reference objects which are not at some time occulted by Mars. Frequent reacquisition (say at the orbital frequency) would be undesirable. In any event, the use of high-gain, highly directional antennas for orbital relay communications would be very desirable but may result in unacceptable increases in system complexity and reduce reliability.

The ability to accurately and reliably direct an antenna toward Earth each day is a central problem governing the success of a direct Mars/Earth communication link. Fortunately, presuming a stationary lander, the absence of the attitude control problem of the orbital relay is a simplifying factor. Numerous techniques of varying degrees of sophistication are presumably under study for this task. High-gain antenna pointing methods are possible which rely on a solar sensor, a clock, and a computer to generate antenna steering commands. Less sophisticated systems are assumed herein which simply align a fan-shaped beam to the celestial latitude occupied by Earth during its transit of the Martian sky.

b. Constraints and Assumptions. The ABL calls for an extended mission period of approximately two Earth years duration. This requirement dictates the necessity to communicate over the minimum and maximum range excursions which occur between Mars and Earth as a result of their orbit motions; i.e., approximately 0.4 A.U. (or 60×10^6 km) to 2.66 A.U. (or 400×10^6 km). To illustrate the distance constraint, Figure 6.2-1 is presented.* Here Earth-Mars range variation and subtended angle versus probable mission times are depicted. To facilitate the assessment of related parameters and constraints, Figures 6.2-2 and 6.2-3 are given to show free space loss versus distance for several frequencies and communication transit time versus distance, respectively.

A command-control capability is required between Earth and the ABL Lander to provide some flexibility in the conduct of various scientific measurements and to furnish a degree of control (or backup control) for normal

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*For a more complete picture of the Earth-Mars communication geometry see Appendix 11, Volume VI.

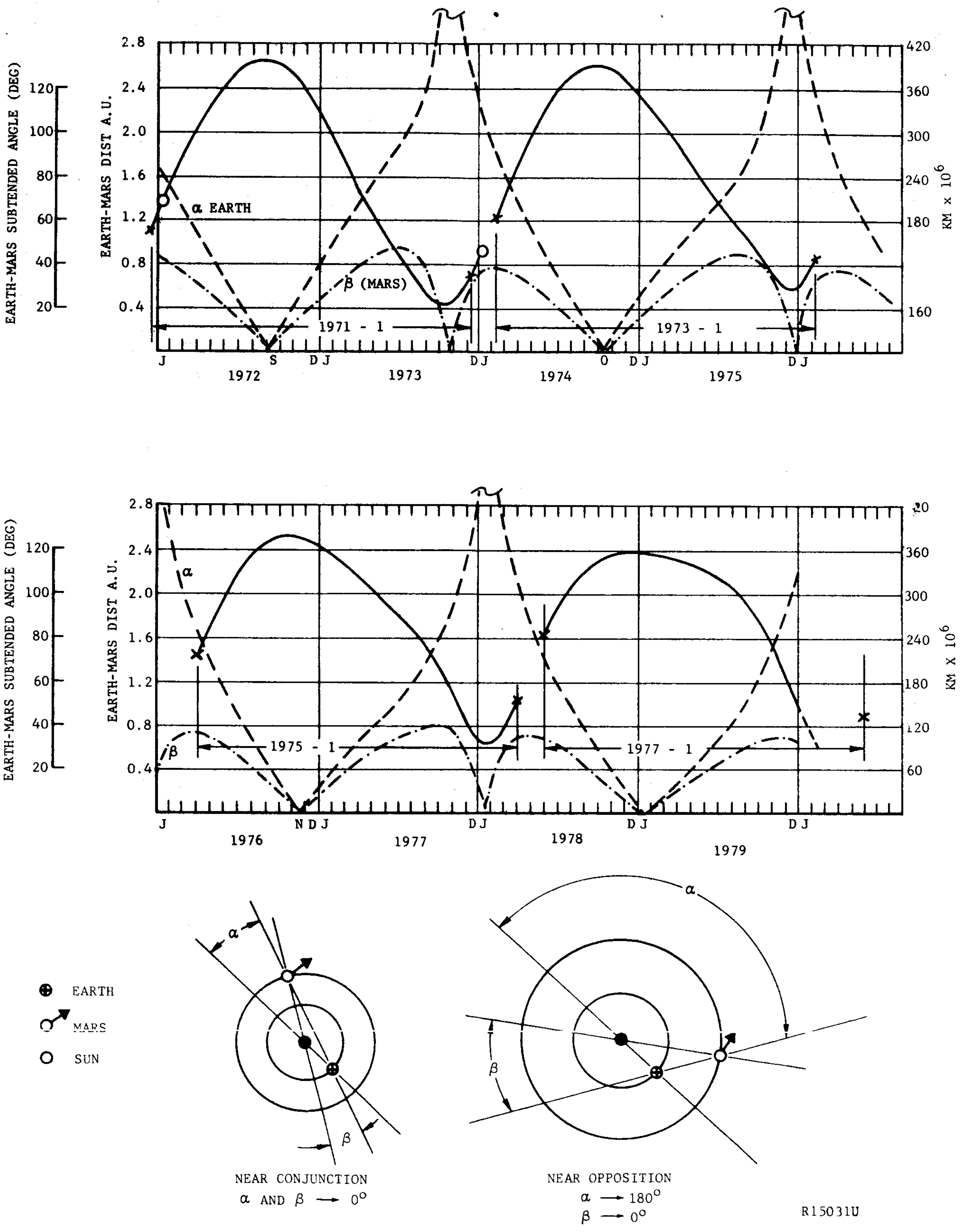
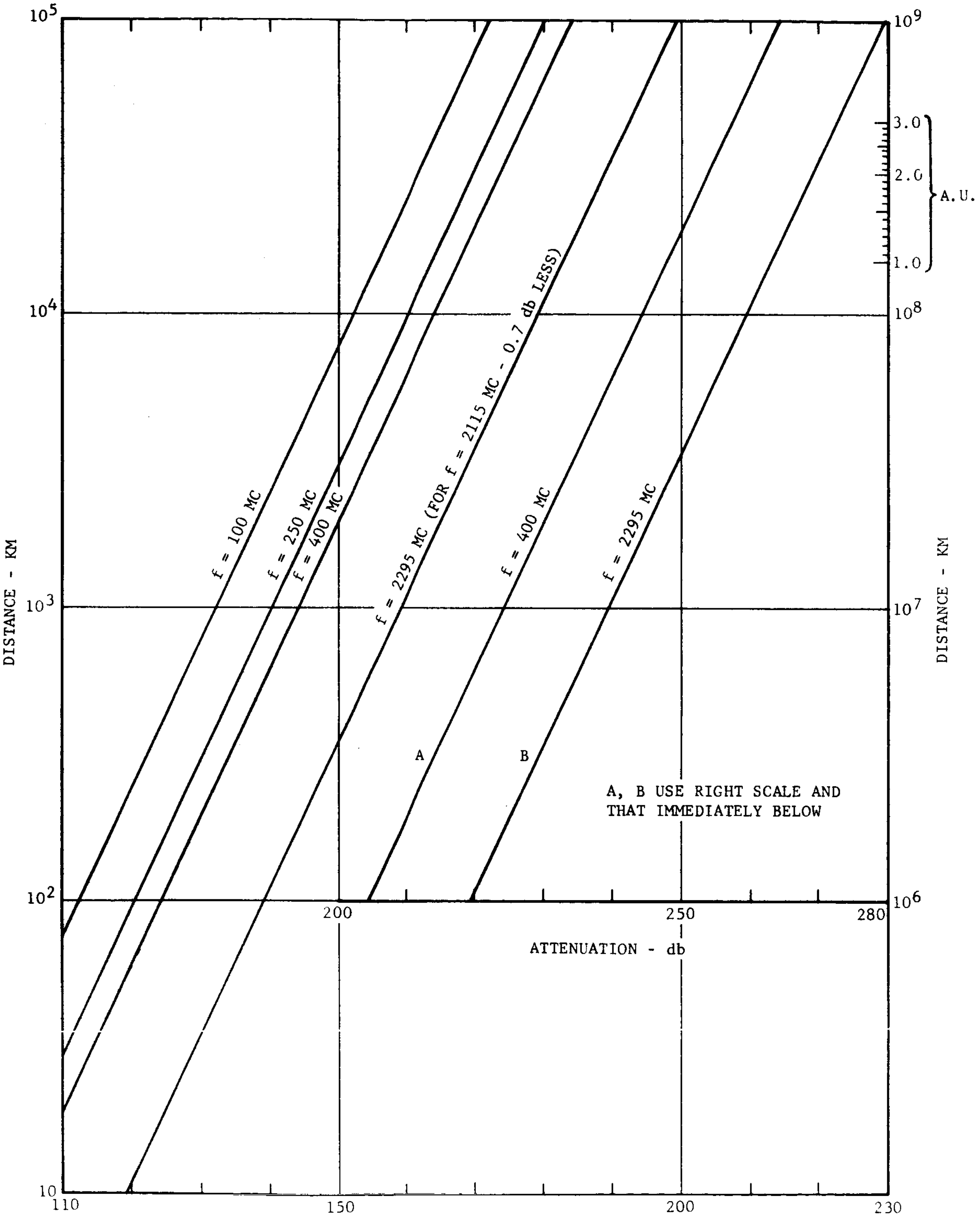


FIGURE 6.2-1. EARTH-MARS COMMUNICATION GEOMETRY



ATTENUATION - db

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FIGURE 6.2-2. FREE SPACE LOSS VERSUS DISTANCE

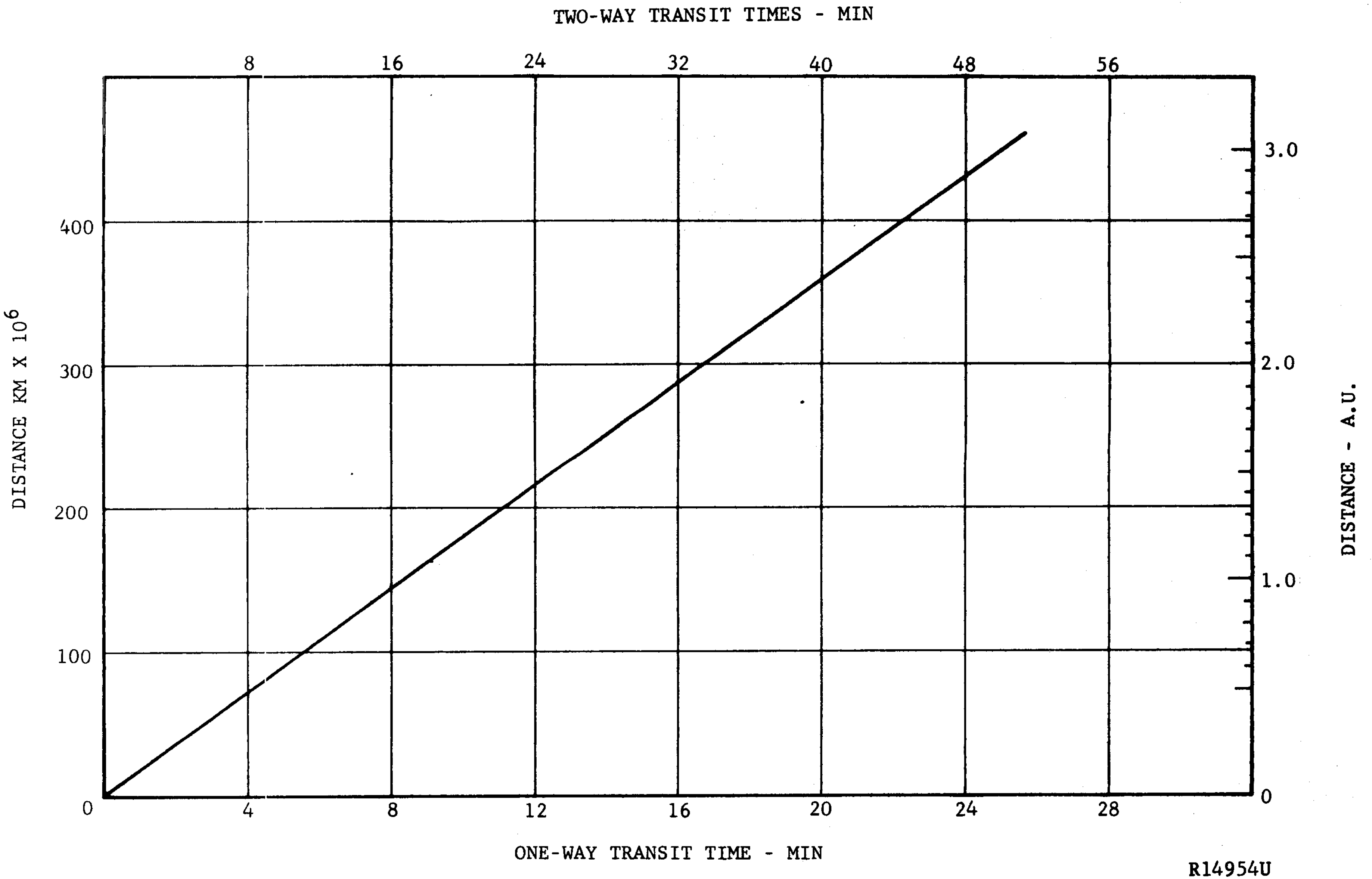

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FIGURE 6.2-3. EARTH-MARS COMMUNICATION TRANSIT TIMES programmed operations. For example, antenna orientation and positioning at specified times during the ABL mission period may be accomplished by Earth commands.

The NASA Deep Space Net (DSN) will be employed as part of the overall ABL Earth-Mars telecommunication and command-control link. DSN coverage will be provided by stations (i.e., Goldstone, Canberra, and Madrid) approximately 120 degrees apart and within ±40 degrees of the equator. Hence, no communication blind periods because of Earth rotation will exist. Other blind periods, however, will exist, such as the blind period caused by Mars daily and yearly rotation cycles and that caused by solar interference.

The choice of a landing site on Mars, as previously mentioned, is an important constraint, since communication times or modes of operation are significantly affected by lander location. However, other factors, such as the desired experiment program, choice of Mars trajectory, and year of landing, serve as modifying constraints, all of which must be traded off with communication times to effect a satisfactory compromise. Antenna breakdown considerations based on estimates of the Mars surface atmospheric conditions also act as a constraint governing transmitter power selection and associated data transmission rates.

6.2.3 COMMUNICATION SYSTEM ANALYSIS

Deep-space communications are complicated by the large communication distances and the requirement for line-of-sight contact between transmitting and receiving stations. Relative motion of transmitter and receiver, rotation (fixed to planet or orbiting), and translation through space generally necessitate directional antennas, with the attendant antenna-pointing or orientation requirements. In addition, solar interference is possible over extended mission times.

The basic free-space transmission equation expressed in terms of received signal-to-noise power illustrates the relationship among the variables involved:

$$\frac{P_r}{P_n} = \frac{P_t G_t G_r \lambda^2}{K T_e B (4\pi R)^2} \qquad (1)$$

where

P_t is transmitted power (watts)

G_t is transmitting antenna gain (relative to isotropic)

G_r is receiving antenna gain (relative to isotropic)

λ is transmitted signal wavelength (meters)

K is Boltzmann's constant (1.38×10^{-23} joules/degree Kelvin)

T_e is effective receiving system temperature (degree Kelvin)

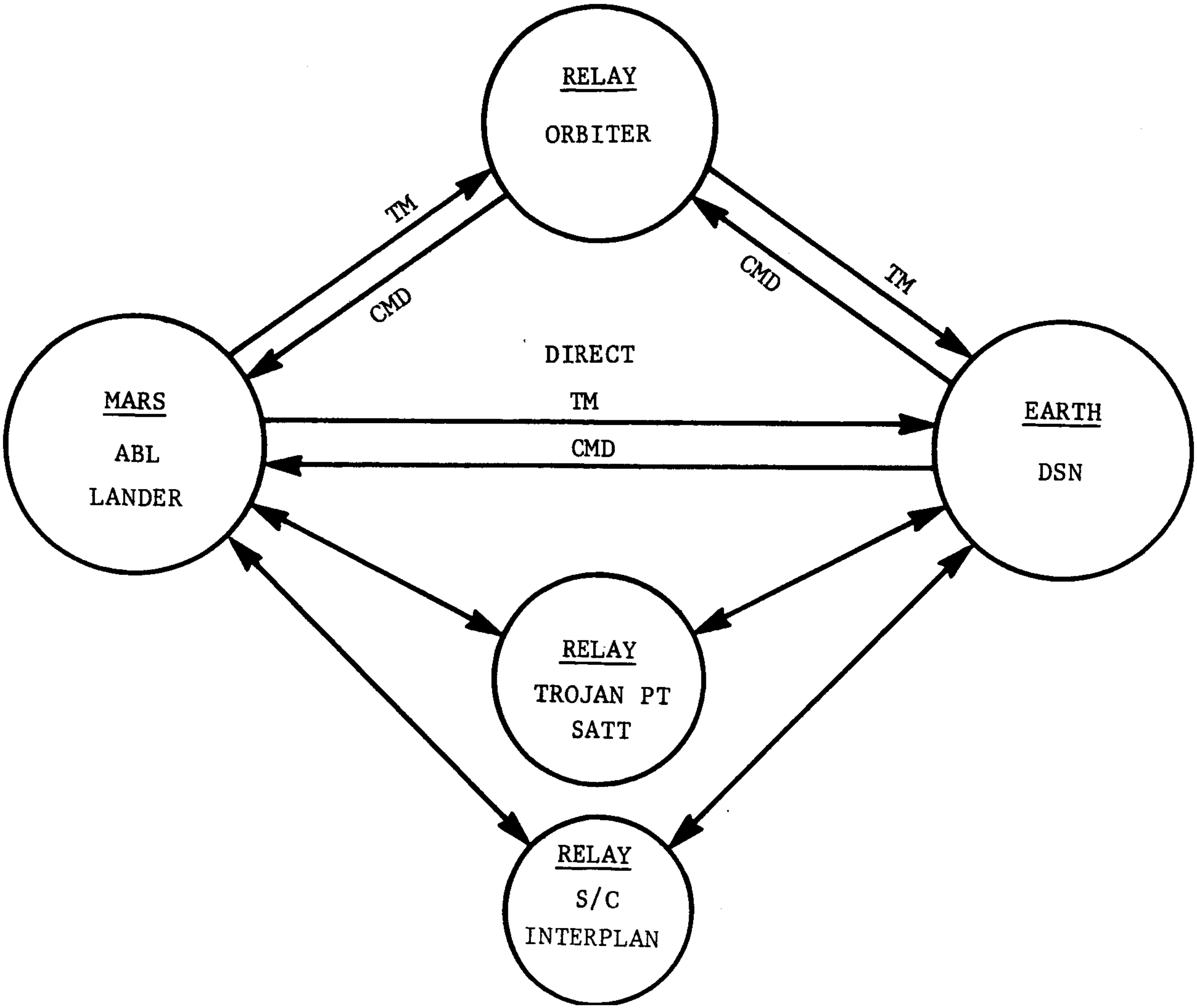
B is predetection or phase lock loop bandwidth (cps)

R is line-of-sight range (meters)

Thus, a given signal-to-noise performance, with additional allowance for various circuit and link performance margins can be achieved for certain specified values of the affected parameters. Our purpose is to identify a reasonable set of these parameters and evaluate the associated information transmission characteristics for Direct and Relay links between Earth and the ABL.

a. Basic Transmission Modes. The basic modes of transmission and command-control are shown in the diagram of Figure 6.2-4. The direct link requires the minimum operating system, which for ABL missions is an important consideration, providing an adequate amount of information can be obtained. A major uncertainty associated with establishing a direct link is the ability to successfully land the ABL on Mars and perform the subsequent capsule deployment and antenna orientation operations. In the case of an orbiter relay link, successful capsule deployment is also a requirement, but possibly with a less critical antenna orientation requirement. However, added uncertainties are achieving proper orbit injection of the relay and the successful working of another entire communication system. The other modes of relay transmission possess these same or similar operational uncertainties.

In any case, transmitter power must be provided in the ABL in relation to channel (information) bandwidth and to the varied degrees of sophistication chosen for the communication link; i.e., relay, direct, encoding and decoding scheme, transmitter and antenna system. The bit rate (bandwidth) is in direct proportion to transmitter power and inversely proportional to the distance squared. Hence, the tradeoffs and information transfer characteristics concerned with the use of relay or direct communication modes is best examined by assuming an identical, satisfactory modulation method for each case and allowing the geometrical constraints to act.



R14940U

FIGURE 6.2-4. BASIC TRANSMISSION MODES

b. Modulation Method. The Mariner IV Format, PCM/PSK/PM mode, will be adopted for both the telemetry and command links in this examination. Modulation indices (MI) as employed for carrier and subcarrier operation are thus used, although it is recognized that a more optimum scheme may be employed based upon a more detailed consideration of ABL mission constraints.

The telemetry link power distribution results in the following allocations:

Carrier Power (-4.1 db) = 40 percent

Data Subcarrier Power (-4.6 db) = 38 percent

Sync Subcarrier Power (-10.5 db) = 9 percent

(Note: Data MI - 0.809 rad pk; Sync MI - 0.451 rad pk)

The command link power is distributed as follows:

Carrier Power (-3.2 db) = 49 percent

Data Subcarrier Power (-8.5 db) = 14.2 percent

Sync Subcarrier Power (-5.5 db) = 29 percent

(Note: Data MI - 0.717 rad pk; Sync MI - 0.655 rad pk)

Therefore, the required transmitter power is further determined by the carrier and subcarrier channel system design. The required carrier power depends on the APC noise bandwidth ($2B_{LO}$) and the threshold SNR in $2B_{LO}$. The required data and sync power depend on desired bit rate, R_b, and required bit error rate, P_e. This may be further illustrated for both telemetry and command by including these requirements in the transmission equation cited above. From Equation (1) the normalized received signal-to-noise ratio can be expressed as:

$$\frac{P_r}{P_{n_o}} = \frac{P_t G_t G_r \lambda^2}{K T_e B_o (4\pi R)^2} \qquad (2)$$

For the carrier channel, the normalized SNR is then

$$\frac{P_{r_c}}{P_{n_o}} = L_c + \text{SNR in } 2B_{LO} + 2B_{LO} \text{ (in db)} \qquad (3)$$

while the normalized SNR for the data or sync subcarrier channel is

$$\frac{P_{r_{sc}}}{P_{n_o}} = L_{sc} + \frac{ST}{N/B} + R_b \text{ (in db)} \qquad (4)$$

where L_c and L_s are the carrier and subcarrier modulation losses, respectively, and ST/N/B is a constant for a given P_e. Again, note that additional (margin) allowance is required to compensate for various circuit and channel performance tolerances. The required power in either the data or sync channels can differ for each set of values L_{sc}, P_e, and R_b selected, and is seen to increase for increasing bit rate.

c. Direct Communication Antenna Pointing. An important communication systems consideration directly affecting required transmitter power and associated data rates is, of course, the transmitting antenna gain and coverage characteristics. Direct Link communications are enhanced when antenna gain and pattern coverage are optimized for a given ABL mission. The consequences of such optimization are the realization of a maximum daily information transfer rate with a minimum transmitter power and associated power supply or battery weight. During the course of the ABL studies, several antenna pointing techniques were examined. Although a 1971 Mars mission was examined as typical, the ideas are applicable to any time period requiring only adjustments in the initial conditions and overall angular spread.

(1) Earth-Sun Geometry. The position of the Earth and sun in a Mars equatorial coordinate system for late 1971 and early 1972 is shown in Figure 6.2-5. This time period shows the first six months of a 1971 Type I Mars lander mission. Longitude in the figure is referenced to the meridian containing the sun. A given landing site would undergo a daily motion from west to east along a constant latitude line in this coordinate system. For a representative landing date of 15 December 1971 (minimum energy mission), Earth is approximately 24 degrees below the Martian equator while the sun is approximately 18 degrees below the equator. Subsequently, the Earth and sun move northward, with the sun remaining a few degrees north of the Earth. With this frame of reference, material in Appendix 11 shows that, for a two-year mission, Earth may be seen to move within a band of 26 degrees above and below the Martian equator.

(2) Antenna Orientation Techniques. The efficiency of direct lander to Earth communications is strongly dependent upon the antenna gain that may be reliably employed. Ideally, it would be desirable to direct a high-gain pencil beam antenna at the Earth during its daily motion above the landing site horizon. Such an operation would be quite difficult to implement because of the rather elaborate sensor and antenna steering requirements.

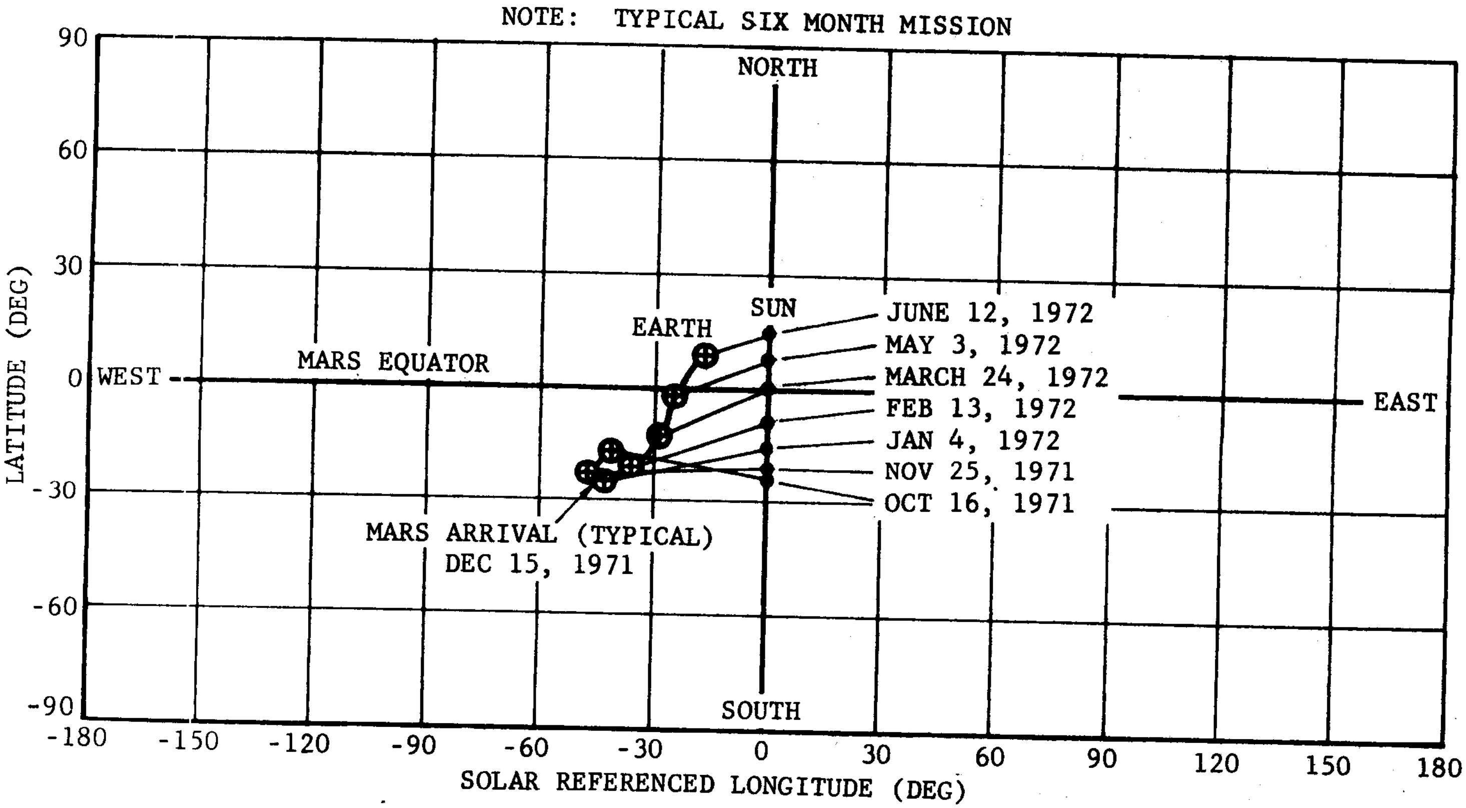


FIGURE 6.2-5. EARTH-MARS COMMUNICATION GEOMETRY - 1971

The reliability with which such a process could be performed for a two-year mission would certainly be doubtful. A more desirable approach would be to seek means of accomplishing the antenna-directing process without recourse to the actual tracking of Earth. A partial listing of such methods includes the following.

(a) Erection of Conical Beam to Local Vertical. If the landing site is sufficiently near the latitude of Earth, a broad conical beam would sweep across the position of Earth on a daily basis. Because of the 40-degree latitude change of Earth during the six months after landing, it is apparent that a broad cone pattern is required. (For the two-year period, this would grow to a 52-degree change.) Only slight improvements, therefore, over omnidirectional propagation would result.

(b) Westward Drift Method. If a conical beam pattern is centered on the sun and then fixed with respect to the lander, the westward drift of the Earth and sun will cause the Earth to pass through the beam at a known time on a daily basis. The first pass of Earth through the beam occurs approximately 21 hours after the alignment with the sun for the 15 December 1971 landing. The technique is successful because of the latitude similarity between the sun and Earth. The cone angle must be sufficient to overcome the latitude discrepancy and provide sufficient communication duration. Because of this changing latitude of the Earth and sun, reorientation would have to be performed periodically. An advantage of this method is that it works for arbitrary landing sites, and prior knowledge of the landing location or accurate establishment of the local vertical is not required.

(c) Use of Fan Beam. A modification of the westward drift approach can be used to increase the duration of available communication time for a given antenna gain. This is accomplished by orienting a fan beam with its long dimension in the path of Earth's apparent motion. The sun can again be used as the needed reference. The most general procedure would be to first align the beam axis to the sun, fix the axis in this position, and then, after a prescribed time interval, rotate the fan about this axis to again place the sun in the fan. Corrections for latitude (declination) differences between the Earth and sun could be subsequently accomplished.

An especially simple orientation process is possible if the time of local noon is known or can be sensed and if the landing-site latitude differs sufficiently from that of the sun. This process is discussed in detail below.

(3) Simple Fan Beam Orientation Method. Under the assumption that the Mars landing site will not be at a latitude in common with the sun and that the time of local noon can be estimated or sensed with sufficient accuracy, the following technique can be utilized for orienting a fan-shaped

beam. After landing, a local vertical, denoted by $\hat{z}$ in Figure 6.2-6, is established. At local noon, a sun sensor is used to align the $\hat{x}'$ axis (fan axis) to the plane containing the sun and the landing site. This is accomplished by rotating about the local vertical. The elevation angle β can then be adjusted to the required value for Earth, again using the sun as a reference. The latter steering process could be done either electronically or mechanically. The required changes in β to account for the changing latitude of Earth would be known in advance.

To evaluate the effectiveness of the beam pattern, it is helpful to consider the motion of the Earth in the beam coordinate system defined at the bottom of Figure 6.2-6. The position of Earth in these coordinates is given by

$$\begin{Bmatrix} \cos\theta_2 \ \cos\theta_1 \\ \cos\theta_2 \ \sin\theta_1 \\ \sin\theta_2 \end{Bmatrix} = \begin{bmatrix} \cos(\beta-\mu) & 0 & -\sin(\beta-\mu) \\ 0 & 1 & \\ \sin(\beta-\mu) & 0 & \cos(\beta-\mu) \end{bmatrix} \begin{Bmatrix} \cos\delta \ \cos\lambda \\ -\cos\delta \ \sin\lambda \\ \sin\delta \end{Bmatrix} \tag{5}$$

where

δ is declination of Earth

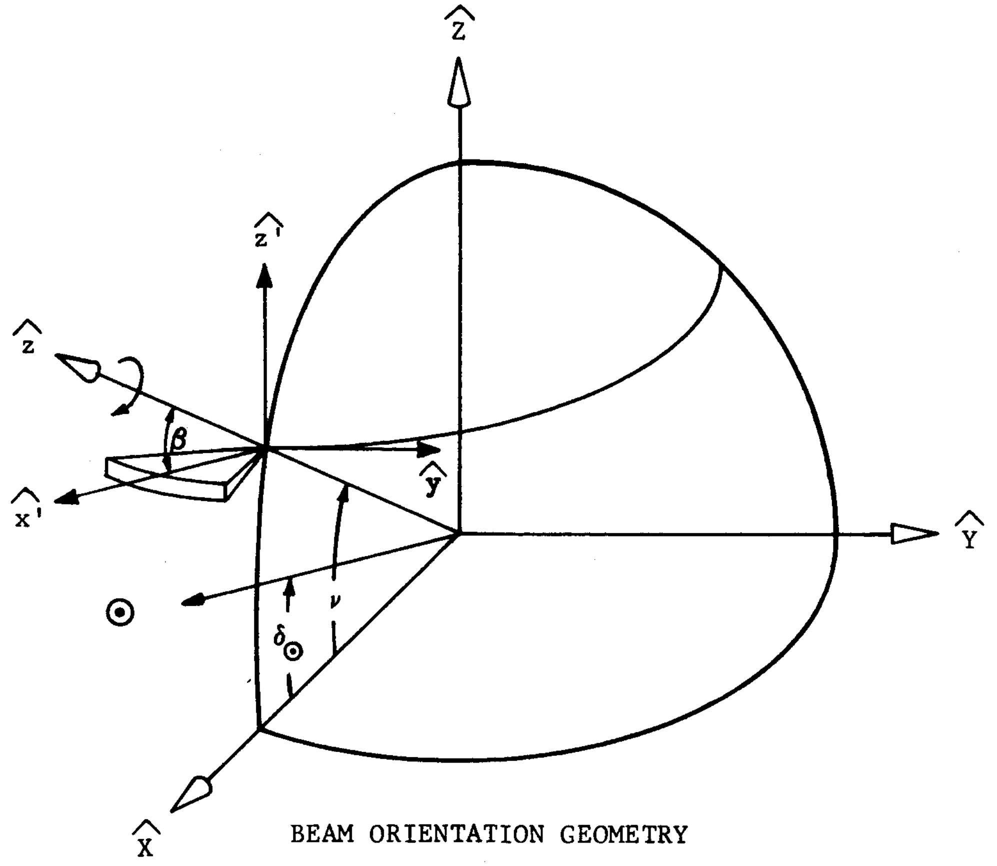
λ is longitude of landing site minus longitude of Earth

μ is landing site latitude

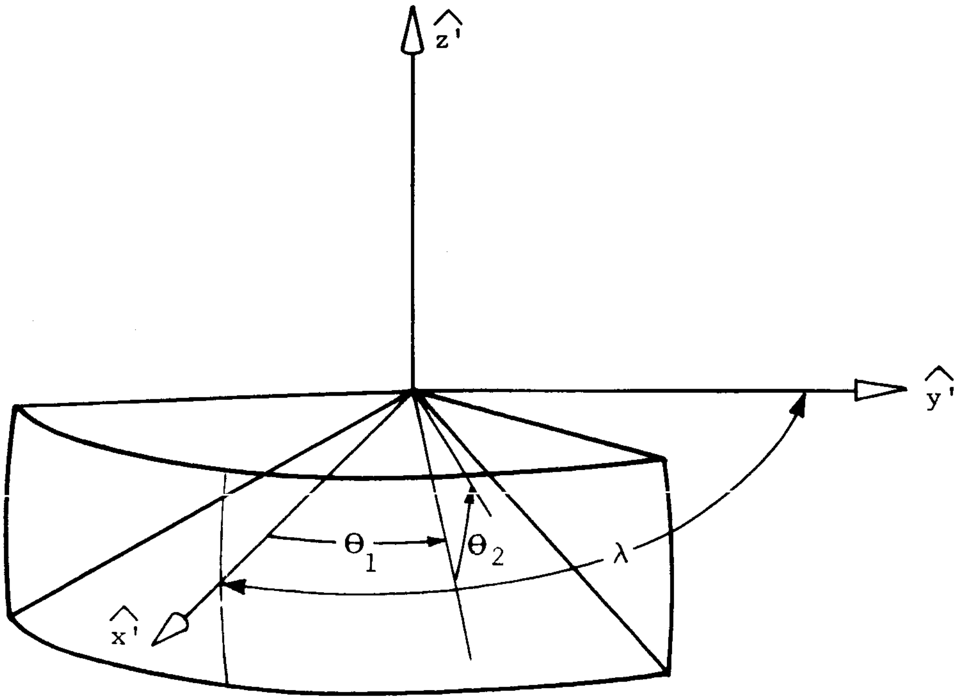
β is complement of beam elevation

Figure 6.2-7 shows the resulting motion of the Earth in beam coordinates for the 1971 mission. A 10-degree-by-40-degree fan initially centered on the Earth is seen to provide complete coverage for approximately two months after landing. Communication after this time would require a change in the value employed. Crucial to the system is the accuracy with which it may be oriented. An error in the orientation of the $\hat{x}$, $\hat{y}$, $\hat{z}$ coordinate system results in modified beam coordinates. A small rotational error can be represented as a vector of the form

$$\bar{\alpha} = \alpha_1 \hat{x}' + \alpha_2 \hat{y}' + \alpha_3 \hat{z}' \ . \tag{6}$$



BEAM ORIENTATION GEOMETRY



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BEAM COORDINATES

FIGURE 6.2-6. FAN BEAM ANTENNA GEOMETRY

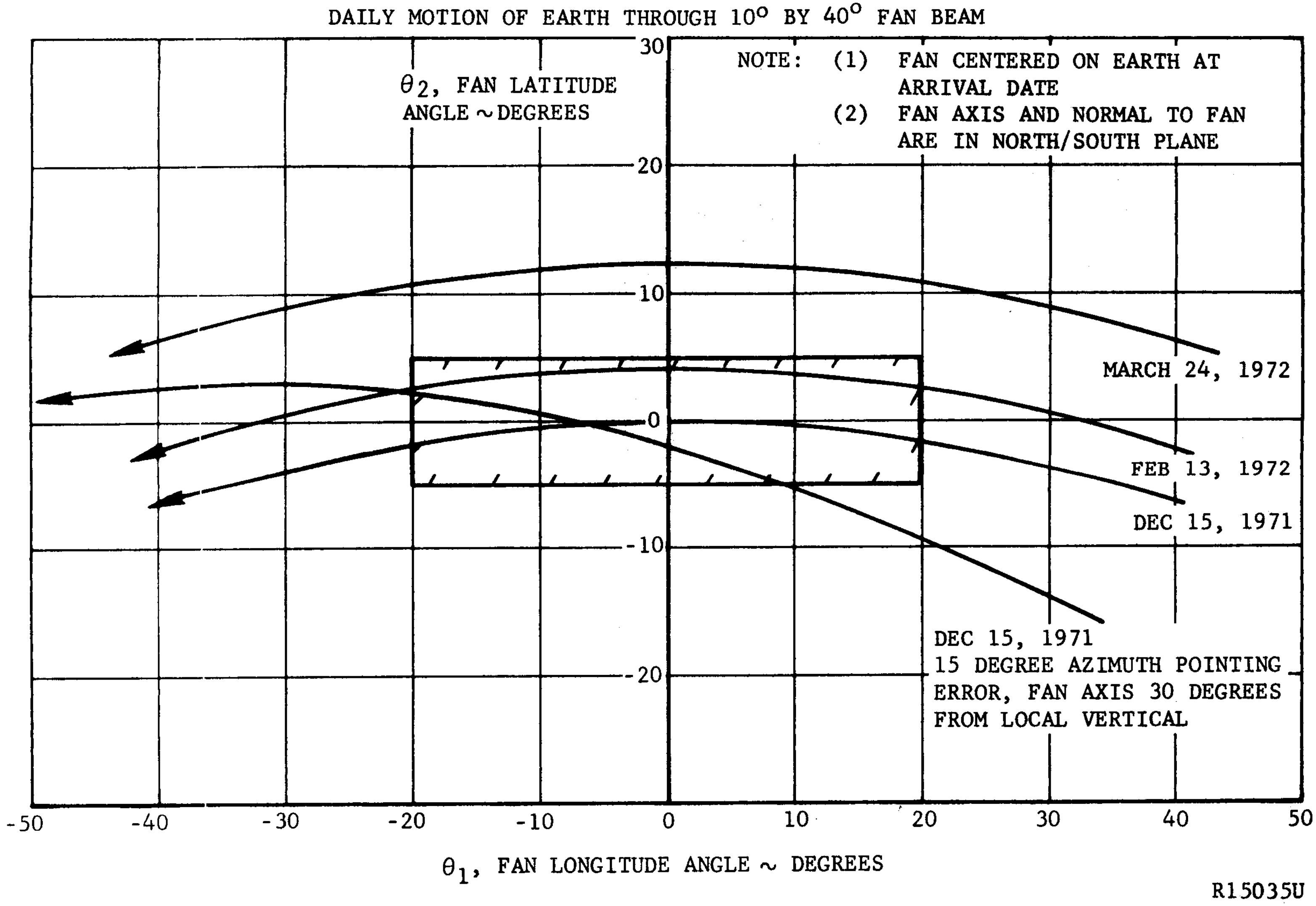

FIGURE 6.2-7. EARTH MOTION IN FAN BEAM FOR 1971 MISSION INTERVAL

By denoting the modified beam coordinates by $\tilde{\theta}_1$ and $\tilde{\theta}_2$, the effect of angular errors may be computed from

$$\begin{Bmatrix} \cos\tilde{\theta}_2 \ \cos\tilde{\theta}_1 \\ \cos\tilde{\theta}_2 \ \sin\tilde{\theta}_1 \\ \sin\tilde{\theta}_2 \end{Bmatrix} = \begin{bmatrix} 1 & \alpha_3 & -\alpha_2 \\ -\alpha_3 & 1 & \alpha_1 \\ \alpha_2 & -\alpha_1 & 1 \end{bmatrix} \begin{Bmatrix} \cos\theta_2 \ \cos\theta_1 \\ \cos\theta_2 \ \sin\theta_1 \\ \sin\theta_2 \end{Bmatrix} \tag{7}$$

The effect of a 15-degree error in aligning the azimuth of the $\hat{x}'$ axis is shown in Figure 6.2-7. A β value of 30 degrees was assigned for this computation. Even for this substantial error, significant communication time is available. As will be noted in Paragraph 6.2.4c, various trade-offs between fan beam sector coverage and gain may be made for a given communication time.

d. Relay Communication Orbit Perturbations. Another important consideration in the ABL communication system analysis is the effect of orbit perturbations on relay communications. The oblateness of Mars will cause the elements of an orbit about Mars to change with time. This will have an effect upon the use of an orbital relay concept for Lander-to-Earth communications. The most significant effect will be produced by the rotation of the orbit line of apsides (apoapsis/periapsis line). The rotation of the line of apsides on a per-revolution basis is given by

$$\Delta\omega = 3\frac{\pi}{2} J_2 (R♂/p)^2 (4-5 \sin^2 i) \tag{8}$$

where

$R♂$ is Mars radius

p is orbit semilatus rectum

i is orbit inclination

J_2 is second potential harmonic term ≈ 0.002.

The magnitude of the potential term has been determined by a number of investigations, as reported in Reference 3.

The above equation was used to evaluate the apsidal precession rates shown in Figure 6.2-8. Rates are expressed on a per-day rather than a per-revolution basis. Elliptical orbits were utilized, reflecting current

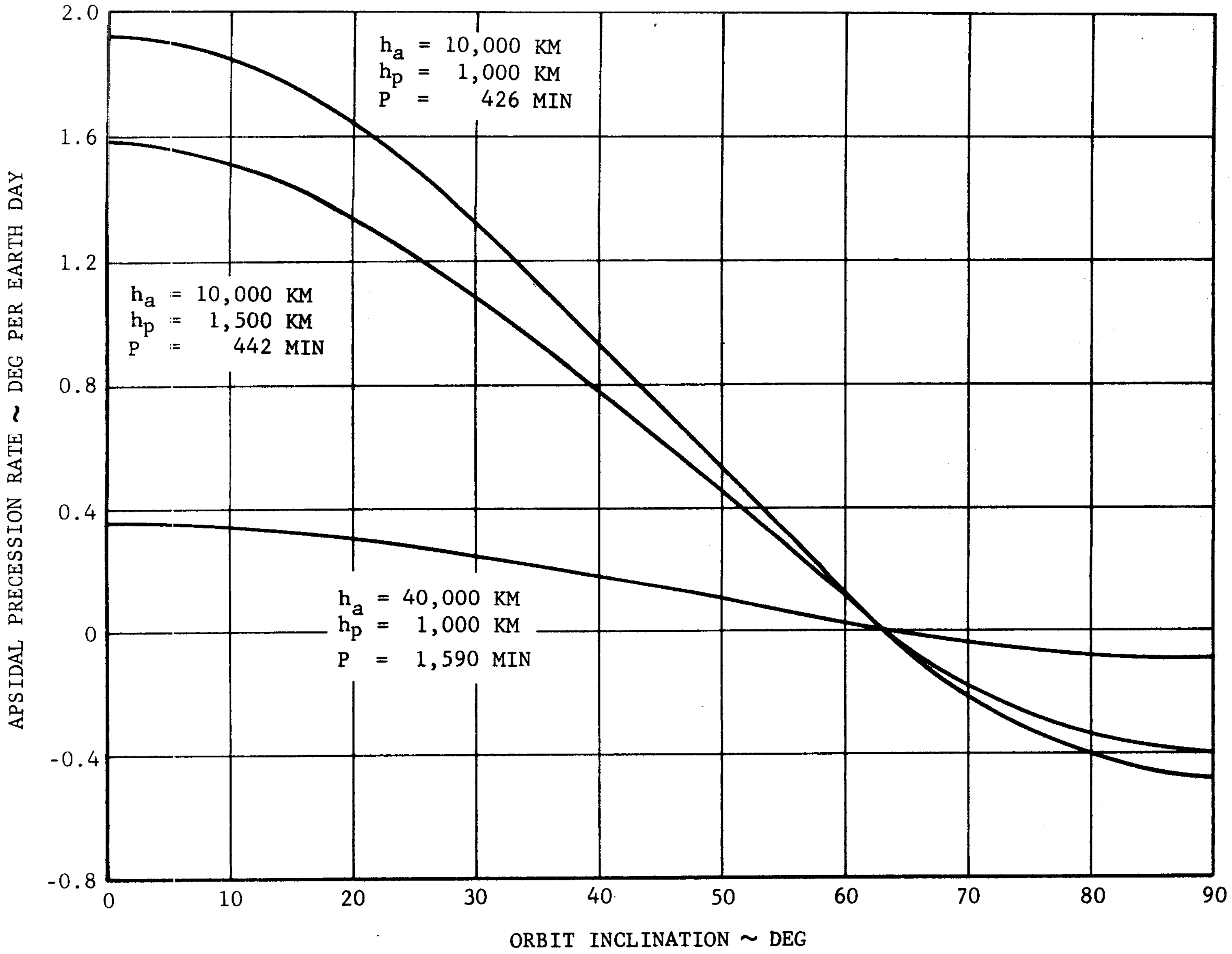

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FIGURE 6.2-8. MARS ORBIT APSIDAL PRECESSION RATES thinking with regard to reducing propulsive requirements for establishing the orbit. These apsidal precession rates were used to establish average communication times between the landing site and the orbiter, as shown in Figure 6.2-9. A periapsis altitude of 1500 kilometers and an apoapsis altitude of 10,000 kilometers were utilized. A polar orbit was assumed, and the landing site was taken to be just north of the Martian equator. Average available time per orbit varies between approximately 70 and 90 minutes. Since the orbital period is approximately one-third of a day, the average daily communication time will represent roughly 200 to 300 minutes. Since there is a substantial difference between the orbital period and the length of day, there will be no extensive periods during which communication opportunities are absent.

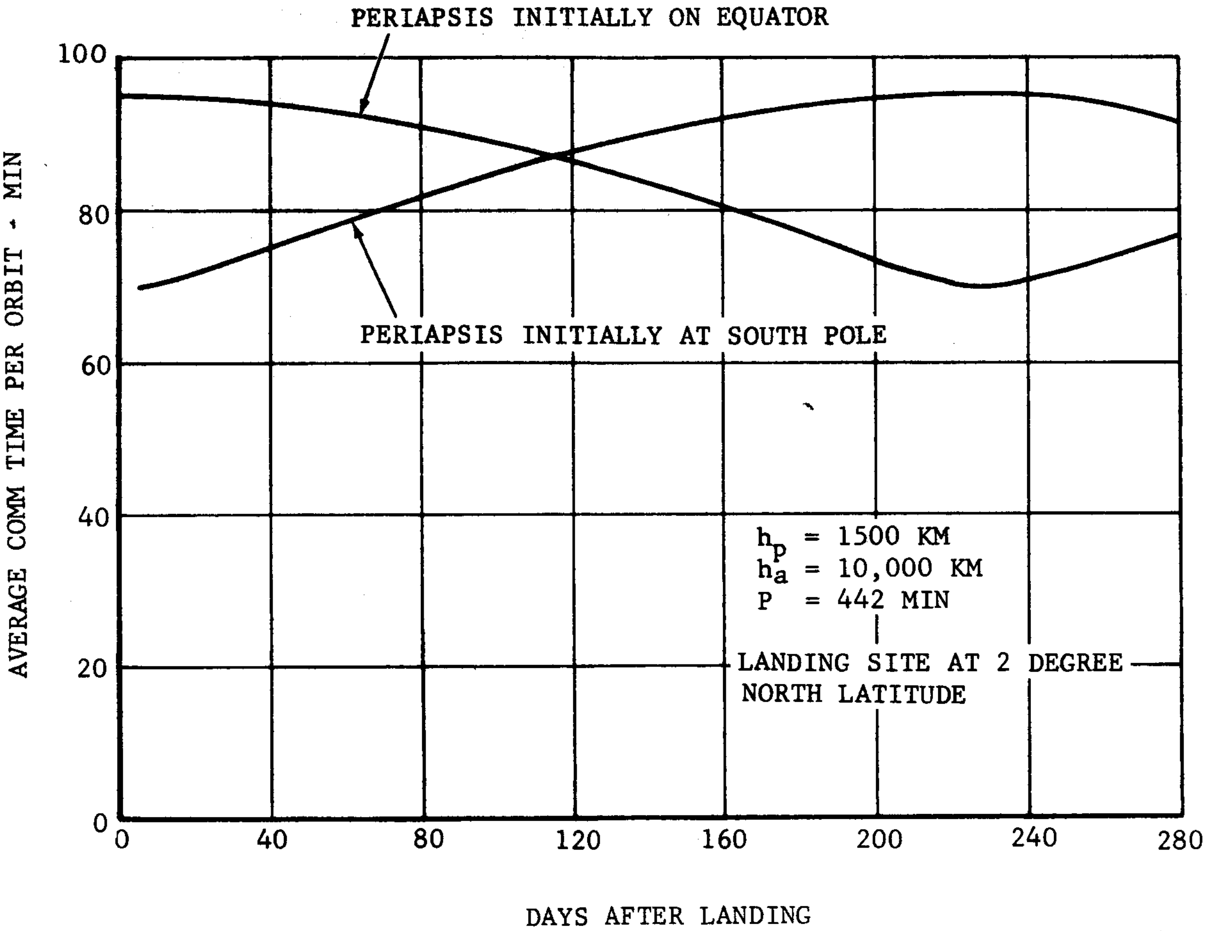

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FIGURE 6.2-9. AVERAGE COMMUNICATION TIMES - MARS ELLIPTIC ORBIT

6.2.4 DIRECT LINK TELECOMMUNICATION ANALYSIS

For the Direct Link, the major characteristics are determined by the DSN and the maximum communication distances involved. For compatibility, therefore, reception and transmission of a phase-modulated (PM) RF carrier operating at S-band (i.e., 2295-Mc reception and 2115-Mc transmission frequencies) are required. Use of subcarriers which are phase-shift-keyed (PSK) by the binary or pulse-code data and sync waveforms are required to phase-modulate the carrier. Coherent demodulation and matched filter detection are employed.

For any ABL Mars mission, an important variable is range. Reference to Figures 6.2-1 and 6.2-2 shows that the minimum-to-maximum range excursion constitutes a 17-db space loss differential. A communication link designed for the maximum range condition and possessing a minimum data rate capability of n bits/second would have this 17 db as excess margin for the minimum range condition, assuming all other parameters fixed. This increase in margin must be appropriately scaled to mission time, however, since, for any given mission in the 1970 decade (based upon Type I trajectory arrival times), the full margin is realized only near the end of the mission. This excess margin can be employed in the data channel to increase data rate capability. Thus a 50n bits/second maximum capability is possible at the minimum range, or a similar reduction in transmitter power could be realized.

The important point is that a schedule of increased data rates or decreased transmitter power or some combination thereof, appears desirable for ABL extended-range missions. This conclusion has been reached in earlier deep space programs and is not new.

a. Telemetry Link. To visualize an actual telecommunication link design, a two-year (1975, Type 1) mission beginning with a 7 April 1976 arrival date is selected for evaluation. A PCM/PSK/PM (Mariner IV Format) telemetry link design is employed utilizing a transmitter power of 80 watts and a maximum range condition of 2.53 A.U. (380×10^6 km). A peak antenna gain of 12 db or better is required to effect carrier tracking at the maximum range condition for the specified design cited. Use of the highest possible transmitter power and antenna gain maximizes the data rate, permitting a greater total data transfer for any given period. This affords a degree of trade-off with available communication time. Reduced data transmission periods obviously minimize the burden placed upon the DSN, releasing it for other operations and necessary maintenance schedules.

The Design Control Table (Table 6.2-I) depicts values for all parameters entering into the link design for the design point system described in Paragraph 6.2.8. Use of a multifan beam antenna system of 15.5-db peak gain is assumed. The data rate capability for this design is depicted as a point in Figure 6.2-10, which is a parametric plot of bit rate, range, and effective radiated power. The significant variations caused by mission

TABLE 6.2-I

TELECOMMUNICATION DESIGN CONTROL TABLE (DESIGN POINT)
MARS-EARTH DIRECT TELEMETRY LINK

Project: ABL Lander
Channel: ABL Facsimile and Bio Data
Mode: PCM/PSK/PM (Mariner IV Format)

No.	Parameter	Value	Tolerance		Source
1	Total Transmitter Power, 80 w	+49.0 dbm	+1.0	-1.0	FPC, ADP
2	Transmitting Circuit Loss	-2.0	+1.0	-0.5	FPC, ADP
3	Transmitting Antenna Gain*	+15.5	+0.0	-2.0	FPC, ADP
4	Transmitting Antenna Pointing Loss	-3.0	+3.0	-0.0	
5	Space Loss at 2295 Mc, R = $\frac{380 \times 10^6 \text{ km}}{2.53 \text{ A.U.}}$	-271.3			FPC, ADP
6	Polarization Loss	-0.3	+0.3	-0.3	FPC, ADP
7	Receiving Antenna Gain	+61.0	+1.0	-1.0	JPL TM 33-83
8	Receiving Antenna Pointing Loss	-1.0	+0.1	-0.1	JPL TM 33-83
9	Receiving Circuit Loss	-0.1	+0.1	-0.1	JPL TM 33-83
10	Net Circuit Loss	-201.2	+5.5	-4.0	Σ2 thru 9
11	Total Received Power	-152.2 dbm	+6.5	-5.0	Σ1, 10
12	Receiver Noise Spectral Density $(N/B)_o$ T system = $30^\circ \pm 5^\circ$K	$-183.8 \frac{\text{dbm}}{\text{cps}}$	+0.7	-0.9	TM 33-83
13	Carrier Modulation Loss	-4.1	+0.7	-0.9	JPL Spec MC-4-310A
14	Received Carrier Power	-156.3	+7.2	-5.9	Σ11, 13
15	Carrier APC Noise BW ($2B_{LO}$ = 12 cps)	+10.8 db,cps	+0.0	-0.5	Spec - 310A

TABLE 6.2-I (Continued)

No.	Parameter	Value	Tolerance		Source
	Carrier Performance - Tracking (One-Way)				
16	Threshold SNR in $2B_{LO}$				
17	Threshold Carrier Power				
18	Performance Margin				
	Carrier Performance - Tracking (Two-Way)				
19	Threshold SNR in $2B_{LO}$				
20	Threshold Carrier Power				
21	Performance Margin				
	Carrier Performance				
22	Threshold SNR in $2B_{LO}$	+6.0			Spec-310A
23	Threshold Carrier Power	-167.0 dbm	+0.7	-1.4	Σ12,15,22
24	Performance Margin	+10.7	+8.6	-6.6	Σ14,(-23)
	Data Channel				
25	Modulation Loss $\theta_D = 0.809$	-4.6	+0.4	-0.4	Spec-310A
26	Received Data Subcarrier Power	-156.8 dbm	+6.9	-5.4	Σ11,25
27	Bit Rate (1/T) 19.0 bps	+12.8 db cps			
28	Required ST/N/B $P_e = 2.5 \times 10^{-3}$ **	+7.5 $\frac{\text{db cps}}{\text{bps}}$	+0.5	-0.5	WFL, ADP
29	Threshold Subcarrier Power	-163.5 dbm	+1.2	-1.4	Σ12,27,28
30	Performance Margin	+6.7	+8.3	-6.6	Σ26 (-29)

TABLE 6.2-I (Continued)

No.	Parameter	Value	Tolerance		Source
	Sync Channel				
31	Modulation Loss $\theta_s = 0.451$	-10.5	+0.1	-0.0	Spec-310A
32	Received Sync Subcarrier Power	-162.7 dbm	+6.6	-5.0	Σ11,31
33	Sync APC Noise BW ($2B_{LO} = 1$ cps)	0.0			
34	Threshold SNR in $2B_{LO}$	+11.0 $\frac{\text{db cps}}{\text{bps}}$	+0.5	-0.5	WFL, ADP
35	Threshold Subcarrier Power	-172.8 dbm	+1.2	-1.4	Σ12,33,34
36	Performance Margin	+10.1	+8.0	-6.2	Σ32 (-35)

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* Transmitting Antenna Assumed: 56x13-Degree Fan Beam

** $\frac{ST}{N/B} = 6.0$ db.$\frac{\text{cps}}{\text{bps}}$ for $P_e = 2.5 \times 10^{-3}$. An additional +1.5 db is, however, added to this theoretical value, to allow for performance tolerances in a practical system mechanization.(4)

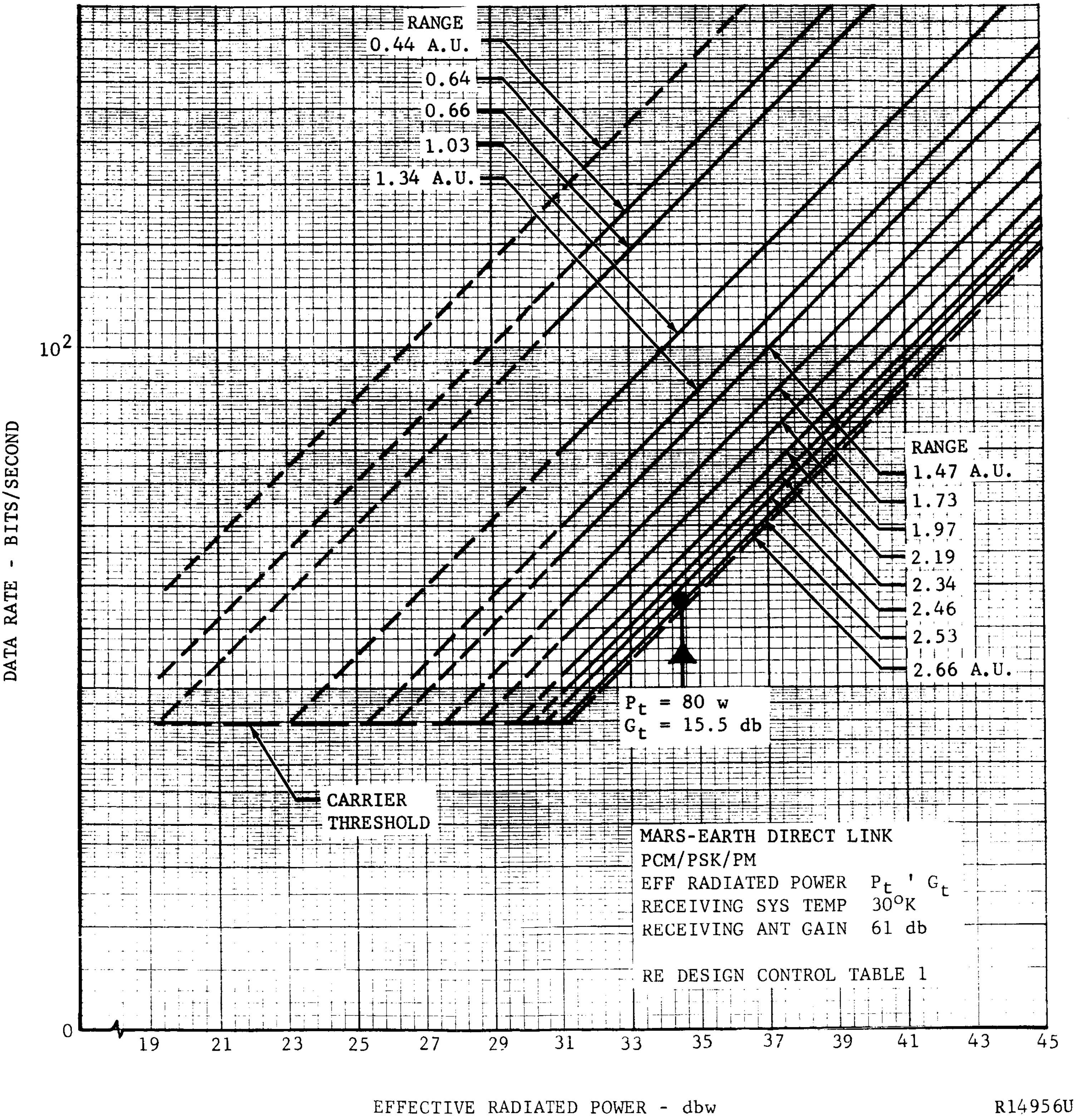

FIGURE 6.2-10. ABL DATA RATE VERSUS EFFECTIVE RADIATED POWER AND RANGE

duration and other potential mission periods covering the 1970 decade are shown in Figure 6.2-11 for the design point value of effective radiated power, +34.5 dbw. The excess margin (margin in excess of worst-case tolerances) in the TMcarrier channel versus range is shown in Figure 6.2-12. At encounter, 1.47 A.U. (or 220 x 10^6 km), an excess margin of 5.2 db results. This can be used to facilitate initial carrier acquisition. Moreover, this same margin is present in the data channel and is employed to provide increased data rate capability at the start of the Lander operations.

For the 1975 mission cited, bit rate capability begins at approximately 58 bps and is reduced to 19.0 bps at maximum range; a 300-bps peak rate is possible at minimum range. If one assumes a 3-hour-per-day communication time for the direct link (which is consistent with the postulated fan beam antenna coverage) and takes 68 bps as the mean value of bit rate possible over the 1975 mission period, a mean value of total data transferred is 7.0 x 10^5 bits per day. It should be noted that mission periods become less favorable from the Earth-Mars communication geometry standpoint as time progresses into the 1970 decade. This is illustrated by the data in Figure 6.2-1 and Appendix 11. Consequently, the data rate capability realized in the first few months of a mission period is progressively degraded from subsequent mission to mission. Based upon the previously cited telecommunication link parameters, a mean bit rate of about 100 bps is evaluated for the 1970 decade. Thus a mean value of total data transferred on this basis is 1.1 x 10^6 bits per day, a factor of about 1.5 better than the specific value obtained above for the 1975 mission period. This simply points up the fact, as mentioned previously, that a schedule of discrete bit rate variation versus mission time should be employed in the design to maximize the data transfer characteristic for any given mission.

b. Command Link. Earth-to-Mars command-control is required to facilitate the conduct of ABL experiments by affording a minimum degree of control or flexibility in experiment sequencing or selection. To be compatible with the DSN, a PCM/PSK/PM (Mariner IV Format) telecommunication link design is cited. The Design Control Table (Table 6.2-II) depicts the design requirements associated with the command link for a range of 2.53 A.U. This corresponds to the maximum distance point in a 1975 ABL Mission with a 7 April 1976 arrival date. A turnstile antenna with a 6-db gain and 90 degree beamwidth is assumed to minimize pointing requirements while providing needed gain. The importance of achieving medium gain in the receiving system is fundamental to the successful operation of the command link when one observes the 100-kw transmitter power utilization that is required. The mode of operation is to provide full mission duration coverage for command-link operation via the command antenna. Once operation is secured and telemetry reception has been verified, coverage to maximum distance may be included by switching command reception to share the

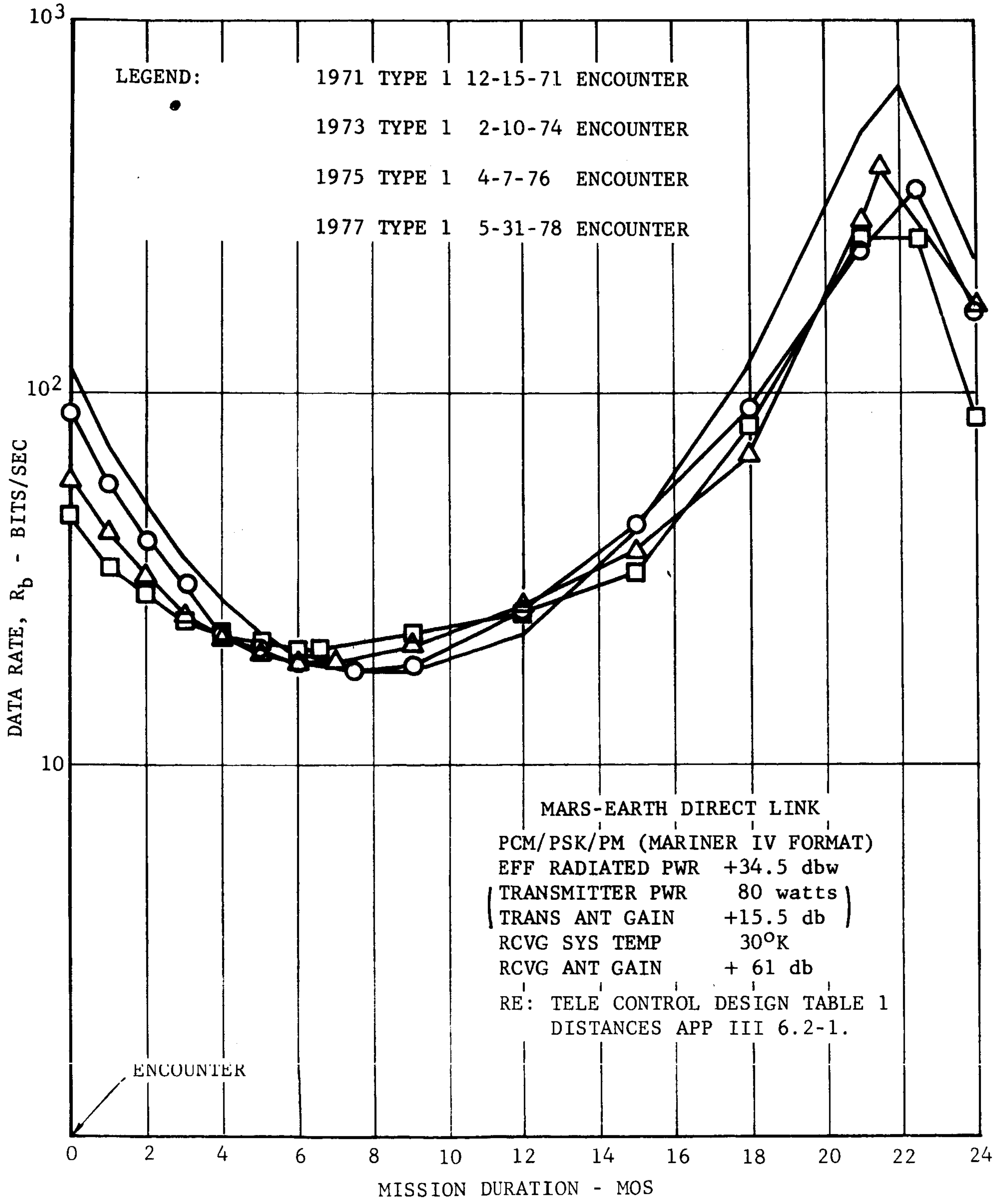

FIGURE 6.2-11. ABL DATA RATE VERSUS MISSION DURATION - 1970 DECADE

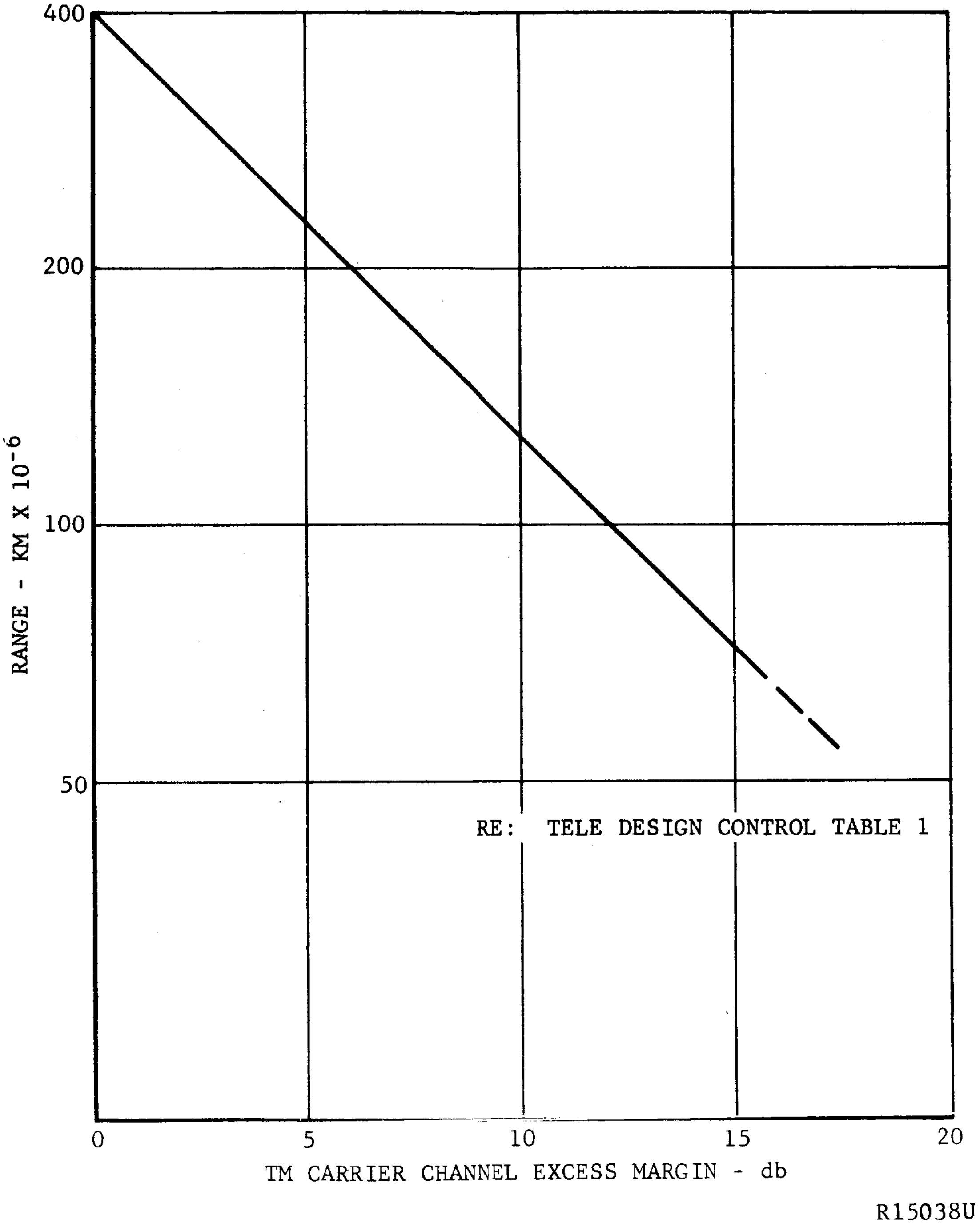

FIGURE 6.2-12. CARRIER EXCESS MARGIN VERSUS RANGE

TABLE 6.2-II

TELECOMMUNICATION DESIGN CONTROL TABLE (DESIGN POINT) MARS-EARTH DIRECT COMMAND LINK

Project: ABL Lander
Channel: Command
Mode: PCM/PSK/PM (Mariner IV Format)

No.	Parameter	Value	Tolerance		Source
1	Total Transmitter Power, 100 kw	+80 dbm			JPL Spec MC-4-310A
2	Transmitting Circuit Loss	-0.4	+0.1	-0.1	JPL TM 33-83
3	Transmitting Antenna Gain	+53.0	+1.0	-0.5	-310A
4	Transmitting Antenna Pointing Loss				
5	Space Loss* at 2115 Mc, $R = \frac{380.0 \times 10^{6} \text{km}}{2.53 \text{ A.U.}}$	-270.5			FPC, ADP
6	Polarization Loss				
7	Receiving Antenna Gain**	+6.0	+1.0	-3.0	FPC, ADP
8	Receiving Antenna Pointing Loss	-1.0	+0.1	-0.1	FPC, ADP
9	Receiving Circuit Loss	-1.5	+0.4	-0.4	FPC, ADP
10	Net Circuit Loss	-214.4 db	+2.6	-4.1	Σ2 thru 9
11	Total Received Power	-134.4 dbm	+2.6	-4.1	Σ1, 10
12	Receiver Noise Spectral Density (N/B) $T \text{ system} = \frac{1140^{o}\text{k}^{+900^{o}\text{k}}_{-250^{o}\text{k}}}{\text{NF} = 5.5 \text{ db}}$	-168.0 $\frac{\text{dbm}}{\text{cps}}$	+2.5	-1.0	FPC, ADP
13	Carrier Modulation Loss	-3.2	+0.3	-0.3	-310A
14	Received Carrier Power	-137.6	+2.9	-4.4	Σ11, 13

TABLE 6.2-II (Continued)

No.	Parameter	Value	Tolerance		Source
15	Carrier APC Noise BW ($2B_{LO} = 20$ cps)	+13.0			
	<u>Carrier Performance - Tracking (One-Way)</u>				
16	Threshold SNR in $2B_{LO}$				
17	Threshold Carrier Power				
18	Performance Margin				
	<u>Carrier Performance - Tracking (Two-Way)</u>				
19	Threshold SNR in $2B_{LO}$				
20	Threshold Carrier Power				
21	Performance Margin				
	<u>Carrier Performance</u>				
22	Threshold SNR in $2B_{LO}$	+8.0	+1.0	-1.0	-310A
23	Threshold Carrier Power	-147.0	+3.5	-2.0	Σ12,15,22
24	Performance Margin	+9.4	+4.9	-7.9	Σ14 (-23)
	<u>Data Channel</u>				
25	Modulation Loss $\theta = 0.717$	-8.5	+0.2	-0.2	-310A
26	Received Data Subcarrier Power	-142.9	+2.8	-4.3	
27	Bit Rate (1/T) 1 bps	0.0			-310A
28	Required ST/N/B	+15.7	+1.0	-1.0	-310A
29	Threshold Subcarrier Power	-152.3	+3.5	-2.0	Σ12,27,28
30	Performance Margin	+9.4	+4.8	-7.8	

TABLE 6.2-II (Continued)

No.	Parameter	Value	Tolerance		Source
	Sync Channel				
31	Modulation Loss $\theta = 0.655$	-5.5	+0.3	-0.2	-310A
32	Received Sync Subcarrier Power	-139.9	+2.9	-4.3	Σ11, 31
33	Sync APC Noise BW ($2B_{LO}$ = 2 cps)	+3.0	+0.8	-0.8	-310A
34	Threshold SNR in $2B_{LO}$	+15.7	+1.0	-1.0	-310A
35	Threshold Subcarrier Power	-149.3	+4.3	-2.8	Σ12,33,34
36	Performance Margin	+9.4	+5.7	-8.6	Σ32 (-35)

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* The 2.53 A.U. Distance is the maximum distance point in 1975 Type I Mission.

** Receiving Antenna Assumed: Turnstile 90-degree half-power beamwidth.

higher-gain fan-beam telemetry antenna. A nominal 4-db improvement would then be realized, which more than compensates for the additional 0.5-db space loss incurred as communication distances increase from the 2.53 A.U. (or earlier) distance to a potential maximum mission distance of 2.66 A.U.

Problems to be examined to improve command-link performance are in the area of lowering receiver system threshold sensitivity. Providing a low-temperature heat sink (utilizing the Mars cold-temperature environment) for the receiver front end would permit threshold improvement in proportion to temperature reduction; e.g., a one-half reduction in system temperature results in a 3-db added margin in performance. This improvement would permit command-link communication for the entire mission duration without any antenna switching requirement. It should be noted, consequently, that a DSN operating constraint requiring use of the 100-kw command transmitter appears as a prerequisite, assuming use of an 85-foot command antenna. This would imply command capability only from the Goldstone Site or dictate the additional requirement to have high-power transmitter command capability at the other DSN sites. On the other hand, use of the 210-foot antenna with 100-kw command capability would cover most eventualities, including allowance for essentially omnidirectional command antenna coverage. An additional operating constraint is derived from a consideration of Figure 6.2-1 and ABL mission experimentation. The plot shows one- and two-way communication transit times can consume up to 44 minutes duration at the maximum ranges. In general, this is not considered a major problem for direct-link communications but must be considered in scheduling Lander operations. Discussions pertinent to antenna considerations and solar blackout periods are referenced and described in the following paragraphs.

c. Antenna Discussion. Several antenna orientation schemes and methods were discussed earlier in Paragraph 6.2.3c. This paragraph pursues in more detail the various trade-offs and implementation considerations in connection with utilization of the fan-beam antenna system. In addition, a discussion of the potential antenna breakdown problem is presented in response to the constraint identified in Paragraph 6.2.2b.

(1) Fan-Beam Antenna Considerations. The fan beam minimizes antenna orientation and positioning requirements, relying on the relative movement of Earth within a beam sector width. Initial orientation Earthward will be accomplished in conjunction with the ABL vertical erect function. Beam switching and position changes will be required to provide adequate antenna coverage for a two-year period. It should be noted that the initial six months is the more critical period, because of the longer distances and the high reliance on needed gain. With some sacrifice in data transfer, antenna pointing requirements can be lessened as mission time progresses (and distance decreases). Antenna operating mode changes will be controllable as part of the normal experiment sequencing, which is presumed to require auxiliary control via Earth command control.

To facilitate a discussion of the trade-offs and implementation schemes, the following operating requirements are identified. A communication time of three hours per day is assumed, based on an equatorial-band Lander location. The intent is to utilize a physically optimum communication geometry which has essentially three hour guard bands on either side of the preferred period. Antenna polarization is circular. Frequency is 2100 to 2300 Mc. Power handling capability is 80 watts, with an antenna peak gain of 12 db or better desired. Antenna-beam positioning requirements for a two-year mission are a minimum of 4 to 5 incremental changes for relatively wide-beam coverage and 12 db gain to some number of n changes, based upon smaller beam-width characteristics. Beam-switching can be accomplished either electronically or mechanically to insure proper Earthward orientation. The total solid angle covered by the antenna system during an ABL mission can be determined by a knowledge of the data acquisition time per day and the duration of the mission. The east-west coverage angle, θ_1, of the solid angle is a function of the rotational period of Mars and the desired communication time and is determined from the following:

$$\theta_1 = 360 \frac{T}{P} \text{ degrees} = 360 \frac{3}{24.5} = 44 \text{ degrees} \qquad (9)$$

where

θ_1 is east-west coverage angle, degrees

T is data acquisition time, hours

P is rotational period of Mars, hours

The north-south coverage angle, θ_2, is a function of the "nodding" of the rotational axis of Mars relative to the Earth over the incremental duration period of the mission. For illustration purposes, assume the plot of Figure 6.2-5 defines a desired incremental angular period of coverage. For this six-month period of the 1971 example cited, $\theta_2 = 36$ degrees. The total solid angle over which antenna coverage is required on an incremental basis therefore is 44 by 36 degrees.

To illustrate the varied trade-offs which may be made, Figures 6.2-13 and 6.2-14 are presented. Figure 6.2-13 gives data on antenna peak gain versus half-power beam cross section. Auxiliary scales at the top and bottom of the figure give additional information on transmission time and antenna size as a function of beamwidth. For the example cited, the solid angle of 44 by 36 degrees may be covered by a single antenna beam whose peak gain is 12.3 db; the antenna size would be 9 x 11 inches if a flat planar array were chosen.

Increasingly higher gains can be realized if the solid coverage angle is divided into a number of small beams and the transmitter is switched to the appropriate beam at the appropriate time. The mechanization suggested

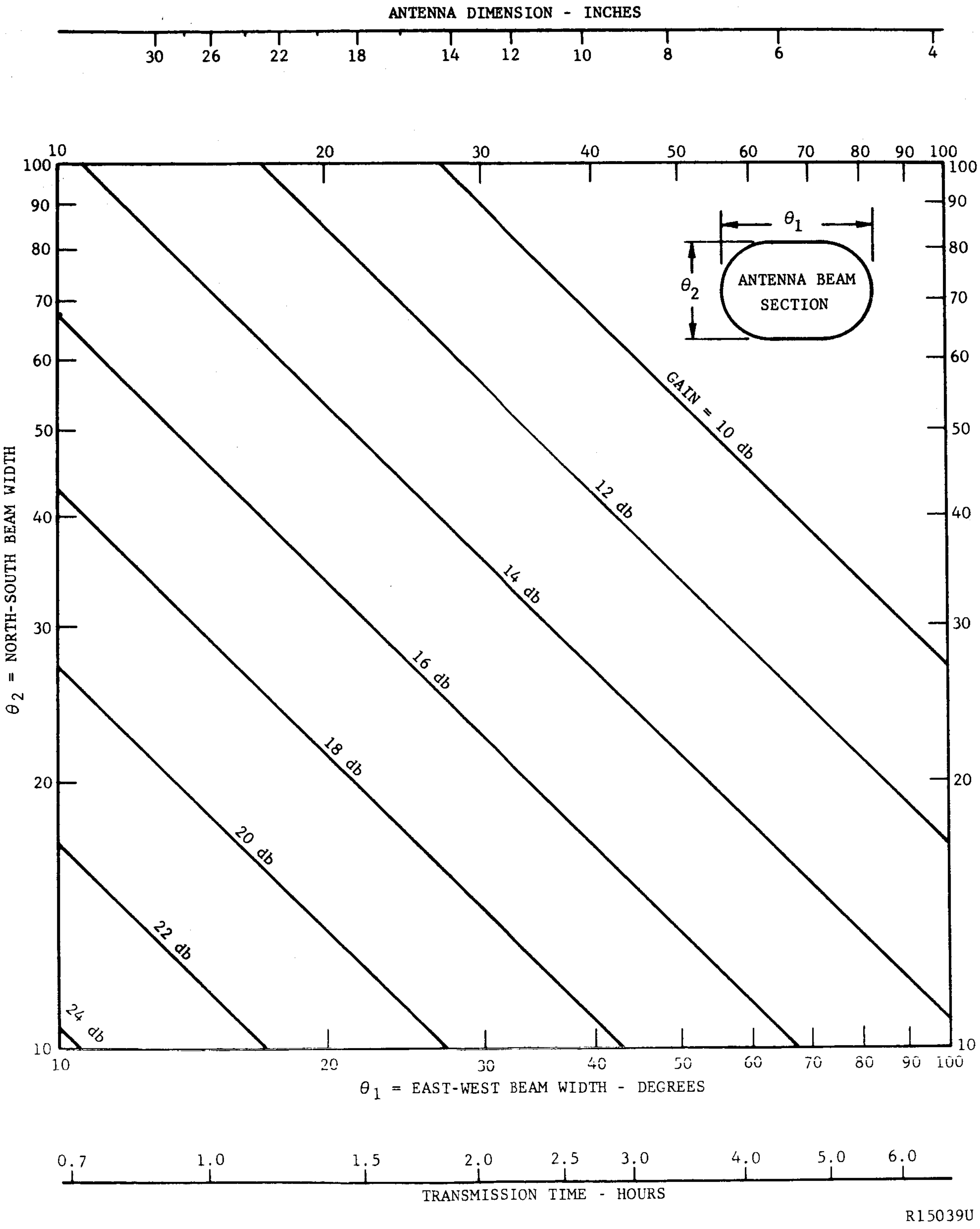

FIGURE 6.2-13. PEAK GAIN VERSUS ANTENNA BEAM CROSS SECTION

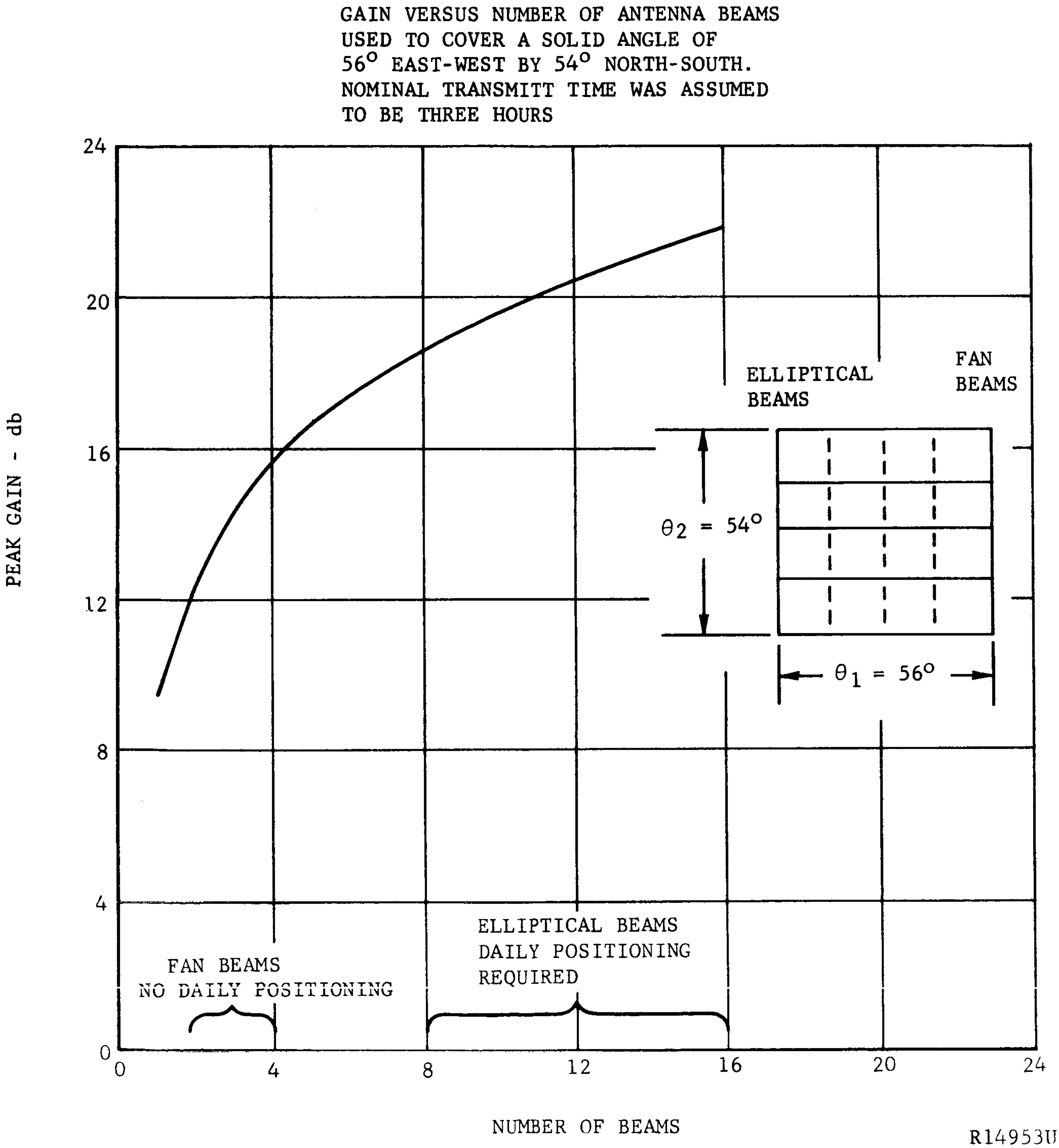

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FIGURE 6.2-14. ANTENNA GAIN VERSUS NUMBER OF FAN BEAMS here, at least in the simpler schemes, is to maintain the east-west beam angle fixed and only vary, at programmed times, the north-south beam angle. Hence, the desired communication times are realized, and Earth changes in declination (north-south angle) relative to a Mars "equatorial" location are encompassed by appropriately controlled beam changes. Figure 6.2-14 gives the amount of peak gain available from the antenna versus the number of beams into which the coverage area is divided. Again, for the case cited, assume a slightly expanded coverage to 56 by 52 degrees to allow for overlapping of the beams and misalignment of the array. By dividing the sector area into two fan beams of 56 by 26 degrees, a peak gain of 12 db is realized. Beam-switching is, of course, required at least twice to cover the desired incremental six-month-period or 56 by 52 degree sector. By dividing the sector area into four fan beams of 56 by 13 degrees each, a peak gain of 15.5 db is achieved. The size of the array in this case is 30 by 7 inches. To provide continuous coverage over a six-month interval would require at least four to five beam switchings. By dividing the area further into sixteen pencil beams of 14 by 13 degrees, a gain of 21.7 db is realized using a 28-by-30 inch antenna. This last approach requires beam-switching in both east-west and north-south beam angular directions and consequently increases in complexity.

It may be concluded that a variety of trade-offs are connected with each implementation scheme. The data in Figures 6.2-13 and 6.2-14 may be used with other mission constraints to define required antenna characteristics.

(2) Antenna Breakdown. Antenna breakdown in the anticipated Martian atmosphere has been investigated by Raytheon[5], General Electric[6], and others[7,8] by simulating various gas mixtures. For a pure argon concentration, General Electric concluded that breakdown power levels were about 50 percent lower than in air for the same antenna. Results of a JPL-funded experimental study for a specified Martian atmosphere (i.e., nitrogen 87.5 percent, carbon dioxide 7.5 percent, and argon 5.0 percent at an overall 40-mb surface pressure) showed that breakdown power levels in the simulated atmospheres were essentially the same as in (Earth's) air. Subsequent tests performed in air following this conclusion were conducted on a six-turn axial mode helix at 3000 Mc. Minimum breakdown power was found to be 125 watts at a pressure of 3 mm Hg. At 15 mm Hg (about half the NASA Model 1 atmosphere surface pressure and between Models 2 and 3), the peak pulse power required for breakdown increased to more than 600 watts. Although some variation is evident, depending on the particular atmosphere concentration, the design point case of 80 watts used here is not considered a problem. By providing a fan-beam antenna array, the potential problem of breakdown is circumvented, since arrays afford the characteristic of keeping the radiated power per element significantly less than the total power. Encapsulation of the feed also represents a preventive measure.

d. Solar Blackout. Communication between ABL and Earth is virtually continuous over any mission period. However, the communication geometry is such that, at conjunction (where α and β are both zero, in Figure 6.2-1, the sun is in the DSN antenna beam and also in the ABL receiving (command-link) antenna beam. For the case of opposition (α = 180 degrees and β = 0 degree, in Figure 6.2-1), the sun is only in the Mars-based antenna. A blackout telemetry data communication occurs at conjunction, therefore, and has an estimated duration of about 10 to 20 days.[9] This estimate appears reasonable based upon the following.

The mean Earth orbit rate of 360 degrees/year is 1.14×10^{-5} deg/sec. The mean Mars orbit rate is about one-half this, or 0.57×10^{-5} deg/sec. At conjunction, the net angular velocity of planet movement relative to one another and to the sun as an obstruction is about 0.6×10^{-5} deg/sec. Assuming one can track to within a minimum of 2 degrees of the sun's limb,* and allowing one degree for the angle at Earth subtended by the sun (0.5 degree is more likely), a total minimum angular displacement of 5 degrees results. A maximum excursion can be taken as twice this, or 10 degrees. These minimum and maximum angles, therefore, can be traversed in (i.e., result in blackout times of)

$$\text{(1)}\quad \text{Minimum: } \frac{5}{0.6 \times 10^{-5}} = 8.35 \times 10^{5} \text{ sec} = 232 \text{ hours} = 9.7 \text{ days}$$

and

$$\text{(2)}\quad \text{Maximum: } \frac{10}{0.6 \times 10^{-5}} = 16.7 \times 10^{5} \text{sec} = 464 \text{ hours} = 19.4 \text{ days}$$

These basic times represent upper limits for the telemetry link blackout problem. Because of the wider assumed (Mars) receiving antenna beamwidth (90 degrees), the command problem is considered one of solar disc obstruction to the Earth-issued commands rather than receiving system blackout, as would occur with a narrow-beamwidth antenna seeing the entire source temperature of the sun. Since blackout will occur in the direct link only at one time during a Mars ABL Mission (i.e., from Figure 6.2-1) coincident with maximum range, a loss of 2.8 degrees (maximum) of data-taking time can result. From the communication standpoint, this data loss is not significant enough to warrant any special implementation to recover. However, normal anticipated data acquisition and processing will be continuing passively, and a certain storage capability will exist. This may act to minimize the potential data loss. On the other hand, experiment requirements may dictate the need to store additional data obtained during this period. A further study of this problem is warranted.

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* Mrs. Nannylou Deiter, a radio astronomer at the Cambridge Research Laboratory has provided the information that star occultations have been observed to within two degrees of the sun's limb, using a frequency of 3000 Mc/sec and an antenna beamwidth of about 1/2 degree.

e. ABL Lander-to-Earth Visibility. Line-of-sight vision between a point on the Martian surface (ABL location) and the center of the Earth is shown in the visibility ratio curves of Appendix 11. Essentially, eleven hours per day (45 percent) represents the mean time available for communication with Earth for a Mars equatorial landing site (i.e., 0 degree latitude to ±30 degrees north or south). For other higher north and south latitudes, communication visibility times vary from 0 to 100 percent. Consequently, proper landing-site attainment constitutes an important constraint governing direct-link communication operation as well as associated mission success.

6.2.5 RELAY LINK

a. General. Several modes of Relay Link communication between the ABL and Earth are possible, as noted in Figure 6.2-4. For a long-term (2-year) mission, certain of the modes become impractical to employ. The Spacecraft (flyby) or Interplanetary Relay approach would afford coverage for only a very brief interval of time based upon the geometry implications of achieving reasonable communication distances. Hence the applicability of the flyby approach is severely time-limited and is useful only in the initial stage of attempting interplanetary probes, as demonstrated by the Mariner IV Mars probe and the past Venus probe.

The Trojan point satellite or relay link is similarly impractical to employ from the standpoint of communication distances involved and the degree of complexity required to achieve the libration point position. The position of such a relay is at the apex of an equilateral triangle which has the sun and Mars at the other two apexes. The relay is constrained to the Mars orbit and can either precede or follow Mars in its orbit cycle. The initial portion of such a Mars-to-Earth relay link always involves Mars-sun) distances of between 1.38 and 1.67 A.U., the perihelion and aphelion points, respectively. In addition, the basic Earth-Mars distance variation, as shown in Figure 6.2-1, would apply in the remaining leg of the relay link. The distance problem alone, therefore, for a long-term ABL mission obviates the usefulness of the Trojan point relay approach. The search for a useful relay mode thus narrows down to an orbiter relay link.

b. Mars Orbiter Relay TM Link. A typical case of an elliptical orbit is considered which varies in altitude from 1500 to 10,000 km. The particular orbit cited has a period of 442 minutes (7 hours), allowing about three orbits per day. Average communication time per orbit is about 83 minutes. This yields a daily average communication time of about 4 hours per day. This further assumes a polar-orbit and an ABL site just north of the Martian equator.

A feasible telecommunication design employing a 20-watt, 250-Mc transmitter power is presented. Again the PCM/PSK/PM Mariner IV Format is selected, and Table 6.2-III depicts the detailed parameters for the maximum range condition. A 300-bps data rate capability exists for the ABL-to-Orbiter portion of the relay link in this design. To compare it on an equal transmitter power basis with the direct link (80 watts), the bit rate capability increases to 1200 bps. Hence, for a daily communication mean time of 4 hours, a potential mean total data transfer of between 4.3×10^6 bits/day (20 W) and 1.7×10^7 bits/day is possible. This constitutes a one and two order-of-magnitude increased data transfer characteristic for the initial leg of the relay link over the basic direct link. Since there are many variables associated with any particular mission and orbit, the preceding observation is not the final, blanket comparison but applies only for the case cited. (The time per orbit, for example, is a function of lander latitude, periapsis latitude, and orbital inclination, eccentricity, and period.)

Antenna gains of zero db were assumed for both the Orbiter and ABL because of the varied geometry implications. Increased APC noise bandwidth has been included in the carrier tracking channel to facilitate acquisition, since Orbiter motion yields doppler frequencies and rates which must be accommodated in the receiver system.

For the Orbiter-to-Earth portion of the Relay Link, the previous analysis for the Direct Link is assumed to apply. However, an additional antenna gain factor is included to allow for the increased gain expected of the Orbiter antenna over that of the ABL fan-beam antenna. A net 8.0-db gain increase is therefore realized (i.e., assuming an Orbiter antenna gain of 23.5 db, as in Mariner IV). This 8.0 db represents a factor of 6.3 increase in Direct Link bit rate capability. Thus, the previous mean bit rate of 68 bps increases to a mean rate of 430 bps for the Orbiter-to-Earth relay leg. This element of the Relay Link, by virtue of the much-increased look-angle capability (Paragraph d following) yields a significant improved data transfer capability of about 3×10^7 bits/day. The previously cited figures conveying potential mean total data transfer, however, constitute the limiting portion of the Relay Link. Data transfer capability is thus limited to the maximum 1.7×10^7 bits/day set by the up link from the ABL-to-Orbiter leg. This presumes no interruption in desired communication time because of Orbiter occultation by Mars. Ultimately, this "duty-cycle" constraint which is a function of Relay orbit must be established before final estimates of overall relay performance can be made. Command control for the Orbiter-to-Earth portion of Relay Link may be depicted as in the Direct Link. The increased gain realized by use of the Orbiter antenna would facilitate command-control link operation by permitting continuous operation with increased APC bandwidth to accommodate peak doppler rates resulting from Orbiter motion.

Command-control from the Orbiter-to-ABL portion of the relay link has not been examined in detail. Provision would necessarily be included in Orbiter to route command signals to the Lander, however. This would essentially be the reverse process of that employed in the telemetry up link or ABL-to-orbiter relay leg previously described.

c. Reliability Considerations. Reliability of relay transmission versus direct transmission must be considered in ABL Lander extended-time missions. Such an analysis is beyond the scope of the present ABL study efforts. However, reference can be made to detailed comparative analyses performed by JPL for the Mariner 69 and Voyager projects.[10] Unpublished studies made at Philco led to similar conclusions; i.e., the Direct Link is more reliable than the Relay Link. This is not surprising, considering the serial nature of the events; JPL denotes six series subsystems in Direct versus 19 in the Relay technique.

TABLE 6.2-III

TELECOMMUNICATION DESIGN CONTROL TABLE MARS ABL-ORBITER RELAY LINK

Project: ABL
Channel: ABL Facsimile and Bio Data
Mode: PCM/PSK/PM Mariner IV Format

No.	Parameter	Value	Tolerance	Source
1	Total Transmitter Power, 20 w	+ 43.0 dbm	+1.0 - 1.0	FPC-ADP
2	Transmitting Circuit Loss	- 1.0	+0.3 - 0.3	FPC-ADP
3	Transmitting Antenna Gain*	0.0	+3.0 - 3.0	FPC-ADP
4	Transmitting Antenna Pointing Loss	-		
5	Space Loss At 250 Mc, R = 10 x 10^3 km	-160.5		
6	Polarization Loss (incl. in gain)			
7	Receiving Antenna Gain*	0.0	+3.0 - 3.0	FPC-ADP
8	Receiving Antenna Pointing Loss	-		
9	Receiving Circuit Loss	- 1.0	+0.3 - 0.3	FPC-ADP
10	Net Circuit Loss	-162.5	+6.6 - 6.6	Σ 2 thru 9
11	Total Received Power	-119.5	+7.6 - 7.6	Σ9, 10
12	Receiver Noise Spectral Density (N/B) T system = 1140°K $^{+900°K}_{-250°K}$ NF = 5.5 (incl. 160°K Sky Temp.)	-168.0 $\frac{\text{dbm}}{\text{cps}}$	+2.5 - 1.0	FPC-ADP JPL Spec
13	Carrier Modulation Loss	- 4.1	+0.7 - 0.9	MC-4-310A
14	Received Carrier Power	-123.6	+8.3 - 8.5	Σ11, 13
15	Carrier APC Noise BW ($2B_{LO}$ = 150 cps)	+ 21.8		FPC-ADP (WDL)
	Carrier Performance - Tracking (One-Way)			
16	Threshold SNR in $2B_{LO}$			
17	Threshold Carrier Power			
18	Performance Margin			
	Carrier Performance - Tracking (Two-Way)			
19	Threshold SNR in $2B_{LO}$			
20	Threshold Carrier Power			
21	Performance Margin			
	Carrier Performance			
22	Threshold SNR in $2B_{LO}$	+ 6.0		-310A
23	Threshold Carrier Power	-140.2	+2.5 - 1.0	Σ 12, 15, 22
24	Performance Margin	+ 16.6	+9.3 -11.0	Σ 14, (-23)
	Data Channel			
25	Modulation Loss $\theta_o = 0.809$	- 4.6	+0.4 - 0.4	-310A
26	Received Data Subcarrier Power	-124.1	+8.0 - 8.0	Σ 11, 25
27	Bit Rate (1/T) 300 bps	+ 24.7		
28	Required ST/N/B $P_e = 2.5 \times 10^{-3}$**	+ 7.5	+0.5 - 0.5	WFL-ADP
29	Threshold Subcarrier Power	-135.8	+3.0 - 1.5	Σ 12, 27, 28
30	Performance Margin	+ 11.7	+9.5 -11.0	Σ 26, (-29)
	Sync Channel			
31	Modulation Loss $\theta_s = 0.451$	- 10.5	+0.1 - 0.0	-310A
32	Received Sync Subcarrier Power	-130.0	+7.7 - 7.6	Σ 11, 31
33	Sync APC Noise BW ($2B_{LO}$ = 1 cps)	0.0		
34	Threshold SNR in $2B_{LO}$	+ 11.0	+0.5 - 0.5	WFL-ADP
35	Threshold Subcarrier Power	-157.0	+3.0 - 1.5	Σ 12, 33, 34
36	Performance Margin	+ 27.0	+9.2 -10.6	Σ 32, (-35)

* Omni Antenna Gains are assumed.

**$ST/_{N/B} = 6.0$ db $\frac{\text{cps}}{\text{bps}}$ for $P_e = 2.5 \times 10^{-3}$. An additional +1.5 db is, however, added to this theoretical value, to allow for performance tolerances in a practical system mechanization.(4)

d. ABL-to-Orbiter Relay-to-Earth Visibility. The data transfer characteristics of the ABL-to-Orbiter Relay Link leg are directly related to the duration of viewing time per orbit. This line-of-sight vision characteristic is a function of lander latitude, periapsis latitude, and orbital inclination, eccentricity, and period. For the case cited, a 45-percent viewing time per orbit was possible. Appendix 11 contains curves which show the variation in viewing time per orbit for varied lander and periapsis latitude. (The curves of Figures 6.2-6 and 6.2-7 supplement these data.) For example, for polar orbits and higher lander latitudes, some percentage of viewing time exists on each orbit regardless of the periapsis latitude. At the lower lander latitudes, there are many cases of zero viewing time. Hence, data transfer times are highly subjective to assumed physical constraints.

For the Orbiter-to-Earth portion of the Relay Link, viewing times for the polar orbit case are a function of the orbit relative to the line of sight. The data in Appendix 11 indicate that viewing times approaching 100 percent are realizable. Even with certain adverse assumptions, viewing time only reduced to 50 percent. Hence, data transfer time capability may be conservatively estimated at 85 percent of the full viewing time, or about 20 hours.

6.2.6 DIRECT VERSUS RELAY TELECOMMUNICATIONS

The characteristics of direct and relay telecommunications designs for a Mars-to-Earth data link have been examined and will now be compared. A 1975 mission with a 7 April 1976 arrival date received the most detailed analysis. However, data pertaining to alternate mission periods of the 1970 decade are also included. This comparison comprises only a gross analysis of this broad problem, but still certain important results emerge. To facilitate the analysis, specific feasible telecommunication link designs have been employed. Both direct and relay and telemetry and command utilize a PCM/PSK/PM Mariner IV Format as a modulation scheme. A comparison of performance characteristics observed and required follows:

a. Mars-to-Earth ABL Direct Link.

(1) For the 1975 two-year mission period, a mean bit rate of 68 bits/second is realizable with a (2295-Mc) transmitter power of 80 watts and Lander antenna peak gain of 15.5 db. Predicted DSN system capabilities for the period and an equatorial-band lander location are assumed.

(2) Over the 1970 decade, Mars-Earth orbit geometry restricts the overall mean bit rate capability to about 100 bits/second, assuming all other parameters as in (1). An order-of-magnitude improvement in transmitting power or antenna gain over this period will yield a similar improvement in the mean value of bit/rate possible.

(3) A daily mean value of total data transfer capability based upon (1) above and a 3-hour communication time is about 7.0×10^5 bits/day. For the 1975 mission period, a mean value of total data transfer capability is about 5.1×10^8 bits. This does not take into account a potential 20-day communication blackout period.

(4) Solar blackout is not expected to interrupt direct telemetry communications for longer than 20 days and only once during a mission, coincident with the maximum Mars-Earth orbit excursion. Performance as cited for the command link will probably not be subject to blackout effects, but planet occultation by sun may result in a brief noncommunication period.

(5) Command control via the Direct Link is achievable over the entire 2-year ABL mission period with use of 100-kw command transmitter power. Relatively little excess margin exists at the maximum distance; nevertheless, the basic margin is satisfactory. It is noted that command reception assumes no antenna switchover to the high-gain telemetry antenna system, although this alternative may represent a backup or failure-prevention mode.

(6) A schedule of discrete variations in data (bit rate) is required for a 2-year ABL mission, to successfully achieve the (above-cited) mean value of bit rate possible.

(7) Bit rate capability approaching that possible in a relay link requires the use of a highly directive antenna system on ABL.

(8) The Direct Link affords greater reliability than a Relay Link (based upon other studies) and possesses excellent growth capability. Minimum interface requirements with a Voyager-type spacecraft can be maintained. Following successful ABL deployment and basic orientation operations, no other major subsystem operation is needed to complete a telecommunication link between Earth and Mars.

(9) Antenna breakdown does not appear to be a significant problem, at least for the cases cited. However, as transmitter power capability grows, it will constitute a problem. The actual Martian environment may change these observations. These particular remarks are applicable to the Lander-to-Relay link leg also.

b. Mars-to-Earth ABL Relay Link.

(1) A Mars Orbiter Relay Link is conclusively the only practical relay system, of the several briefly examined, capable of satisfying long-duration ABL mission requirements.

(2) For the 1975 2-year mission period, a mean bit rate capability of 300 to 1200 bits/second is realizable with a (250-Mc) transmitter power of 20 to 80 watts, respectively. The assumptions involved include zero-gain transmitting and receiving antennas, an elliptical polar orbit (1500 km minimum and 10,000 km maximum altitudes), and an equatorial-band lander location.

(3) A daily mean value of total data transfer capability from Lander to Orbiter, based upon the above and a potential 4-hour-per-day communication time, is 4.3×10^6 (20 w) to 1.7×10^7 bits/day, assuming all other parameters unchanged. By including the Orbiter-to-Earth Relay leg, which is assumed to have the same capability as the above direct link with a specified 8.0-db antenna gain improvement factor, an approximate 430 bit/second maximum capability results. This leg of the Relay Link results in an increased data rate capability of about 3×10^7 bits/day. However, the limiting portion of the Relay Link is the up link from ABL-to-Orbiter. For the case cited, the daily mean value of total data transferred is thus limited to a 1.7×10^7 bits/day capability. For the entire 2-year ABL mission period, therefore, the mean value of total data transfer capability for the Relay case cited is 1.3×10^{10} bits. If an Orbiter transmitter power reduction is considered, the data-handling capability would be reduced accordingly.

(4) Because of the Mars-to-Earth portion of the relay link, a schedule of discrete variations in data is required for a 2-year ABL mission to realize the mean bit rate capability possible.

(5) The Relay Link reduces the overall ABL mission reliability when compared to a Direct Link alone. In conjunction with a successful ABL deployment and basic orientation operation, the entire relay system must achieve a specified orbit and sustain long-term operation of its various subsystems to complete the Mars-to-Earth relay transmission link.

(6) Solar blackout communication interruptions are basically the same as noted for the direct link. The command link would be similarly adversely affected.

(7) Command control via the relay link is possible over the entire ABL mission period. However, more complexity in both hardware and geometrical implications would serve to act as added constraints for the command problem.

c. Conclusion. The Relay Link is seen to have a decided advantage in total data transfer capability. Reliability considerations and a multiplicity of constraints act as serious disadvantages, however, for long-term ABL usage of a Relay Link. The ABL must be successfully deployed and operating for either telecommunication link to be satisfactory. Consequently, utilization of the Direct Link, which is assumed to operate similarly in conjunction with a successful Lander deployment, is considered to afford greater simplicity and greater chance for success for the long-term ABL mission.

6.2.7 SAMPLER COMMUNICATION ANALYSIS

a. General Application. To supplement the Mars ABL experiment measurement program, a potential requirement exists for a sampling device which can be deployed locally and/or remotely relative to the Lander. A locally deployed device lends itself to hardline communication between Lander and the local Sampler vehicle. As distances between Lander and Sampler are increased, a remote vehicle utilizing rf communications and control is required. While such a device was not proposed in connection with the design-point ABL considered in this study, the control communication and navigational requirements of a remote Sampler for eventual use with ABL-class missions were of sufficient general interest that the communication analysis covered by this paragraph was performed.

Use of a roving vehicle on Mars is subject to the Martian physical environment, which currently is speculative. Related assumptions regarding vehicle environment must, therefore, be considered highly conditional and subject to large uncertainties. Nonetheless, certain estimations or identification of likely communication system performance parameters may be made, based upon recently postulated Martian physical properties.(11,12,13)

(1) Martian Environmental and Topography. The Planet Mars(14) has a radius of approximately 0.53 that of Earth. The surface of Mars has three striking features distinguished by virtue of their color: white polar caps, reddish to ochre-yellow "deserts," and dark neutral-gray "maria." No discernible oceans or sharp mountain ranges are considered to exist. Seasonal influences are apparent with minimal cloud-type cover observed at times, the most notable being the so-called blue haze. Wind velocities, similar in magnitude to that on Earth, are reported in literature. Since surface pressures are estimated between 0.1 and 0.01 that of Earth, wind dynamic pressures on Mars should be small. The troposphere is assumed to extend to at least 30 kilofeet. Atmospheric composition is principally nitrogen, with carbon dioxide and traces of argon present. Water vapor is quite meager in all estimations, 10^{-3} to 10^{-4} gm/cm^2 of surface area (i.e., some 10^2 to 10^3 times less than amounts present in the air over Arizona deserts). Oxygen content of Mars' atmosphere is very low (estimated at 10^3 times less than the amount in the Earth's atmosphere).

(2) Roving Vehicle Functions.(15) Based upon an unknown terrain, there is a need for positional and navigational type information which dictates the use of a facsimile or TV and infrared sector-scanning device in the Rover vehicle control loop. Pseudo-real-time direction of the Rover would thus be realizable, facilitating its mobility over potentially irregular topography. Consequently, command control of stopping, starting, simple maneuvering, speed changes, lens-aperture adjustments, and experiment sequencing would be necessary to provide some level of control. In

addition, fail-safe features are also necessary to keep the Rover within communication range and clear of obstructions. Telemetry experiment data would be obtained at varied locations on Mars during selected measurement periods. Certain narrow-band environmental data and Rover performance status and command verfication data would be fed as desired, or periodically, to the parent ABL. A wide-band capability would be required to accommodate sector scan facsimile or TV control data. Slow (360 degree) scan picture data could have a lesser bandwidth requirement and lower data rate transmission.

(3) Mars Communication Considerations. The problem of Martian surface communication immediately arises when one considers the present unavailability of data describing the atmospheric and ionospheric properties of Mars. Only hypothetical values of these characteristics have been derived to date.(16) One can only assume, therefore, based upon such postulated environmental conditions and chemical composition, the existence of fairly dense, multilayered, high-altitude ionosphere about Mars.(17) This assumption suggests that certain of the terrestial communication techniques may be applicable on Mars, with possibly different frequency and skip-distance usage.

The need for over-the-horizon or beyond-the-line-of-sight communications coverage is also required because of two inherent factors peculiar to Mars. First, the decreased radius of Mars relative to the Earth results in shorter line-of-sight distances than those realized on Earth. Secondly, atmospheric characteristics which are substantially different from those of Earth result in a lesser refractive and reflective atmospheric characteristic.

To further illustrate the effect of the (Mars) geometric line-of-sight range constraint, Figure 6.2-15 is presented. Assuming a perfectly smooth spherical Mars surface, the geometric horizon distance is shown versus antenna height. Mars line-of-sight distance is about 0.7 that of Earth's. To find the maximum line-of-sight distance, given both a transmitting and receiving antenna elevation, sum the individual contributions (i.e., dg + dg', the sum of the distance to the horizon from the transmitting antenna and the distance to the horizon from the receiving antenna.) Two vehicles on a flat plane, one having an antenna elevation of 5 meters and the other having an antenna supported 10 meters in elevation, could be separated by about 14 kilometers for line-of-sight communication. It should be noted that such line-of-sight restraints are well within hard-line payout capabilities estimated by some, although difficulties increase in accordance with increased data bandwidth requirement.

(4) Rover Communication Modes. Several modes of communication (and control) between a remote roving surface vehicle and a parent, stationary vehicle are possible. The more obvious method is direct-link communication

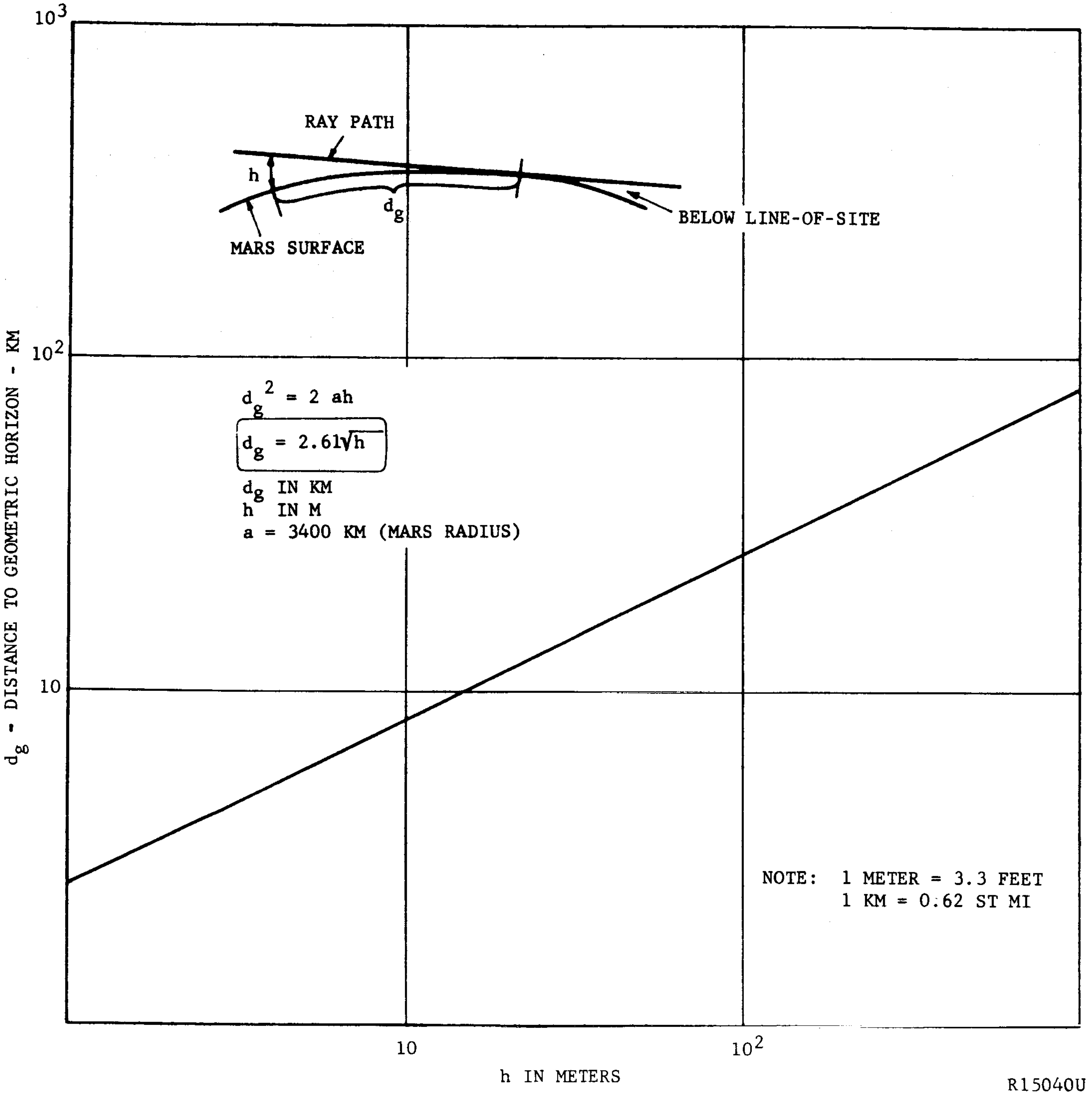


FIGURE 6.2-15. MARS GEOMETRIC HORIZON DISTANCE VERSUS ANTENNA HEIGHT

via hard-line or rf propagation. Other possible modes include Sampler control and communication via a Mars orbiter relay, line-of-sight surface repeater relays, an Earth-base and/or an extraterrestial-base relay. For purposes of simplicity in an initial ABL Mars mission, a version of the first case is examined herein; i.e., that of providing a radio link between the Rover and the Lander capsule. The hard-line case is considered a practical solution for the locally deployed Rover, but discussions here are aimed at exploring the remote radio link case.

b. RF Modes of Propagation.(18)

(1) Earth RF Propagation Modes. The several modes of radio propagation over the Earth's surface are classified as sky waves, tropospheric or space waves, and ground waves. Sky waves refer to rf energy that is propagated in space above the Earth under conditions subject to influence by the ionosphere. The ionosphere, or ionized region which begins about 80 km above the Earth's surface, has the property of refracting radio waves back to the Earth. This mechanism accounts for practically all very long-distance radio communication, except at the very lowest of radio frequencies. Sky waves are propagated at the high frequencies (HF) in the range of 3 to 30 Mc.

Space or tropospheric waves represent rf energy that travels in the Earth's troposphere; i.e., that portion of the Earth's atmosphere in the first 10 miles adjacent to the Earth's surface. The space wave commonly consists of a direct-ray path and an Earth's surface reflected-ray path between a transmitter and receiver. Space wave energy transmission may also be accomplished by the reflection or refraction produced by variations in the electrical characteristics of the troposphere and by diffraction around the curvature of the Earth, hills, etc. Rf transmission at frequencies above 30 Mc is normally space wave propagation. This covers the VHF, UHF, and higher rf transmission bands.

The ground wave (also called surface wave) exists when transmitting and receiving antennas are close to the surface of the Earth and are vertically polarized. This rf energy, supported at its lower edge by the presence of the ground, is of practical importance at broadcast and lower frequencies. Ground wave transmission is propagated at the medium frequencies (MF) and lower (i.e., less than 3 Mc).

(2) Mars RF Propagation Modes. Analogous to the terrestial case, the atmosphere of Mars is expected to be frequency-selective, so that a critical frequency caused by ionospheric influences will exist. Waves of the critical frequency and lower will be reflected from the layer in question irrespective of angle of incidence. Waves having frequencies greater than the critical value will pass on through the layer. An upper frequency limit exists because of attenuation by atmospheric gases.

The critical frequency is proportional to the square root of the maximum electron density in the ionosphere layer. Recent models of the electron density distribution in the ionosphere of Mars result in mean daytime electron density estimates of between 10^4 and 10^5 per cm^3, as compared to about 10^6 per cm^3 for earth (19) (also Kellog and Sagan, 1961, and Danilov, 1963). The electron density layers are estimated to occur at greater heights on Mars but with lower density. A critical frequency for the estimated densities is obtained from

$$f_c = 9 \sqrt{N} \tag{10}$$

where N is the number of electrons per cm^3

f_c is the critical frequency in Kc

To assure refraction of an oblique path, the rf frequency should be about one-fifth the critical frequency, or below about 0.5 Mc. (Conversely, penetration frequencies are on the order of 10 Mc and above. This is an important consideration for communication between a surface vehicle and all points beyond the Martian atmosphere; i.e., orbiter relay, earth.)

The upper frequency limit is about 60 Gc, if determined by oxygen absorption, and about 22 Gc, should significant amounts of water vapor be present.(20) It may be observed that the propagation modes, as described for Earth, become modified somewhat in the case of Mars. Table 6.2-IV depicts the variation.

TABLE 6.2-IV

MARS/EARTH RF PROPAGATION MODES

	Frequency Band or Range	
Propagation Mode	Earth	Mars
Ground or Surface Wave	< 3 Mc	< 0.5 Mc
Sky or Ionospheric Wave	3-30 Mc	0.5-10 Mc
Space or Tropospheric Wave	>30 Mc	> 10 Mc

There is, of course, overlap in the specified regions, since the diurnal and seasonal variation of the Martian layers will, in general, be similar to that of the corresponding terrestrial layers.

(a) Ground Wave. Ground or surface wave propagation would be accomplished by means of vertically polarized wave travel over the Martian surface, since the horizontally polarized wave has its electric field short-circuited by the ground. Surface wave attenuation as a function of distance was first given by Sommerfeld as

$$E = A \frac{E_o}{d} \tag{11}$$

where

E_o is field strength of 300 mv/m at a distance of 1 km for an effective radiated power of 1 kw over short vertical antenna, neglecting surface curvature

d is distance to transmitting antenna

A is factor taking into account the ground losses, which depend on conductivity and dielectric constant of the surface, the frequency, and the distance to the transmitter in wavelengths.

The antenna is nondirectional in the horizontal plane and has a radiated field proportional to the cosine of the elevation angle. Also, for the values of radiated power, E_o is proportional to $\sqrt{P \text{ (in kw)}}$ (e.g., with P = 0.1 kw, E_o = 100 mv/m).

Estimations of the conductivity, σ, and dielectric, ϵ, for Mars are obtained by taking low values of the Earth's typical ground constants. Thus

ϵ = 5 esu

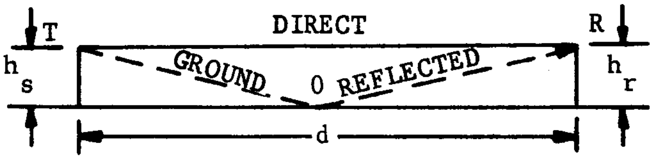
and

$\sigma = 10^{-14}$ emu

It must be noted that these assumed quantities are expected to vary greatly with conditions, as in the case of Earth.

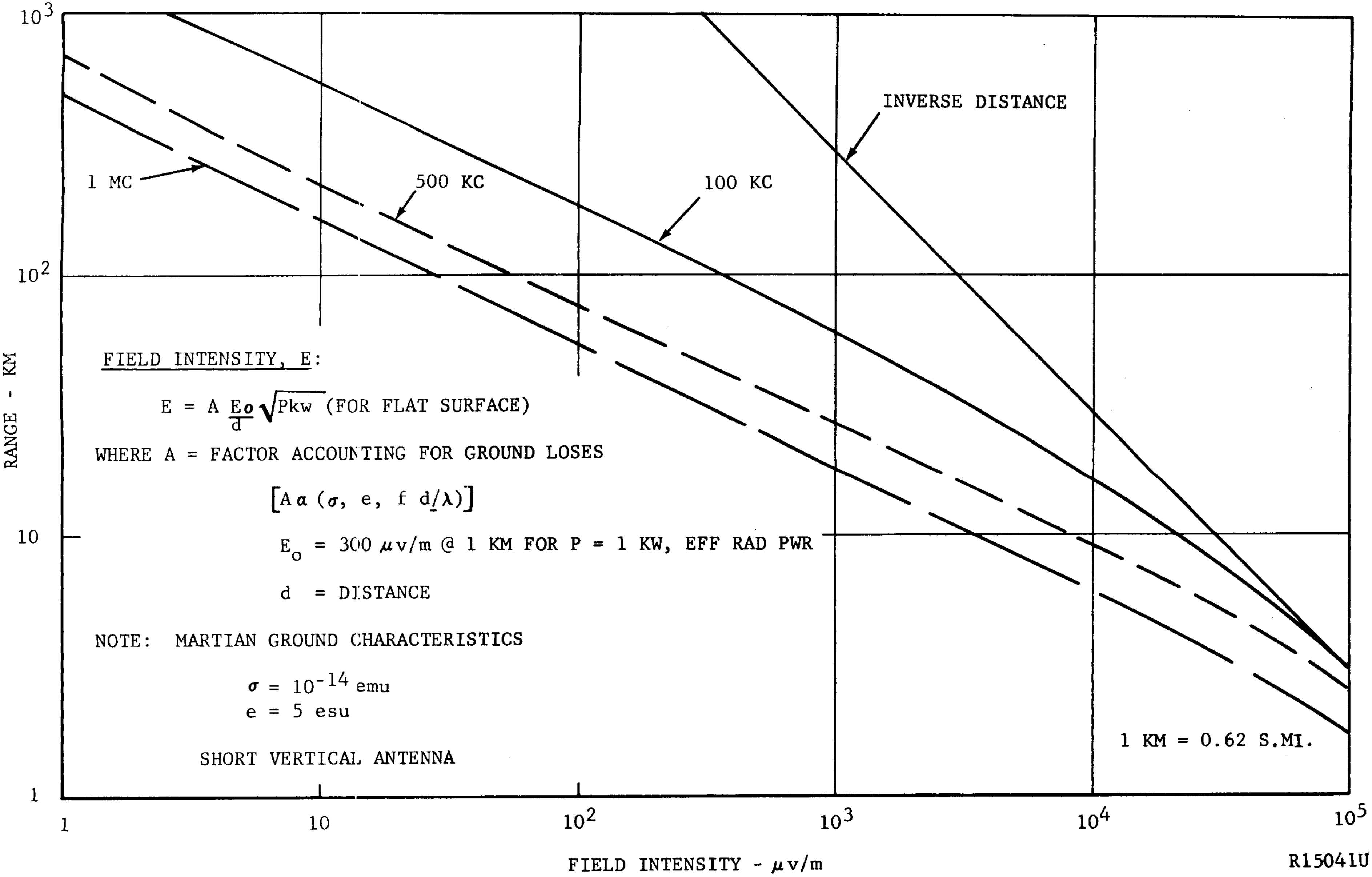
The reduction factor, A, for frequencies in the region of approximately 1 Mc and lower, is determined for a given distance by f^2/σ and is almost independent of ϵ. Propagation is enhanced, therefore, when the frequency is low and/or conductivity is high. At frequencies of the order of 10 Mc and greater, ground wave attenuation at a given distance is then determined by the factor $f/(\epsilon+1)$. Hence, high dielectric constant and low frequency reduce the attenuation. Curves showing surface-wave attenuation versus distance for several frequencies are shown in Figure 6.2-16. These curves indicate that the use of low frequencies is favorable. However, physical or practical considerations favor higher frequency usage. Increased antenna efficiencies and size advantages are obtained at the higher frequencies. Bandwidth considerations also favor the higher frequencies, as do galactic noise considerations. It should be noted that the power required in Figure 6.2-16 is 1 kw effective radiated power. Upon reception with a 10-percent efficient receiving antenna (short vertical antenna), a 65-μv/m intensity would be required to achieve 20 μv/m at the receiver. This reduces the idealized range capability to less than 250 km for the 100 Kc case. With surface curvature taken into account, the distance capability is further reduced (probably under 150 km) for the assumed parameters. Any consideration of long-range surface communications can be seen to impose a rather severe power requirement.

(b) Space Wave Propagation. For radio-frequency transmission above about 10 Mc, the Martian ionosphere is not expected to refract energy to the surface, while ground wave propagation attenuates very rapidly in a relatively few hundred feet. Propagation is achieved at these frequencies by means of the space wave traveling between elevated transmitting and receiving antennas. This constitutes the more conventional application regarding missile and space telemetry.



Space wave propagation is made up of direct and indirect paths by which energy travels from a transmitting antenna to a receiving antenna. The field strength at the receiving antenna, R, is the vector sum of the fields represented by the two rays. When the distance, d, is large as compared to antenna heights h_s and h_r, the angle of incidence at the surface (assumed flat here) will be small. The reflection at 0 takes place with no essential change in magnitude and with a phase reversal irrespective of polarization. For these conditions, the two waves have equal amplitude and generally different phase. Field strength is given by

$$E = \frac{2E_o}{d} \sin \frac{2\pi h_s h_r}{\lambda d} \qquad (12)$$



FIELD INTENSITY, E:

$E = A \frac{E_o}{d} \sqrt{Pkw}$ (FOR FLAT SURFACE)

WHERE A = FACTOR ACCOUNTING FOR GROUND LOSES

$[A \alpha (\sigma, e, f\ d/\lambda)]$

E_o = 300 μv/m @ 1 KM FOR P = 1 KW, EFF RAD PWR

d = DISTANCE

NOTE: MARTIAN GROUND CHARACTERISTICS

$\sigma = 10^{-14}$ emu
e = 5 esu

SHORT VERTICAL ANTENNA

FIGURE 6.2-16. SURFACE WAVE FIELD INTENSITY VERSUS DISTANCE where

E_o is field strength of direct ray at unit distance

d is distance from transmitter to receiver

λ is wavelength, same units as for d

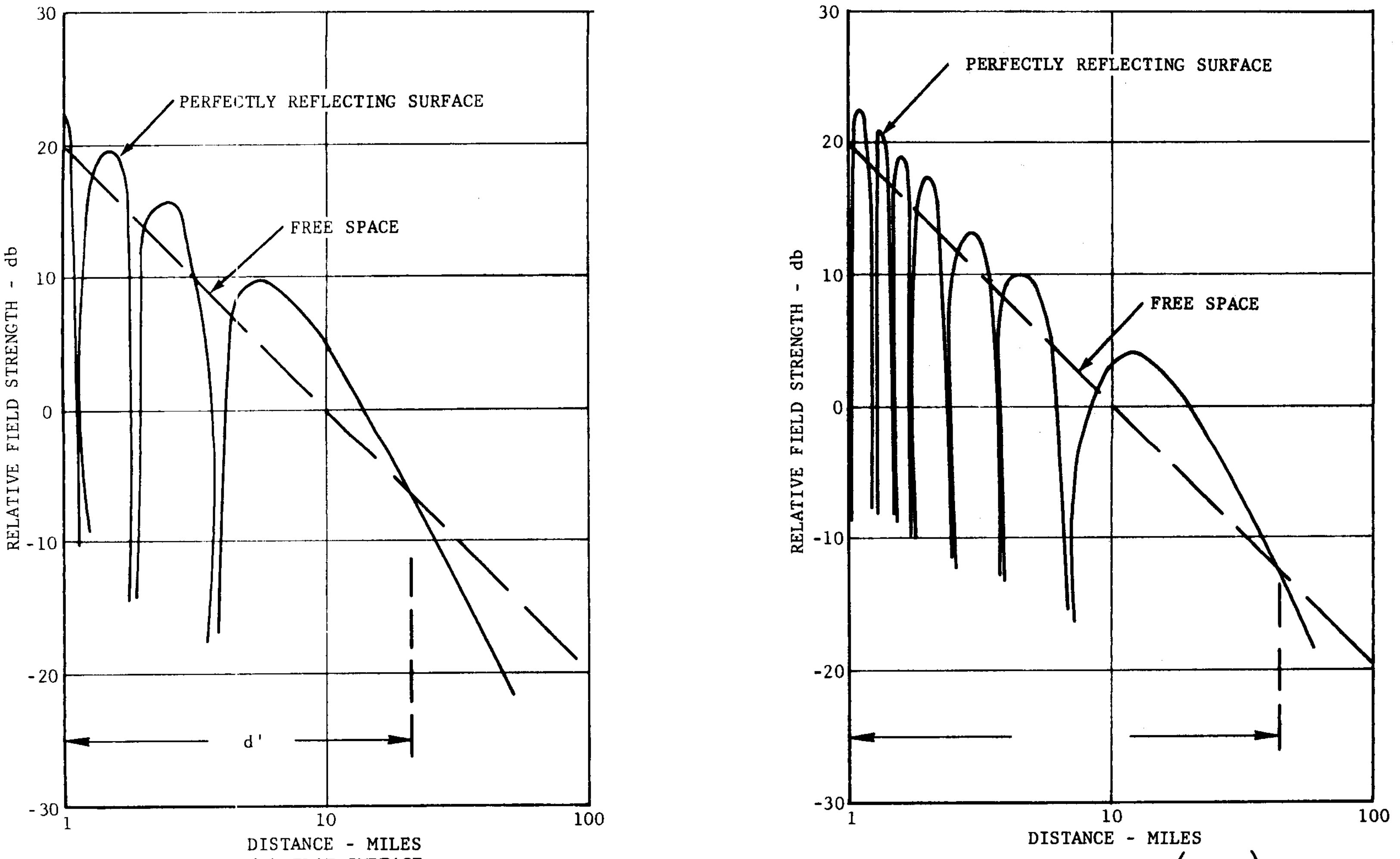
h_s, h_r are heights of antennas, same units as for d.

Typical curves showing field strength variation with distance are shown in Figure 6.2-17a. For a perfectly conducting earth, the maximum amplitude of the field strength oscillations is twice the free-space value ($2E_o/d$) and occurs at distances so related to antenna heights that the direct and ground-reflected waves add in phase. The minimus occur similarly based upon (out-of-phase) cancellation of the direct and ground-reflected waves. For distances greater than d' where the angle $(2\pi h_s h_r)/\lambda d$ is less than $\pi/6$ (plus other effects), the two rays are largely out of phase, and field strength at the receiving antenna is less than the free-space value. And at distances appreciably greater than d', field strength becomes inversely proportional to distance squared; i.e.,

$$E = \frac{4\pi h_s h_r}{\lambda d^2} E_o \tag{13}$$

Increasing $(h_s h_r)/\lambda$, either by increasing antenna heights or the frequency, produces the result shown in Figure 6.2-17b; i.e., an increase in field strength at larger distances. (However, distance beyond line-of-sight field strength is less, the higher the frequency.) When surface curvature effects (as in the Earth case) are included, Equation (13) is found to apply with reasonable accuracy as long as the direct (line-of-sight) path remains clear. In reality, the ground-reflected wave does not undergo perfect reflection, since the finite conductivity and dielectric constant of the surface cause the magnitude of the reflection coefficient ($R = \rho\epsilon^{i\psi}$) to be less than unity and the phase reversal characteristic to differ from 180 degrees. Hence the maxima become less and the nulls fill in, as suggested by the dotted lines in Figure 6.2-17. It should be noted that these effects are much less pronounced with horizontally polarized waves than with vertical polarization. With vertical polarization, the magnitude of the reflection coefficient is generally quite small at small angles of incidence. Consequently, horizontal polarization would be specified when enhanced range capability is desired and complete vertical coverage not necessary.

The outstanding problem with respect to line-of-sight propagation on Mars (or on Earth for that matter) is the geometric constraint imposed by



(a) FLAT SURFACE

(b) SAME AS (a) EXCEPT $\left(\frac{2\pi h_r h_s}{\lambda}\right) \times 2$

NOTE: FLAT EARTH IS SHOWN TO ILLUSTRATE EFFECTS

BASED UPON SPACE WAVE

$$E = \frac{2\,E_o}{d} \sin \frac{2\,h_s h_c}{d}$$

R15042U

FIGURE 6.2-17. FIELD STRENGTH VARIATION VERSUS DISTANCE an ideal surface with curvature. Figure 6.2-15, supplemented by earlier discussions, illustrates this problem. Unless significant antenna heights can be achieved, communication distances will be severely restricted. Transmitter power, information bandwidth, equipment reliability, and availability present no adverse requirements which could not be met by present state-of-the-missile and space-borne hardware.

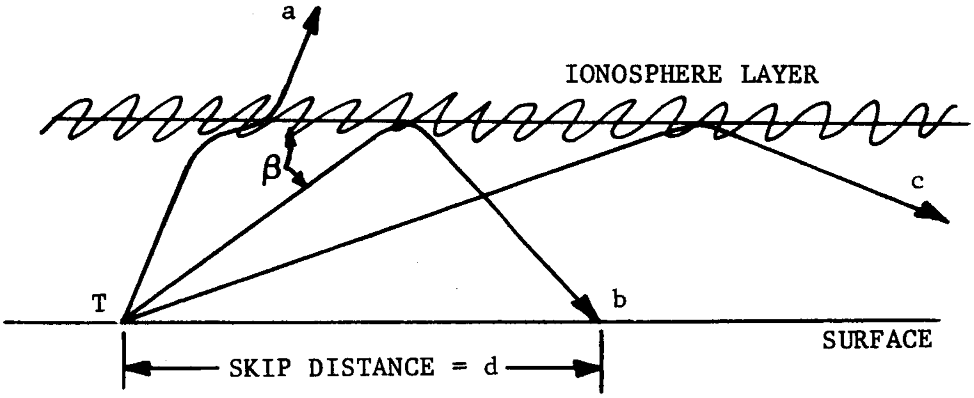
Other space-wave considerations, such as fading, terrain-shadowing effects, and atmospheric effects, should receive additional examination in more detailed assessments of the problem. Some general comments may be made indicating the nature of these effects. Fading or signal-strength variations occur by virtue of changing tropospheric conditions and also because of multipath transmission. Shadowing effects are the result of a reduction in the strength of the ground-reflected ray caused by scattering and/or absorption of energy by hills or rough ground. A corresponding loss in signal strength occurs, since the action is equivalent to a reduction of the reflection coefficient. Refraction of rf energy is attributable to atmospheric effects. One effect of refraction is to extend the distance to the horizon, thus increasing communication range. However, for Mars, the decrease in refractive index with altitude is not expected to be as significant as on Earth. The lower barometric pressure and meager (water) vapor pressure content would seem to imply a lesser index-of-refraction change (decrease) with (increasing) altitude. Consequently, increased radio horizon extension beyond the geometric horizon is not anticipated as being as fruitful as in the case of Earth.

Finally, extended-range propagation resulting from tropospheric scattering and reflection affords communication enhancement, but more would have to be learned about the Martian atmosphere before it could be represented as reliable, interruption-free mode of communication for a Rover vehicle application.

(c) Sky or Ionospheric Wave Propagation. By virtue of the previously suggested propagation frequency modes for Mars, sky wave transmissions would appear to be more restricted in the frequency sense. A narrower band in the transition region between surface and space wave propagation is seen to exist (i.e., 0.5 to 10 Mc). As in the Earth case, the principal use of frequencies in this region would be for moderate to long-distance communications, where the ionosphere is used to refract and/or reflect the sky wave back to the Mars receiving point. Propagation characteristics under such conditions depend on both the transmitted frequency and ionospheric conditions.

As previously described, transmission frequencies below the critical frequency of the significant ionosphere layer are returned to the surface irrespective of the angle of incidence at the ionosphere. Transmission to receiving points quite close to the transmitter are thus possible.

However, for transmission frequencies higher than the critical frequency, only those waves will be returned to the surface that strike the ionosphere with an angle of incidence, β, such that $\cos\beta > \mu_0$, where μ_0 is the refractive index (at the point of maximum electron density for the frequency involved). For angles of incidence greater than β (see sketch following), the waves pass on through (path a), while waves of lesser angle are returned to the surface beyond the skip distance (path c). Consequently no sky wave energy is returned to the surface closer to the transmitter than some distance d, which is called the skip distance.



For a Roving vehicle application, this particular phenomenon is considered a principal advantage when constant communication with the vehicle is necessary. Because of the skip phenomenon and the fact that the ground or surface wave dies out rapidly with distance, there is commonly a region beginning beyond the ineffective ground wave coverage point and extending out to the skip distance where no signals at all are received even though strong signals are returned to the surface beyond the skip distance. For this reason, coupled with the variety of unknowns, further study of ionospheric modes of propagation is reserved for subsequent investigations.

c. Summary and Conclusions. A conclusion reached as a result of this investigation is that ground or surface wave propagation appears to offer promise as a reliable, interruption-free, medium-distance form of communication for use in a Rover remote-vehicle application. Distances to 100 km appear feasible. A variety of trade-off studies affecting transmitting power, frequency selection, and antenna requirements should be made in any further study of this problem. Transmitter power requirements promise to be significant, and information bandwidths will probably be limited. Nevertheless, it is believed that the complexity of alternate systems would outweigh these disadvantages.

It must be suggested that hard-line communication between a Rover vehicle and ABL, although not examined here, should receive serious consideration in any further investigations, in the light of many of the unknown radio communication constraints. Similarly, operation in conjunction with an ABL and an orbiter-relay also should receive consideration.

6.2.8 DESCRIPTION OF SELECTED DESIGN POINT TELECOMMUNICATION SYSTEM

a. General. The communication and control studies reported in the previous sections provide a basis for selection of a design point telecommunication system for the ABL mission. The selection is based upon a variety of tradeoffs, principally of the rf power, power supply, antenna gain, communication times, and data transfer parameters, all of which are further constrained by overall mission objectives and criteria. As a consequence, the design point system effects the best compromise of these many factors. The mission designated for consideration is the 1975, Type 1, minimum-energy mission which has a 205-day transit time to Mars with an encounter date of 7 April 1976.

(1) System Requirements. The telecommunication system must operate for two (Earth) years in the Martian environment, commencing at encounter (landing) and following a 6-3/4-month passive deep-space transit period. The long and stringent operational requirements dictate the need for high reliability in equipment operating characteristics. Redundancy and backup capability must exist to facilitate data acquisition under certain failure mode conditions. Maximum data transfer with minimum power is a primary requirement. A data rate schedule varied in accordance with mission range is required. A command capability is required to facilitate the conduct of ABL experimentation and may be used to effect periodic telemetry antenna system pointing. Compatibility of the ABL data transmission equipment with the NASA Deep Space Net, DSN, is required.

(2) System Functions. The overall telecommunication system is comprised of the ABL-housed equipment and the NASA Deep Space Net (DSN). The principal functions of the system are to telemeter Mars biological, scientific, and engineering data from the ABL, and to transmit command-control data to the Lander.

b. Telecommunication System Design. A Mars-Earth direct PCM/PSK/PM telecommunication link design is selected for both telemetry and command-control functions. No provisions are included for either an orbiter-relay or a remote sampler rf link. The design point system is documented by the Telecommunication Control Tables, Tables 6.2-I and 6.2-II, for the telemetry and command, respectively. The block diagram of Figure 6.2-18 depicts the functional elements of the Lander system, while Figure 6.2-19 shows the "standard" DSN equipments plus added elements of ABL program-oriented equipments. The design point system data rate capability versus mission duration is presented in Figure 6.2-20. Data rate capability is seen to vary from 19 bps minimum to 300 bps maximum. The mean bit rate capability for the entire mission period is 68 bps. The data transfer characteristic (see Table 6.2-I and Figures 6.2-10 and 6.2-11) is able to accommodate the relatively high data loads of the laboratory.

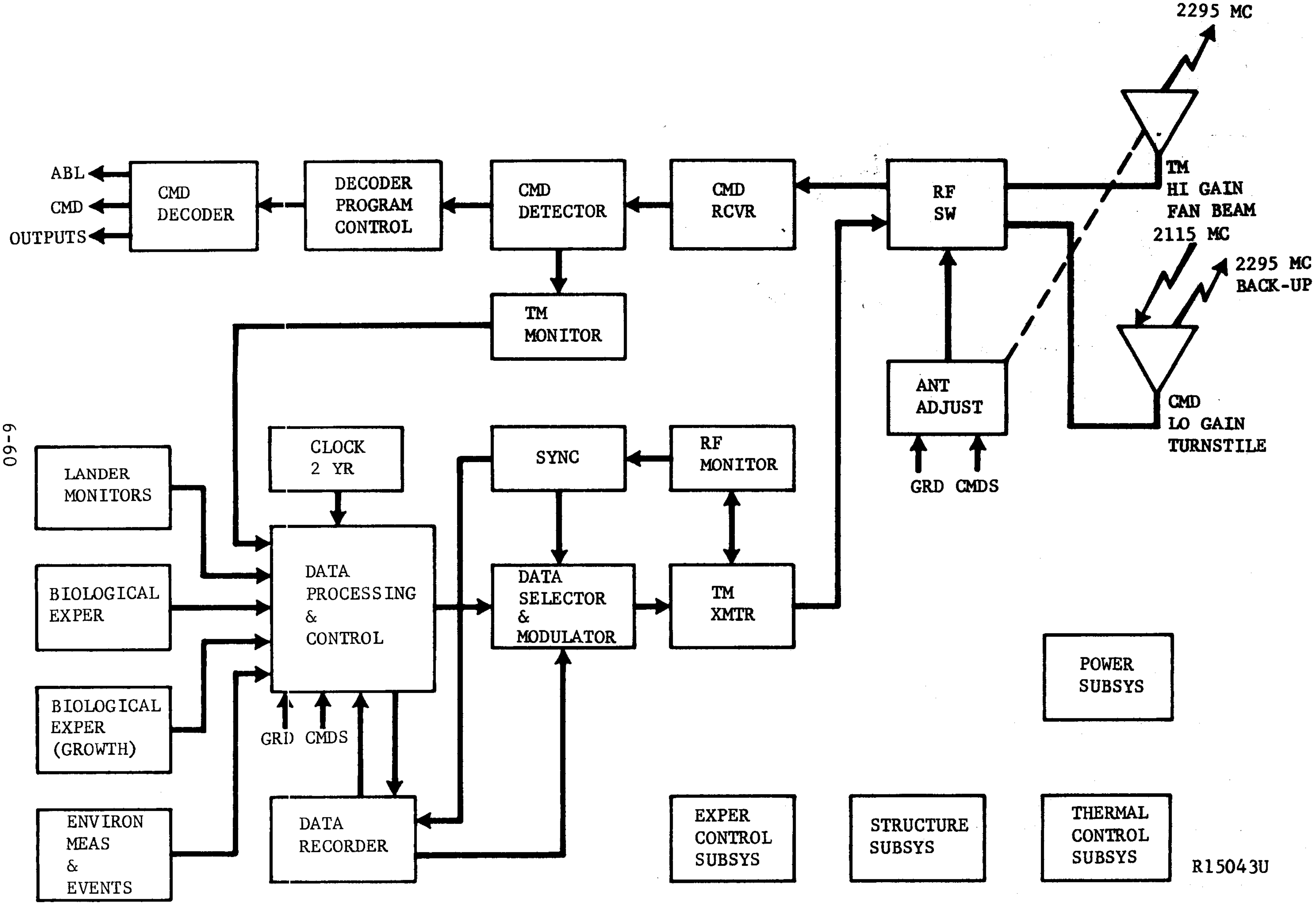


FIGURE 6.2-18. ABL LANDER TELECOMMUNICATION SYSTEM FUNCTIONAL BLOCK DIAGRAM

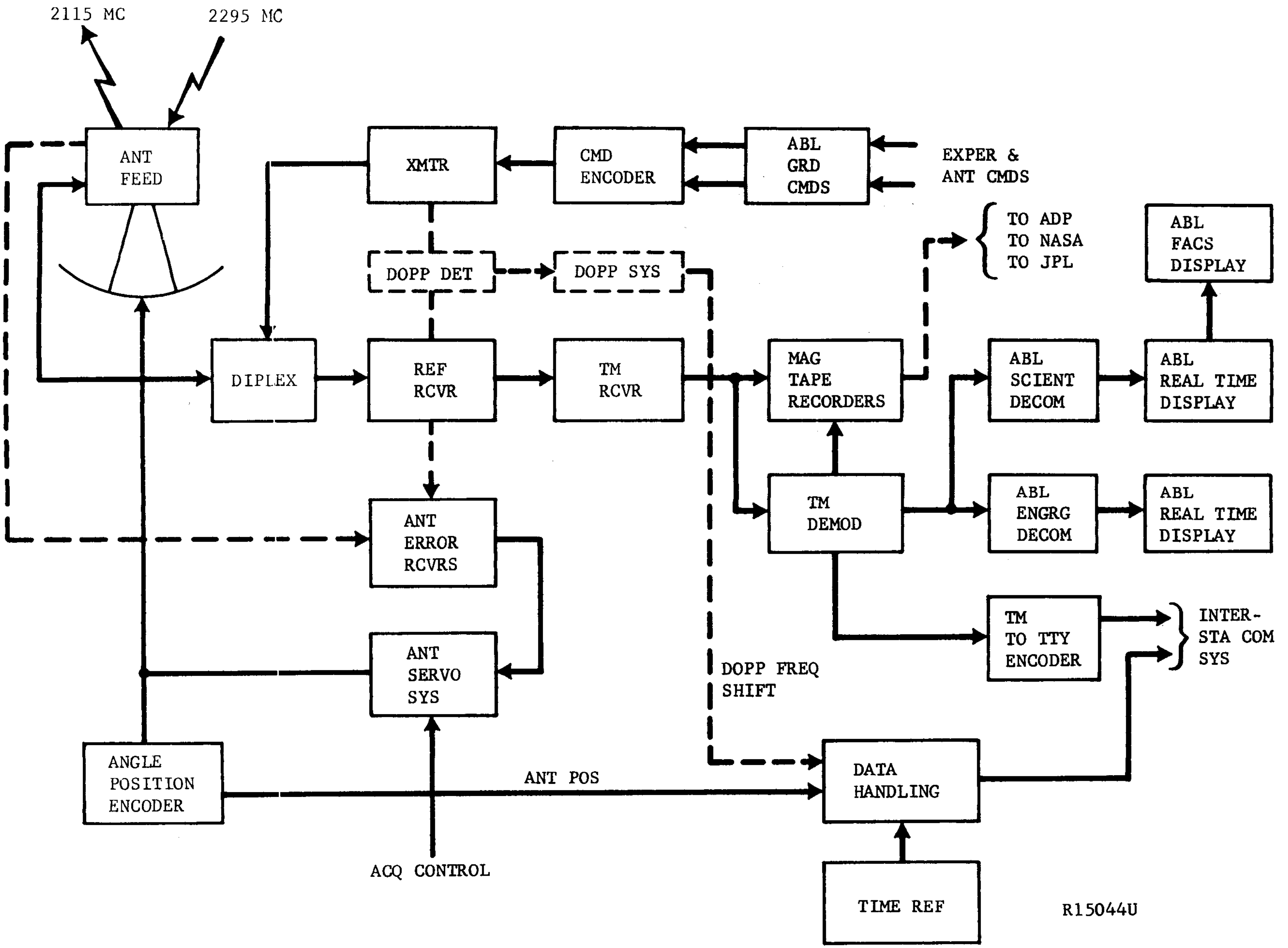


FIGURE 6.2-19. DEEP SPACE NET (DSN) GROUND RECEIVING SYSTEM

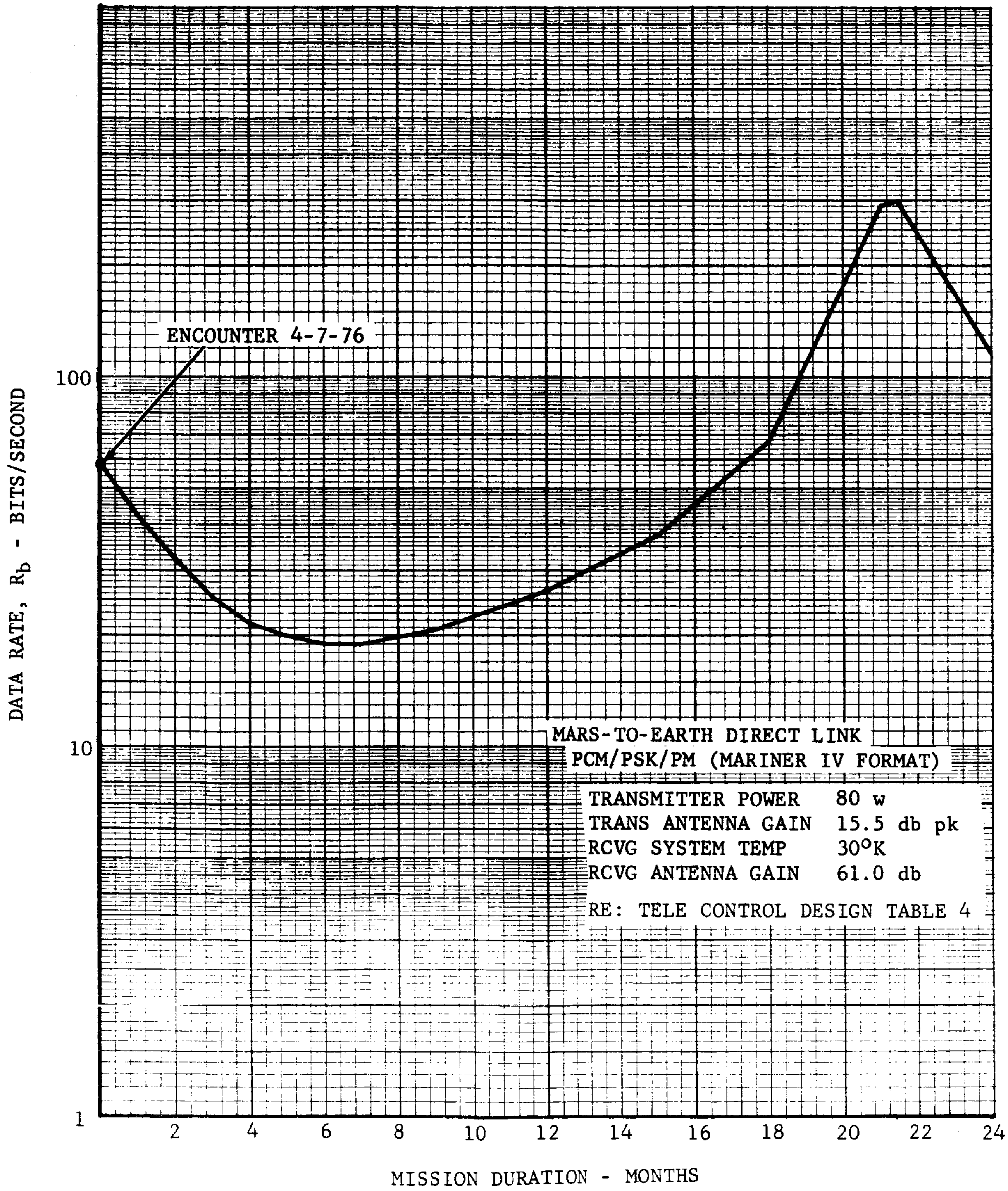


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FIGURE 6-2-20 ABL DATA RATE CAPABILITY - 1975 DESIGN POINT

Data of special importance will be redundantly coded to achieve improved error probability.

The command system bit error probability is taken as 10^{-5} on the basis of satisfactory performance and experience derived in present deep-space programs.

c. Data Load Capability. The design point system data load capability may be determined on the basis of a 3-hour-per-day operating cycle and Figure 6.2-20. By selecting descrete values of data rate and allowing data to accumulate over the scheduled intervals, the cumulative data load capability results as shown in Figure 6.2-21. The tentative telemetry system design point schedule is referenced on the plot B as four separate data rates and four sequences of change. Plot A represents a closer approximation to the continuously variable schedule of rates implied in the basic data rate characteristic of Figure 6.2-20. Thus, a cumulative data total of about 3×10^8 bits is realizable with a minimal schedule of discrete data rates.

An acutal laboratory data load schedule is cited as the "design point data load" and is also shown in Figure 6.2-21. Adjustments in scheduling or tradeoffs can be made, particularly at the beginning and end of the mission, to optimize the match between capability and need capacity.

The previously postulated Orbiter-Relay link case of 6.2.5b is also shown in Figure 6.2-21, denoting the potentially higher basic data transfer characteristics of the relay link. In either the direct or relay modes, excess transmission capability may be utilized for more experiment data.

d. Antenna. An electrically steerable multifan beam antenna array is selected as the design point S-band telemetry antenna system. The steerable phased-array design is essentially an eight-beam position configuration with 56-by-13-degree elemental beam coverage and 15.5-db gain. Figure 6.2-22 shows the volume and layout of the antenna. It consists of two rows of eight, for a total of 16 turnstile antenna elements, which are encapsulated to protect against antenna breakdown. The array is oriented with the long dimension lying in a plane which contains the rotational axis of Mars. The Earth moves through the long beam dimension, as noted in Figure 6.2-7. A tentative layout of the feed system which produces elemental beam coverage in accordance with fixed-beam steering drive signals is shown in Figure 6.2-23. The feed system uses eight power dividers and 12 hybrids. An eight-position rf switch connects between this feed network and the driving transmitter. A preliminary estimate places the feed system weight at about six pounds.

To illustrate the required operational coverage, Figure 6.2-24 shows that seven elemental beam positionings can encompass the Earth track with 5-degree sector overlap. From the antenna discussions in 6.2.4c(1) it was shown that the communication time of 3 hours is accomplished with 20-percent margin by the 56-degree dimension. These pointings would require 16 or 17 sequencing operations. This can be readily accomplished electronically, based upon onboard computer-controlled sequencing, which is discussed further in Paragraph 6.3. Similar results may be achieved in combination with mechanical orientation schemes.

(1) System Description. The design point system employs a hybrid S-band transmitter with an rf output power of 80 watts. The telemetry antenna subsystem is a circularly polarized steerable fan-beam antenna with beam coverage of 56 by 13 degrees and a 15.5-db peak gain. Programmed beam-switching in accordance with mission progress is accomplished essentially as described in 6.2.3c(1) and in paragraph d following. The command antenna is a circularly polarized turnstile configuration with a 90 degree beamwidth and a 6-db gain. For certain mission phases, utilization of the command antenna for telemetry transmissions is feasible in case of telemetry antenna-pointing failure modes. A data selector device effects a minimal schedule of discrete data rates to facilitate the cumulative data acquisition process. A 3-hour-per-day communication duty cycle, which is a reasonable compromise of power supply, data transfer, and antenna subsystem characteristics, is adopted for the full mission duration.

The Lander telecommunication system has a minimum interface with the DSN. Complementary data bandwidth adjustment is scheduled in conjunction with Lander data rate changes to maintain desired system threshold requirements. Experiment, data handling, routine command programming, and emergency provisions create a significant interface requirement within the DSN framework.

(2) Modulation Efficiency. The binary digital coherent PSK modulation process is selected because of its efficient and proven detection characteristic as evidenced in the familiar bit error probability versus predecision SNR curves. The telemetry link ST/N/B of 7.5 db cps/bps, which includes a 1.5-db degradation factor,(21) is based upon a bit error probability, P_b^e of 2.5×10^{-3} (i.e., the ideal ST/N/B is 6.0 db cps/bps). This bit error probability is derived from a word or letter probability, P_ℓ^e of 10^{-2}, which is acceptable for the imaging data comprising the principal data load. The relationship between the two quantities is given by

$$P_b^e = 1 - (1 - P_\ell^e)^{\frac{1}{n}} \qquad (14)$$

where n is the number of bits making up the letter

($n = \ell$ for no parity bits)

For the imaging or facsimile data which makes up three-fourths or more of the total data load, $n = 4$ and $P_\ell^e = 10^{-2}$. Thus, from Equation (14), it is shown that

$$P_b^e = 1 - (1 - 10^{-2})^{1/4} = 1 - 0.9975 = 2.5 \times 10^{-3} \qquad (15)$$

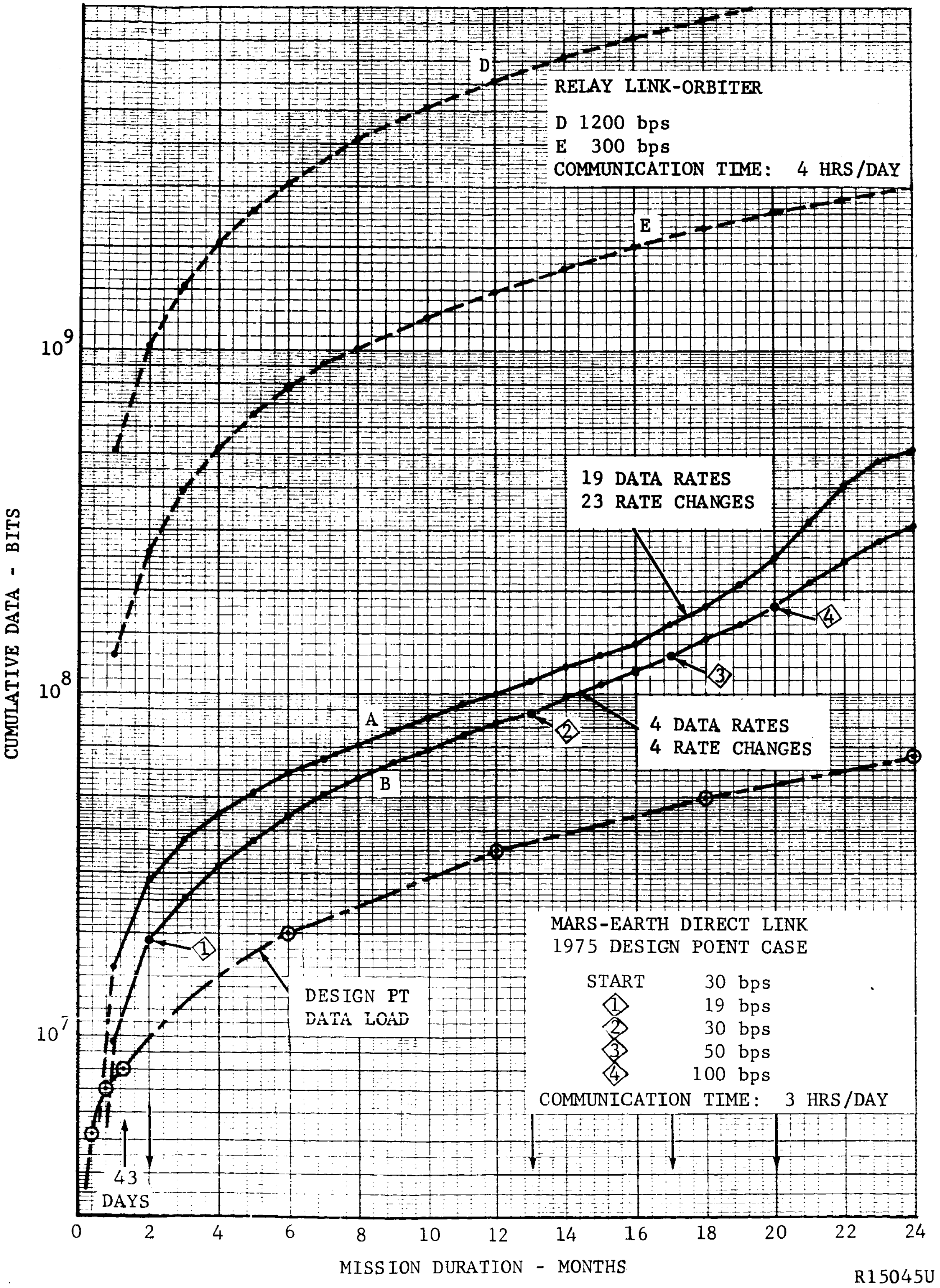

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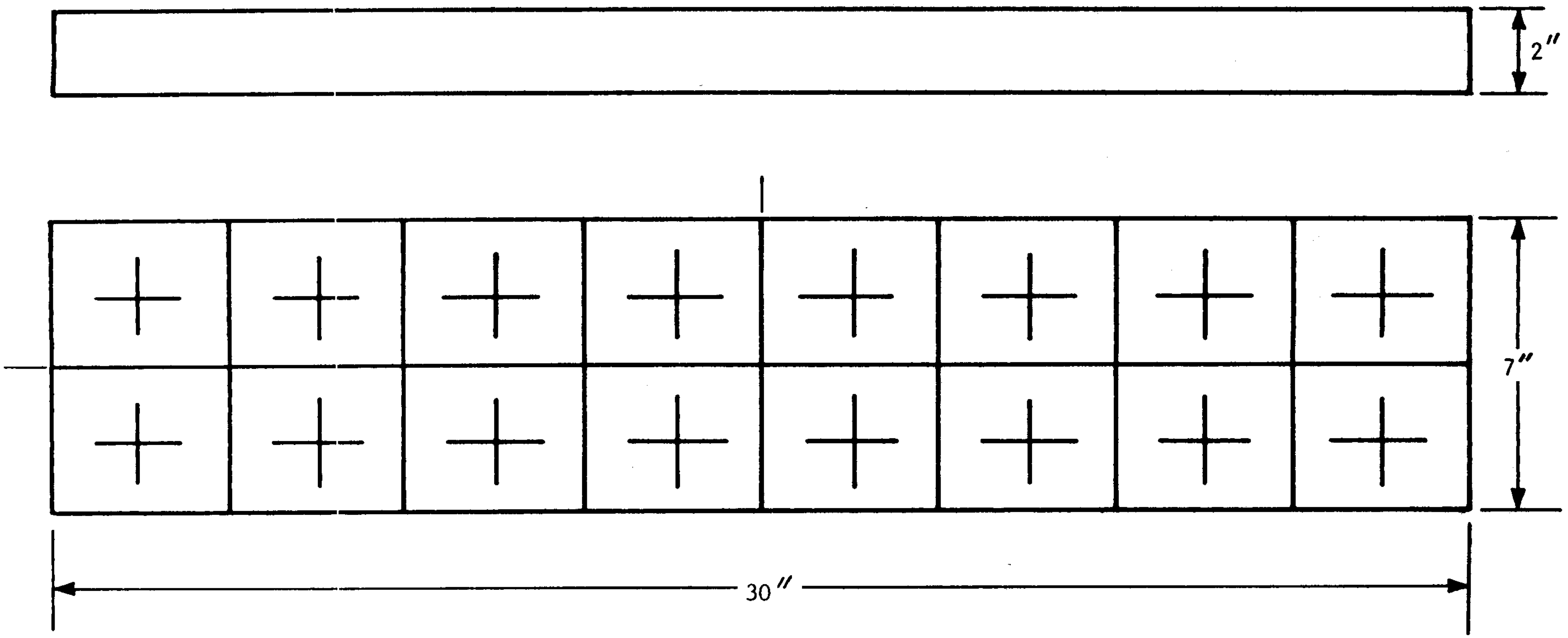
FIGURE 6.2-21. ABL CUMULATIVE DATA CAPABILITY



NOTE: VOLUME REQUIRED FOR 15.5db GAIN FAN BEAM ARRAY CONSISTING OF 16 TURNSTILE ELEMENTS. BEAM IS 13° BY 56° AT THE HALF POWER POINTS

R14955U

FIGURE 6.2-22. MULTI-FAN BEAM PHASED-ARRAY ANTENNA CONFIGURATION

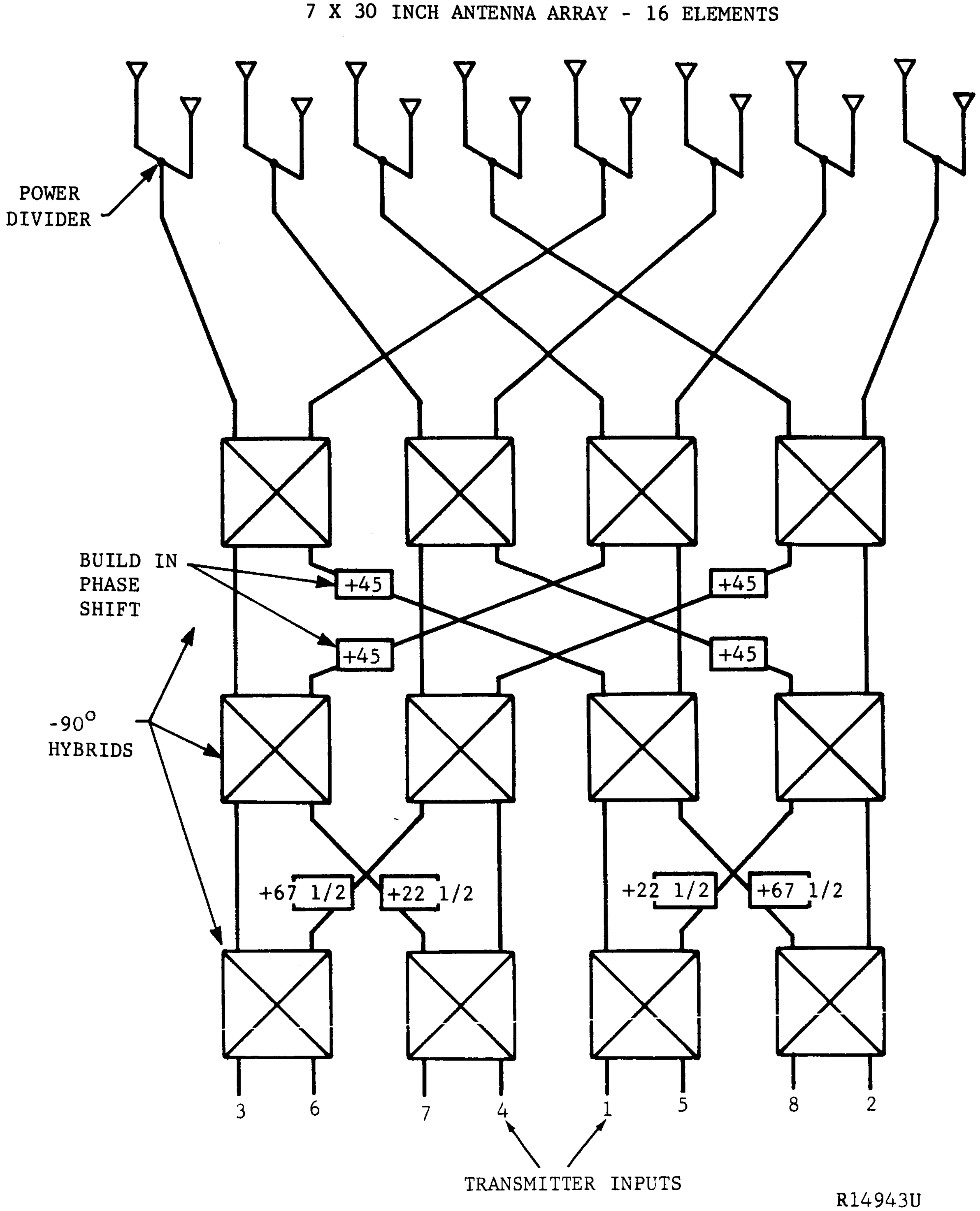


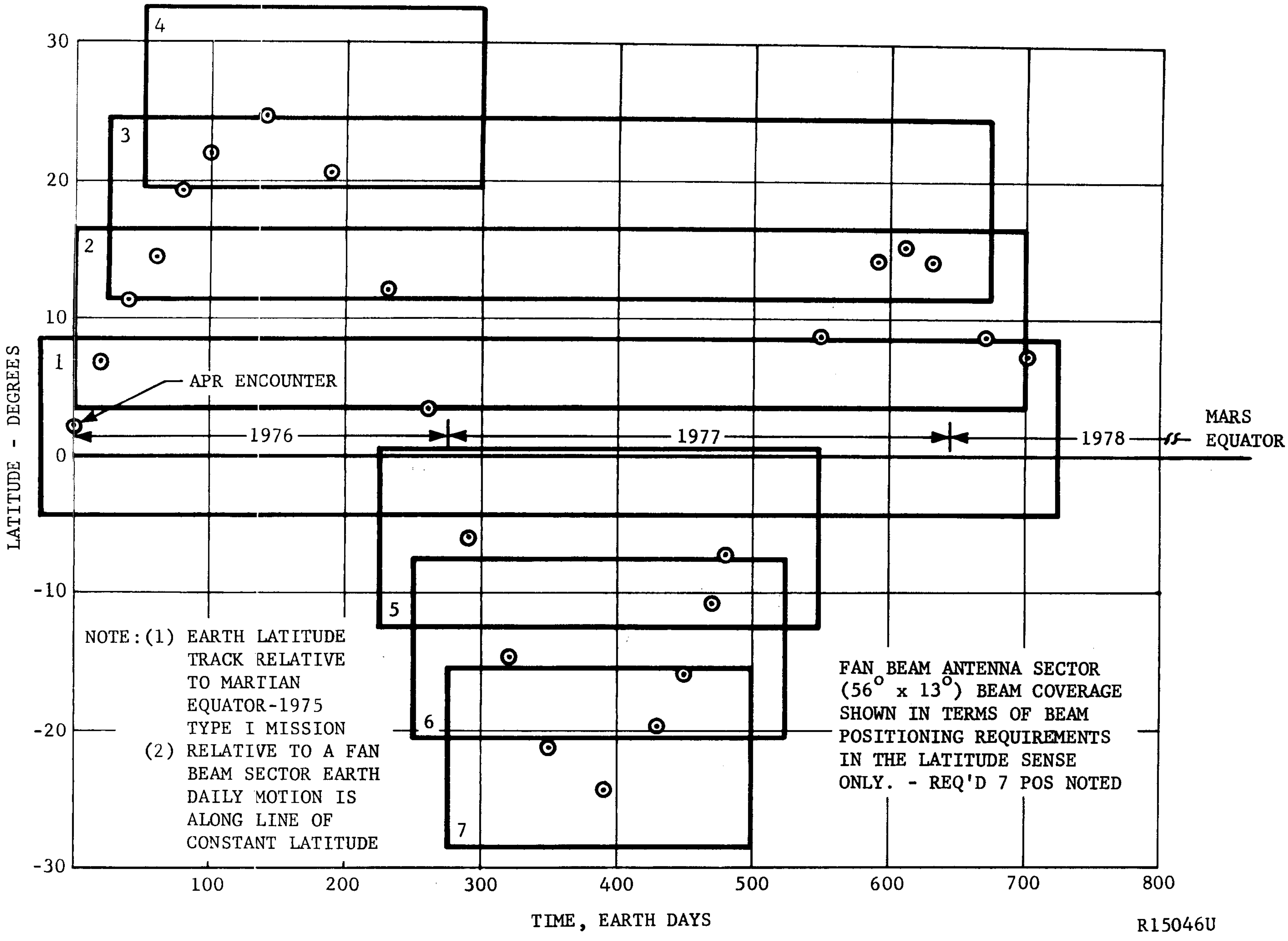
FIGURE 6.2-23. FAN BEAM ANTENNA ARRAY FEED SYSTEM

The design point command antenna system employs a 90-degree-beamwidth, 6-db-gain turnstile antenna design. The overall physical configuration is contained within a 4-inch-diameter cylinder 2 inches in height. The dipole elements are set about 1-1/2 inches above the base ground plane in a Teflon or similar encapsulation. Use of encapsulation or dielectric improves the power-handling capability of the antenna in the event of its use in a backup transmission function.

e. Transmitter. A hybrid S-band transmitter design capable of 80 watts output power at an overall efficiency of 40 percent is assumed for the design point system. A more efficient version of the configuration, shown in Figure 2 of Appendix 12, is employed. The design includes a solid-state crystal-controlled signal source consisting of a transistor crystal oscillator, buffers, power amplifiers, and multipliers. The output stage utilizes two small ceramic triode cavity amplifiers. As described in Appendix 12, the cavity amplifier package is chosen because of a high probability of surviving the landing shock while delivering substantial power at reasonable efficiencies. The 40-percent efficiency is considered achievable for the 1975 mission, although the present state of the art finds cavity amplfier devices operating at efficiencies of about 30 percent. Landing impacts of 500 to 1000 g with several milliseconds duration are possible. The ruggedness factor in ABL landings limits the choice of amplifying devices and the efficiency of satisfactory transmitter designs. Appendix 12 reports on some shock qualification data pertaining to small triode amplifiers and suggests that the larger devices, because of their similar construction, may be capable of withstanding a 500-to-1000-g impact with only small redesign. It must be acknowledged, however, that some tube development and vigorous qualification will probably be necessary. The planer triode, therefore, although not as efficient as the Amplitron and without the power gain of the TWT, appears to be much more rugged and capable of impact qualification.

The design point transmitter configuration is similar to that of Figure 1C of Appendix 12, which utilizes multiple output stages to drive a single antenna through a hybrid power combiner. The hybrid performs functions of isolation, impedance matching, and power summation. The isolation thus provided prevents mismatch caused by failure of one output stage from degrading power output from the remaining stage.

Carrier phase stability is held below two to three degrees to facilitate operation with the narrowband 12-cps carrier tracking loop of the DSN. An output power level monitor, functioning as part of the fail-safe mechanism, is also included. In the event of a drop in output power, bit rate and deviation would be reduced, to ensure at least a reduced level of communication. Primary power would also be removable from the defective stage. This redundancy or backup feature results in increased reliability of a partial mission success. For long-duration missions such as ABL these features are desirable.



NOTE: (1) EARTH LATITUDE TRACK RELATIVE TO MARTIAN EQUATOR-1975 TYPE I MISSION

(2) RELATIVE TO A FAN BEAM SECTOR EARTH DAILY MOTION IS ALONG LINE OF CONSTANT LATITUDE

FAN BEAM ANTENNA SECTOR (56^o x 13^o) BEAM COVERAGE SHOWN IN TERMS OF BEAM POSITIONING REQUIREMENTS IN THE LATITUDE SENSE ONLY. - REQ'D 7 POS NOTED

FIGURE 6.2-24. DESIGN POINT MISSION - EARTH TRACK

The estimated weight and volume of the design point transmitter configuration is 15 pounds and 250 cubic inches.

f. Receiver. The preliminary design has been carried out for a low-standby-power (1.5 watts) S-band command receiver with reliable 2-year operating life to be used in the Lunar Survey Probe. It employs a low-noise, high-gain, circulator-coupled tunnel diode rf amplifier followed by a hybrid ring-balanced mixer. Unique first IF and standard second IF phase-demodulator and synchronization circuits are employed. Oscillator frequency shifts on the order of 5 ppm are expected. The current packaging concepts of this receiver result in a volume at 30 cubic inches and weight at 2.5 pounds, which includes an additional circulator to provide transmit-receive capability with a single antenna.

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6.3 ABL DATA PROCESSING AND CONTROL STUDIES

6.3.1 GENERAL

Data processing offers significant possibilities for improving the effectiveness of the ABL mission. Contributions to mission effectiveness can be obtained in the following general areas:

(1) Control of communications to and from Earth.

(2) Control of overall ABL operations.

(3) Provision of adaptive control of individual experiments, making feasible a high degree of sophistication and thoroughness in the design and conduct of experiments.

(4) Provision of data reduction and analysis to extract the most useful information from experiments and minimize data transmission to Earth.

Data processing technology is still advancing at a very high rate with no signs of retarding. Functions are being performed today that would not have been considered three years ago. Similarly, there are likely to be valuable data processing techniques commonly accepted three and four years from now which are today only in the laboratory stage. These techniques may be either in hardware, software, or functional uses of data processing. Applications in experiment control and process control have been growing rapidly. (1,2,3,4) Computers have been utilized in control of industrial plants and processes for many years because of their reliability, speed, and high accuracies. For the same reasons, they are now being used to control laboratory processes and experiments. Automatically controlled wet-chemical analysis gas chromatography, colorimetry, and physical measurements, such as X-ray diffraction and neutron diffraction, are currently being done with digital computers performing closed-loop control of these operations. Wet-chemical analysis is being done automatically in hospitals as accurately as the average medical technician, in a third to a fifteenth the time, and for less than half the cost. At Brookhaven National Laboratory, work is almost complete on a computer system that will control one X-ray and eight neutron diffraction apparatuses at the new High Flux Beam Reactor. Two neutron time-of-flight analyzers have been run from a common computer control for more than a year, so no problems are anticipated with the nine-experiment operation. The success attained with these computer-controlled processes can be duplicated in the ABL since it consists of a number of similar processes under a common control. Thus, continuing studies and design are desirable throughout the

ABL development cycle to ensure that maximum advantage is taken of powerful data processing tools that already exist and which are being developed rapidly.

The most pressing problem at this stage of examination of ABL processing requirements is that of functional design rather than hardware design. The basic data processing functions must be determined before any meaningful estimates of processing requirements can be made. The conceptual or functional design of processing approaches must be determined. This is where the contribution of the processor to optimization of experimental results and minimizing transmission can be best determined. Once the functional design is established, the programming approach and the specific processor equipment requirements can be determined. It is a straightforward matter to obtain a proper computer design once the basic functional and program requirements are known. It is necessary to understand processor functions before hardware tradeoffs can be intelligently considered. This section presents a first iteration of the steps needed to arrive at a representative design point computer configuration. The degree of thoroughness of the functional analysis and functional design at this stage is not adequate to substantiate any specific computer design. However, the analysis is adequate to confirm that the general types of processing functions described are compatible with the design point computer described. The design presented is based on only modest extrapolations of current capabilities.

6.3.2 DATA PROCESSING FUNCTIONS

The ABL processing functions included in the estimates of ABL data processing requirements are described in the following. At this stage of ABL planning, these cannot be considered an exhaustive list of functions for which data processing may be used. The functions will undoubtedly be refined as the ABL evolves and as more design and tradeoff studies are performed.

The data processing functions are grouped in four general classifications: communication, ABL control, experiment control, and data reduction and analysis.

a. Communication Functions.

(1) Antenna Pointing. The communication antenna must be pointed toward Earth. This requires periodic changes of the antenna position with respect to the Martian surface. (See Paragraph 6.2.) Normally, controls to account for predictable variations would come from Earth; however, it is also necessary to provide the antenna pointing capability entirely within ABL so that the mission can be accomplished even in case of failure in the Earth command link. The position and orientation of the ABL with respect to Mars must be established before the antenna can be properly pointed.

The initial acquisition of Earth signals would be accomplished by

(a) Locating the sun, utilizing a precision time reference and solving the equations of motion, or referring to a stored ephemeris table.

(b) Searching for the earth signal and maximizing response.

A stored ephemeris table plus consideration of Martian latitude from sun angle is probably the easiest way to determine the periodic changes required. Sunrise sensing may be an adequate time reference after the initial acquisition. The equations of motion may well be the most complicated individual computations. There should be slight data storage requirement, but there may be a computation to update antenna pointing controls each Martian day.

(2) Communication Control. The considerable changes in Earth-Mars distance during the mission makes it advisable to change the communication bandwidth in order to ensure optimum communications throughout the mission. Bandwidth is controlled by modifying the pulse rates and pulse duration for both transmission and reception. Again, this capability must be continued within the ABL to ensure mission continuity in case of failure of the receiver. The rotation of Mars also makes it necessary to interrupt communications periodically.

The processor must control the handling of conventional control signals that are part of standard digital communication links. Control signals such as start of message (SOM), end of message (EOM), end of transmission (EOT), error (ERR), and acknowledge (ACK) must be recognized and generated. The appropriate logic for handling the control signal interchange and repeating of messages when necessary is performed by the processor. The processor must also control the buffering or queueing of data for transmission.

The processing requirements for communication control are relatively light. The changing of pulse rates and lengths commonly appears only several times during the entire mission. The Martian daily on-off cycle and the handling of the communication control signals requires only a small amount of processing for each message sent or received.

(3) Coding and Decoding. The coding system used in the transmission link requires processing to generate the code, to interpret the code received from Earth, and to detect and correct errors in received data. Appendix 14 presents a discussion of error correction coding. Most of the error correction and synchronization codes involve a simple program which is repeated frequently, depending on the amount of data to be coded and decoded.

(4) Formatting. The format of data in the processor is normally different than the format used over the data link. Processing is required to convert from the format most convenient for processing to the format most efficient for transmission. This applies both to transmitted and received data. In addition, the processor must generate message headings to identify the types of data being transmitted and must interpret received message headings to be able to reformat the data and initiate the appropriate processing. The programs are straightforward, but also require storage of the heading and formatting data for each type of message.

(5) Buffering and Quenching. The data to be transmitted will be assembled in a buffer which is worked off during transmission periods in order of priority. Data must be saved until acknowledgment of correct receipt is received from Earth. In the case of statistical summary gas chromatograph and mass spectrometer data, only the reduced data are transmitted initially. The detailed data are saved until the next transmission period, and transmitted only if requested from Earth.

b. ABL Control Functions. One of the most necessary control features is flexibility. Adequate flexibility must be included in the functional design to allow for continuing changes in the specific experiments and for redefinition of experiments from Earth during the mission. Perhaps the most effective method of providing a high degree of flexibility at little or no cost is through use of decision tables.

Figure 6.3-1 illustrates the content and logic of a typical decision table. The decision table relates existing conditions to actions which should be taken. It describes logically which actions should be taken for various combinations of conditions. Some of the advantages of decision tables are:

(1) They provide a simple and precise means of stating the control logic which simplifies the analysis and design.

(2) The control logic can be changed easily without changing the basic program on receipt of new logic on Earth or from Earth during the mission using a highly efficient control language.

(3) They provide an extremely efficient means for storing control logic during the mission.

(4) The processing involves simple table look-up operations rather than complex logical algorithms.

Conditions						Actions					
Particle Density Greater than X	Port Closed Half Way	Wind Velocity Greater than Y	Action 3 from Decision Table F	Previous Attempt Failed	Temperature Above Limit Z	Cancel Experiment	Close Port Half Way	Branch to Alternate Path	Continue as Planned	Set Condition 2 in Decision Table G	Reduce Priority by One Level
0	1	0	0	0	0	0	0	0	1	1	0
0	1	0	0	0	1	0	0	0	1	1	0
0	1	0	0	1	0	0	0	1	0	1	0
0	0	0	0	1	1	0	0	1	0	1	0
1	1	0	1	0	0	0	0	0	1	1	1
1	1	0	1	0	1	0	0	0	1	1	1
1	1	0	1	1	0	0	0	1	0	1	1
1	0	0	1	1	1	0	1	1	0	0	1
1	1	1	0	0	0	0	0	0	1	0	1
0	1	1	0	0	1	0	0	0	1	0	1
1	1	1	0	1	0	0	0	1	0	0	1
1	0	1	0	1	1	1	1	0	0	0	0
0	1	1	1	0	0	0	0	0	1	0	0
0	1	1	1	0	1	0	0	0	1	0	0
0	1	1	1	1	0	0	0	0	1	1	0
0	0	1	1	1	1	0	1	0	1	1	0
1	0	1	1	1	1	1	1	0	0	1	0

Each line across the table defines the actions to be taken for a specific combination of conditions. The conditions may be any factors that affect the actions. The actions can be individual actions, combinations of actions, sequences of actions, or initiation of related subroutined algorithms. Decision tables can be linked by letting an action in one table be a condition in another, providing more comprehensive logic efficiently.

FIGURE 6.3-1. EXAMPLE OF DECISION TABLE

Decision tables can also be linked as indicated in Figure 6.3-1 to provide more extensive logic and interrelationships without requiring excessively large tables. For instance, an action in one table may be a condition in another table.

The ability to change actions as conditions change provides a type of adaptive control. By using results in previous experiments as conditions, the actions in subsequent experiments can be adaptively controlled.

(1) Experiment Scheduling and Allocation. The ABL processor must control scheduling of experiments and adaptively allocate and reallocate apparatus, expendables, power, memory, and transmission bandwidth to various experiments on a priority basis. Most of the ABL experiments will be performed on a calendar basis. The times the various experiments are to be performed will be stored in the computer memory. These experiments will generally be automatically performed at predetermined intervals under computer control. This requires the use of a two-year clock in the computer. It should be possible to modify experiment priorities and scheduling on the basis of experimental results, control indications from Earth, random events such as solar flares, and equipment failures.

This function is similar to the common job-shop scheduling application. It considers the many tasks to be performed on a priority basis. A pseudo linear programming approach with some scheduling guides for weighting experiments is probably a satisfactory processing implementation. It allocates the resources to experiments in order to optimize overall experimental results. Since the duration of certain experiments is variable, it is impossible to provide a predetermined schedule. Experiment scheduling and allocation could be performed under Earth control. However, the ABL must have this capability in the event of failure of the command link and to prevent overtaxing the communication capacity. As long as the capability must be provided in the ABL, it is simplest to provide Earth control using the efficient decision table logic control language.

(2) Configuration Control. The ABL should have the capability of monitoring its own performance, diagnosing its difficulties, and taking corrective action (self-test and repair). It should provide detection of errors or faulty operation, error recovery, backup and restart capabilities. In case of failures, it should control the interconnection of the various redundant distributed elements and initiate alternate configurations and operating modes. The processing for configuration control is primarily the execution of diagnostic routines and predetermined logic or decision tables describing what actions should be taken for various conditions of failure or experimental results.

(3) Apparatus Control. There will be anumber of subroutines that are for the specific control of experimental apparatus which are independent of which experiment is being performed. Examples are: gas chromatograph, mass spectrometer, sample collection, and internal sample distribution and storage. The processor should control the collection of samples and the internal routing and distribution of portions of the samples.

The program to handle sample collection and internal distribution should consider the sampling pattern of the surrounding area, results of tests, and measurements of previous samples and their locations. Not even the internal routing and distribution of sample portions can be predetermined, since the nature of the experiments and their sequencing is adaptively controlled.

(4) Executive Routine. Since the processor performs a variety of tasks, it must have a master control program or executive routine , which manages the operation of all the programs. The executive routine is perhaps the most active and most frequently used, although the amount of processing is relatively modest. Typical processing tasks included in the executive routine are:

(a) Control of the order in which processing tasks are performed, maintaining a priority queue of processing tasks.

(b) Control of the time sharing of processing, allowing conduct of a number of experiments simultaneously.

(c) Interrupt processing; when interrupted store contents of registers, receive interrrupt data, lock out interrupt data during critical operations, resume processing where interrupt occurred after processing the interrupt data appropriately.

(d) Provide a time reference for all programs, making available elapsed time as well as absolute, or mission time.

(e) Provide for program error handling, diagnostics, error recovery, backup and restart operations. It is assumed that each program would have its own error checking and error returns.

(f) Perform "housekeeping" tasks to purge unneeded data, update indexes to files, maintain backup files.

(5) Input-Output. Input-output routines are normally centralized, each functional program referring to them as subroutines. This involves setting up the I/O lines and controls to route control data to appropriate apparatus and to receive data from various input lines.

c. Individual Experiment Control. Many of the control functions in individual experiments may be handled in a generalized experiment control routine. The skeleton of this routine would be general enough to handle most of the control functions using parameters for each experiment. Some of the experiments will also require special processing tasks not covered by the generalized program. However, total program storage should be minimized by consolidating as many functions into the generalized program as reasonable.

The generalized experiment control routine would perhaps include such functions as those described in the following paragraphs.

(1) Adaptive Control. Based on existing conditions and previous results, controls for individual experiments should be selected to optimize the experiment and minimize collection of worthless data. Examples of parameters that might be controlled depending on conditions are: measurement scales, time constants, incubation time and temperature, duty cycle, detection or decision thresholds, and sample rates. Since the experiments must be designed without prior knowledge of the actual conditions, they may have to cover a broader range than necessary until the actual conditions are determined. Many of the conditions that affect the design of experiments will vary considerably over the period of the mission. The experiment control methods should allow changing of controls and parameters to modify or redirect an experiment in process based on initial results from that experiment.

The processor can detect when values are exceeding permissible ranges and initiate alarm or corrective actions, such as terminating an experiment. A control decision table for each experiment would provide an efficient solution for this function.

The flexibility in connecting the various experimental apparatus, sample handling, and controls should allow definition of completely new experiments during the mission. The definition of these experiments will normally come from Earth; however, simple modifications to existing designs of experiments may be reasonable under ABL self-controlled adaptive control.

(2) Experiment Sequencing and Timing. The salient parameters relating to the experiment control requirements are shown in Table 6.3-I. Nearly all of the control functions required are of a simple command or switching nature. Even in a few cases where proportion controls are implied as in the case of programmed incubation temperature and sampling depth, etc., incremental switch controls can be used.

TABLE 6.3-I

EXPERIMENT CONTROL SUMMARY

Exp No.	Experiment	Activation C - Command E - Event P - Per Samp	Exp Duration	No. of Control Functions		Remarks*
1	Atmos Temp, Press, and Wind	C-P-E	12 min	11		Check calibrations, monitor temp for equilbrium before reading test for low reading.
2	Atmospheric Humidity	C-P-E	2.5 min	4		Check calibration
3	Wind Trans Particles	E-C	10 min	8		Weigh and store sample
4	Acoustical Monitor	E	2 min	4		Correlate with Exp 24
5	UV and Visible Insulation Flux	C	5 min	2		Reference Source Calibration.
6	Ionizing Radiation Background	C-E	22 min	6		
7	Atmospheric Composition	C	11 min	10		Divert samples of interest to transfer ampules
8	Soil Temp and Water Content	C	30 min	7		Reference calibration, monitor for maximum force.
9	Soil Electrical Conductivity	C	85 min	5	1 depth 20 pos	Calibration and check
10	Soil Density by X-ray Sonde	C	85 min.	11	1 depth, 20 pos	Calibrate and check
11	Soil Mechanics	C	93 min.	47		Comples control req'mts, check continuity switches, select sample method.
12	Soil Sample Encapsulation	C	25 min	9		Control sampler.
13	Elemental Soil Analysis	C	24 hrs	3		Calibrate with reference sample
14	Soil Gas Analysis	C	10 min	9		
15	Soluble Inorganic Ions and pH	C	28 hrs	16		Fairly complex controls
16	Organic Material in Soil	C	152 min	16		Programmed heating
17	Soil Gas Exchange	C	50.5 hrs	21		
18	Amino Acid Analysis	C	135 min	14		
19	Amino Acid Det and Opt Activity	C	535 min	23		
20	Detection of Porphyrins	C	150 min	26		
21	Detection of Flavins	C	375 min	54		Complex control requirements.
22	Detection of Nonsaponifiable Lipids	C	433 min	33		Complex control requirements
23	Detection of Saponifiable Lipids	C	540 min	48		Complex control requirements.
24	Macromol by Vis Absorption	C	232 min	25		
25	Macromol by UV Absorption	C	150 min	24		
26	Functional Group Analysis	C	210 min	27		Fairly complex control
27	Water Sol Macromol by Pyrolysis GC	C	162 min	13		
28	Functional Group Analysis	C	268 min	20		
29	Light and Dark $C^{14}O_2$	C	107 hrs	34		Fairly complex control
30	CO_2 Evolution by Normal Metabolism	C	159 hrs	15		
31	$C^{14}O_2$ Evolution from Labeled Substrates	C	52 hrs	17		
32	$C^{14}O_2$ Uptake from Labeled Substrates	C	90 hrs	44		Complex control requirements.
33	Culture Eval and Growth Detection	C	77 hrs	37	10 temp, 10 values	Image tube growth and position detection, transfer cultures of interest.
34	Optical Motion Detection	E	1 min	1		
35	Visible and IR Macroimaging	C	10 min	11		

*See Appendix 5, Volume VI, for detailed discussion of apparatus and experiment sequences.

The experiments and apparatus which require the more complex controls are relatively slow processes and controlled speed and timing precision are not critical. This includes the sampling devices and the chemical and biological analyses. The other experiments are relatively simple in their control requirements. The imaging experiments have by far the highest output data, but they require a minimum of control.

The sequencing and timing of various events or actions in an experiment can be handled by the central processor. In some cases, there are logical relationships among events which must be satisfied before the next step in the experiment may be initiated. Thus, a generalized control network routine for incorporating logical relationships into the sequencing and timing of experimental steps seems appropriate. Experiment 11 is a good example of the type of control of this nature that is necessary. A generalized program would permit stating the sequencing logic and timing requirements in a very efficient control language. This would simplify definition of new experiments or modification of experiments from Earth. Use of the central processor for this does not preclude separate controls as a part of individual experiments or apparatus, but it eliminates the need for separate control equipment.

(3) Control Sampling. The optimum sampling rate for many experiments cannot be predetermined, but depends on conditions experienced on Mars and results of other experiments. The processor can control sampling rates based on such conditions for cases of periodic sampling, sampling triggered by random events such as Mars quakes or solar flares, and sampling only after certain logical relationships have been met. A statistical design of an experiment subroutine can consider the number of factors and levels in the experiment and determine the number of samples needed to obtain the desired degree of confidence and experimental error. Although this may be more appropriately done on Earth, it may be desirable to include in ABL capability to minimize the control load on the communication link.

(4) Servo Control. Any experiments which require dynamic servo control can use the central processor for sampled data servo control. In most cases, the sensor data will be digitized for other purposes, and the actuators will be under digital control to allow the computer to initiate and control actions. This makes it convenient to use the processor as part of the servo control loop.

(5) Calibrate Measurement Apparatus. Some experimental apparatus and measuring devices need calibration readings in order to provide proper measurement accuracy. The calibration on instruments cannot be maintained throughout the ABL mission without initial and recurrent calibration. The computer can control such actions and store calibration data obtained from standard samples in the processor for transmission or use in data reduction.

d. Data Reduction and Analysis Functions.

(1) Data Compression. A primary function of the data processor is reducing the volume of experimental data that must be transmitted to Earth. The transmission bandwidth and power can be minimized and the intrinsic value of transmitted data can be improved by transmitting only the most significant data. There has been much work and progress recently in the field of data compression. A study was made of this work and is reported in Appendix 13, Volume VI. Data compression is generally performed by the reduction of redundant data in imagery and in repetitive measurements. It is also possible to analyze collected data and send only significant changes; summary statistics such as means, variance, and range; or reduced rather than raw data. Compression methods which could definitely be useful in the various experiment data are listed in Table 6.3-II of Paragraph 6.3.3. It is pointed out there that imaging data comprises three-fourths or more of the total data load. Therefore, a compression method is particularly significant for the image data. Several methods, described in Appendix 13, of curve fitting and one of area coding have been demonstrated which reduce 16-gray scale scenes of high detail by a factor of two. This reduction is assumed in estimating the ABL transmission load. Greater compressions are potentially available but, as demonstrated so far, cause distortion or noise which would be objectionable in the ABL application. A further study of compression methods including laboratory testing appropriate to the ABL is warranted.

(2) Process Raw Data. In some experiments, the quantities of interest can only be determined by processing of raw data from instruments. Most adaptive control features which use previous results must know the value of the primary item rather than the raw measurements. For example, statistical analysis of data can extract the mean range, variance, regression and correlation coefficients. Such quantities are useful both for data compression and for adaptive control of experiments. Such values can be used to set the range and scale for additional, or for other experiments. Analysis of variance can be used to determine the contributions of various factors to the total experimental error. This can be used to determine optimum sampling rates or number of samples required. Aside from data compression and control of experiments, it is preferable to reduce the raw data on Earth rather than to provide added capability in the ABL processor.

(3) Artificial Intelligence. One area of current research that should be carefully considered during the formulation of the conceptual design of the ABL processing system is that of artificial intelligence. This includes pattern recognition, image identification, and adaptive learning. It is difficult to predict now the degree of success of such efforts by the time the ABL conceptual design must be frozen, since the field is developing so rapidly. Philco is doing considerable work in the

TABLE 6.3-II

EXPERIMENT OUTPUT DATA

Experiment (1)			Output Data							
No.	Function	Range	Exp Accuracy	Bits/ Word	Words $^{(2)}$/ Exp	Bits/ Exp Run	Exp Duration	Activation C - Command E - Event P - Per Samp	Compression Methods	Remarks
1.	Static Pressure	10 to 100 mb	±1%	7	(1) 2	55	12 min	C-P-E	Adaptive sampling	Reading once per 3 hrs min
	Dynamic Pressure	0.001	±10%	5	(1) 2					
	Ambient Temperature	-150 to + 38°C	±1%	7	(1) 2					
	Wind Velocity	0 to 15 fps	±1 fps	5	(1) 2					Alarm monitor
	Wind Direction		5°	7	1					
2.	Atmospheric Humidity	To 10-5 mm Hg	±1%	7	(1) 2	14	2.5 min	C-P-E	Adaptive sampling	Reading once per 3 hrs min
3.	Wind Trans Particulate Matter						10 min	E-C	Adaptive sampling	
	Signal Strength		1%	7	1	16				Possible alarm monitor
	Impact Rate (count)	4 decades	1%/dec	9	1					
	Weigh Collection		(rough)	6	3	(18)		C		Once per season at 3 elevations.
4.	Acoustical Monitor						2 min	E	Threshold Activation	
	Sound Intensity	< 0.0002 μbars	150 db	8	24	192				Meas in 24 frequency bands 20 to 20 kcps
5.	Ultraviolet & Vis Insolation	4 decades	1%/dec	9	(1) 10	90	5 min	C		Meas in 9 bands
6.	β and γ Radiation Background						22 min	C-E		2 counters plus up and down facing readings
	Pulse Count	To 100 counts per sec		7	(2) 4	56				
	Pulse Height		±1%	7	(2) 4				Mean only (or quantities)	
7.	Deter of Atmos Constituents						11 min	C	Adaptive sampling	
	Atomic Mass		1 in 400	16	40	1224			Meas peak amps; (or integral) & position only	Mass spectrometer 40 readings avg 9 bits atm mass 7 bits field mag
	Concentration of Constituents	To 10^{-2} mm Hg		12	40					4 col gas chromato 10 readings/ col avg 7 bits concen 5 bits time
	Temperature		1%	7	8					Monitors for gas chromatograph
	Flow rate & pressure			6	8					

TABLE 6.3-II (Continued)

Experiment(1)			Output Data					Activation		
No.	Function	Range	Exp Accuracy	Bits/ Word	Words(2)/ Exp	Bits/ Exp Run	Exp Duration	C - Command E - Event P - Per Samp	Compression Methods	Remarks
8.	Soil Temp and Water Content						30 min	C		Measure at 20 depths
	Water Content	To 10^{-5} mm Hg	1%	7	(20) 40	565				
	Temperature	-150° to +38°C	1%	7	(20) 40					
	Probe Insertion Depth	20 increments		5	1					
9.	Soil Electrical Conductivity		1%	7	(20) 40	280	85 min	C		Calib and meas at 20 depths in core hole
10.	Soil Density By γ-Ray Sonde									Calib and meas at 20 depths
	Density	0.5 to 5 sp gr	1%	7	(20) 40	4065	85 min	C		γ Radiation meas (rate)
	Temperature (Resis Thermometer)	-160° to 50°C	1%	7	(20) 40					
	Temperature (Interferometer)		1%	7	25 x 20					25 point plot
	Depth	20 pos		5	1					
11.	Soil Mechanics Determination						93 min	C		
	Roughness	on/off		8	1	134				Check continuity switches (8)
	Weight (by Particle Size, 3 ea)	1 to 500 gm	1%	7	3					
	Sinkage (2 Sensors)		1%	7	2					
	Force		1%	7	2					
	Shear Torque		1%	7	1					
	Pressure Decay Rate		1%	7	10					
12.	Soil Sample Encap and Preservation		Event	5	2	17	25 min	C		Signal completion, max penetration or max load value
	Weigh		1%	7	1					
13.	Elemental Soil Analysis	4 decade count	1%/dec	9	(16) 32	288	24 hrs	C		α scattering meas 16 sensors plus calib
14.	Soil Gas Analysis	See Experiment 7				1224	10 min	C	Adaptive sampling	Meas and outputs same as Exp 7
15.	Soluble Inorganic Ions and pH									
	α Scattering Analyzer	4 decade count	1%/dec	9	(10) 32	310	28 hrs	C		
	pH Meter	1 - 13	1 in 2000	11	(1) 2					

TABLE 6.3-II (Continued)

Experiment(1)		Output Data						Activation		
No.	Function	Range	Exp Accuracy	Bits/ Word	Words(2) Exp	Bits/ Exp Run	Exp Duration	C - Command E - Event P - Per Samp	Compression Methods	Remarks
16.	Detection of Organic Matl in soil									
	Fluorescence Spectrum	4 decades ampl 450-700 mμ	1%/dec 1 mμ	9	(50) 300	3540	152 min	C		Ampl reading each mμ plus calib
	Ionization Detector		1%	7	60					Read each minute during 60 min programmed heating
	Temperature		1%	7	60					
17.	Soil Gas Exchange						50.5 hrs	C		48 runs; 3 samples, 16 runs each at 3 hour intervals
	Gas Chromatograph (4 col)	Same as Experiment 7		12	40 x 48	45 x 10^3			Adaptive sampling of peaks	Instruments same as Exp 7
	Mass Spectrometer			16	40 x 48					
	Temperature		1%	7	10 x 48					10 readings per run
	Flow Rate and Pressure			6	2 x 48					Meas before and after each run
	β Radiation Counter	4 decades	1%/dec	9	48					Meas after each run
18.	Amino Acid Analysis						135 min	C	Adaptive sampling of peaks(3)	2 column (diff) gas chromatograph, est 30 peaks
	Gas Chromatograph (2 col diff) $d \leq 300\mu$			12	30	450(3)				Sample peaks to 7 bit (area) acc plus time to 5 bit acc
	Temperature			7	6					Read every 5 min during 30 min run
	Flow Rate and Pressure			6	8					4 readings each column
19.	Detection of Amino Acid and Opt Activity						535 min	C		
	Gas Chromatograph	Same as Experiment 18				450(3)				
20.	Detection of Porphyrins						150 min	C		Fluorimeter
	Fluorescent Intensity Wavelength	4 decades 600-700 mμ	1%/dec 1 mμ	9	(20) 120	1080				One reading each mμ plus calib
21.	Detection of Flavins						375 min	C		Fluorimeter
	Fluorescent Intensity Wavelength	4 decades 500-600 mμ	1%/dec 1 mμ	9	(20) 120	1080				One reading each mμ plus calib

TABLE 6.3-II (Continued)

No.	Experiment$^{(1)}$ Function	Range	Output Data Exp Accuracy	Output Data Bits/ Word	Output Data Words$^{(2)}$ Exp	Bits/ Exp Run	Exp Duration	Activation C - Command E - Event P - Per Samp	Compression Methods	Remarks
22.	Det of Nonsaponifiable Lipids						433 min	C		
	Gas Chromatograph			12	30				Adaptive sampling of peaks$^{(3)}$	2 col diff as Exp 18
	Mass Spectrometer			16	30					Same as Experiment 22
	β Radiation Counter			9	30	1200$^{(3)}$				30 peaks est
	Temperature			7	6					
	Flow Rate and Pressure			6	8					
23.	Det of Saponifiable Lipids		Same as Experiment 22			1200$^{(3)}$	540 min	C	Same as Experiment 22	
24.	Det of Macromolecules by Absorption in the Visible Spectrum						232 min	C		Optical-null spectrophotometer, read every 1 mμ.
	Absorbence	4 decades	1%/decade	9	300	2700				
	Wavelength	400-700 mμ	1 mμ							
25.	Det of Macromolecules by Absorption in the μV Spectrum									
	Absorbence	4 decades	1%/dec	9	110	990	150 min	C		μV spectrophotometer, read every 1 mμ
	Wavelength	240-350 mμ	1 mμ							
26.	Optical Activity of Water Soluble Macromolecules						210 min	C		μV polarimeter
	Rotation	0° to 20°	10^{-3} deg	15	2	39				
	Intensity	4 decades	1%/dec	9	1					
27.	Det of Water Soluble Macromolecules by Pyrolysis		See Remarks			930$^{(3)}$	162 min	C	Adaptive sampling of peaks$^{(3)}$	30 peaks est 2 col diff gas chromatograph and mass spectrophotometer output Same as Exp 22 without radiation counter
28.	Functional Group Analysis						268 min	C		IR spectrometer
	Absorbence	4 decades	1%/dec	9	120	1080				
	Wavelength	2 to 14μ	0.1μ							

TABLE 6.3-II (Continued)

Experiment$^{(3)}$			Output Data					Activation		
No.	Function	Range	Exp Accuracy	Bits/ Word	Words$^{(2)}$ Exp	Bits/ Exp Run	Exp Duration	C - Command E - Event P - Per Samp	Compression Methods	Remarks
29.	Light-Stimulated and Dark $C^{14}O_2$ Fixation as Funct of Temp	count rate 4 decades	1%/dec	9	30	270	107 hrs	C		Tagged carbon count with β ionization detector, 6 chambers, 2 temps, 2 incubation times, 5 readings.
30.	Evolution of CO_2 by Normal Metabolism	resisting meas	1%	7	4 x 36	1008	159 hrs	C		CO_2 detector, 4 chambers, 2 incubation times, 2 temps, 9 readings ea chambers.
31.	$C^{14}O_2$ Evolution from Labeled Substrate	count rate 4 decades	1%/dec	9	4 x 12	144	52 hrs	C		β ionization detector, 4 chambers 2 substrates, 2 incubation times.
32.	$C^{14}O_2$ Uptake in Light and Dark and Surs Evolution by Metabolism	count rate 4 decades	1% dec	9	6 x 18	972	90 hrs	C		β ionization counter, 6 processing chambers, 2 incubation times.
33.	Culture Evaluation and Growth Det						77 hrs	C	Image tube for growth det	5 cultures plus 8 (est) transfer cultures, optical density
	Optical Density	4 decades light level	1%/dec	9	13 x 48	(3)				Monitor and pH meter meas every 2 hrs for 48 hrs
	pH	1 to 13	1 in 2000	11	13 x 48	5.9 x 10^4			Position Determination	
	Gas Chromatograph	See Experiment 18		450	13 x 8				Adaptive sampling$^{(3)}$	Meas every 6 hrs
	Concentration (Position)		1 in 8	3	10					Concentration for max growth
34.	Motion Detector	See Remakrs		23	1	23	< 1 min	E	Threshold setting	8 light sensitive detectors covering 360°. Record rate of change, time, det (9 + 11 + 3 = 23 bits)
35.	Macroimaging and IR Scan							C		
	a. Visual - Low Resolution	60° x 360°	03°, 13 gray levels	4	2.4 x 10^5	9.6 x 10^5	~ 10 min		Curve fitting, other See text	
	b. Visual - High Resolution	20° x 20°	0.03°, 13 gray levels	4	4.4 x 10^5	1.78 x 10^6	~ 10 min			
	c. IR	60° x 360°	10, 8	3	2.2 x 10^4	6.5 x 10^4	~ 10 min			

NOTES:
1. Keyed to listing in ABL-217, Table I.
2. Larger number includes calibration points shown in ( ).
3. May be desirable to place entire curves of gas chromatograph and mass spectrometer outputs in interim storage for transmission if compressed data does not appear sufficient.

area of pattern detection and image recognition. A conference held recently at Aeronutronic included most of the significant workers in this field. The rate of progress in this area is such that practical applications of these techniques will probably have been proved by the time the ABL conceptual design must be frozen. However, it is hard to predict which specific techniques will be proved and whether or not they will satisfy ABL requirements. Thus, continued study is recommended because of the great potential benefits from these techniques.

(4) Transient Analysis. The detection of high-frequency transients which occur unexpectedly create a processing problem. When monitoring a sensor for random events or transients, it is quite wasteful to record and store all information when only a very small fraction is involved in the transient of interest. Also, it is desirable to store the initial build-up of the transient before it is detected. Thus, it is desirable to store the unput data in a progressive buffer, analyze the data to detect transients, and select for treatment only the transient data, including the build-up, letting the balance of the meaningless data be destroyed by new information continually coming into the buffer.

6.3.3 DESIGN ANALYSIS

a. Data Rates and Volumes. The number and variety of data sensors in the ABL can be expected to be quite large. Table 6.3-II lists the 35 experiments which have been selected for the design point ABL and the salient characteristics of the output data on the basis of a single run or cycle of each experiment. For purposes of this analysis, it is assumed that all data are handled in digital form; therefore, all analog signals are immediately digitized, and the table presents the equivalent digital output for analog signals.

While Table 6.3-II describes the design point experiment load, it can be considered to represent any likely ABL design for the 1975 era in terms of the diversity of data types. The sensor outputs fall into three groups in terms of their initiation or activation. These are indicated in the table and coded as C-command, E-event, and P-periodic sampling. Those designated C can only have an output following a command as, for instance, the start of a specific experiment or manipulation. E specifies an output for which the occurrence cannot be predicted in advance. These outputs must be monitored constantly if significant data are not to be lost. In some cases, these outputs (for instance, wind velocity, internal laboratory temperature, etc.) will be used as alarm signals to initiate protective measures. The third group of data sensors are those which may simply be sampled on a periodic basis. Many of the engineering measurements which monitor various internal laboratory parameters may be of this type.

The data output per experiment cycle varies over an extreme range from 14 bits for the atmospheric humidity measurement of experiment 2 to 1.78 x 10^6 bits for the high resolution imaging experiment. The bit rates are similarly variable from a few bits per minute to 10^5 bits per second for the image data. The next highest data outputs arise from the mass spectrometer and gas chromatograph which are used in several of the experiments.

Most of the sensors are monitored only when experiments utilizing them are being performed. This limits the number of sensors which are monitored at any given time. While several experiments may be performed at once, there is ample time to permit spacing as desired. Also, the sharing of many pieces of equipment and apparatus by many of the experiments limits the number of experiments which may be performed at the same time. Therefore, aside from imaging data, the short-term data rates to be accepted by the processor are essentially those of the individual experiment outputs.

The total data loads for the design point system are obtained by combining the information on bits per experiment cycle from Table 6.3-II and the planned scheduling of the experiments as defined in Paragraph 4.3 and Appendix 5. Table 6.3-III shows the total bits of output data generated per day for the first 10 days after landing; the cumulative totals for the first 43 days and for each season, and the grand totals for the two year (Earth) life. The engineering data outputs, not covered within the various experiments, ahve been estimated and are lumped as the last row in Table 6.3-III. Many of the engineering parameters will be monitored continuously for abnormal readings and data need not be transmitted if normal conditions prevail. It was assumed, however, that readings on 200 parameters of an average 7-bit word would be taken once per hour for the first ten days and once every two hours thereafter to provide time history data throughout the mission. For the first ten days, the data load varies from about 4 x 10^4 bits per day to 10^5 bits per day, except for the first day which totals 1.2 x 10^6 bits because of the visual and IR imaging experiments. From the two-year totals, it is found that the imaging data (35) comprises 75 percent of the total output, the other experiments (1 through 34) only 10 percent, and the remaining 15 percent is taken up by the engineering measurements. The figures given in Tables 6.3-II and 6.3-III do not include the compression (of at least a factor of 2) which it is expected will be achieved on the image and some other data by redundancy reduction. This compression may partly be traded back for error correction coding, and some expansion will result from the added bits for synchronization and addressing. The conservative assumption has been made that the net total bit load to be transmitted is unchanged.

TABLE 6.3-III

EXPERIMENT CUMULATIVE OUTPUT DATA

		Day 1		Day 2		Day 3		Day 4		Day 5		Day 6		Day 7		Day 8		Day 9		Day 10	
Exp No.	Bits/ Cycle (Exp)	Cycles	Cum Bits	Cycles	Cum Bits for Day 2	Cycles	Cum Bits for Day 3	Cycles	Cum Bits for Day 4	Cycles	Cum Bits for Day 5	Cycles	Cum Bits for Day 6	Cycles	Cum Bits for Day 7	Cycles	Cum Bits for Day 8	Cycles	Cum Bits for Day 9	Cycles	Cum Bits for Day 10
1	55	8	440	8	440	8	440	8	440	8	440	8	440	8	440	8	440	8	440	8	440
2	14	10	140	10	140	10	140	10	140	10	140	10	140	10	140	10	140	10	140	10	140
3	16	20	320	20	320	20	320	20	320	20	320	20	320	20	320	20	320	20	320	20	320
4	192	20	3.8×10^3	20	3.8×10^3	20	3.8×10^3	20	3.8×10^3	20	3.8×10^3	20	3.8×10^3	20	3.8×10^3	20	3.8×10^3	20	3.8×10^3	20	3.8×10^3
5	90	3	270																		
6	56	4	220																		
7	1.2×10^3	1	1.2×10^3																		
8	565	3	1.7×10^3	4	2.3×10^3	2	1.1×10^3														
9	280			1	280																
10	4.1×10^3			1	4.1×10^3																
11	135	2	270																		
12	17	1	17																		
13	288	4	1.2×10^3																		
14	1.2×10^3	1	1.2×10^3																		
15	310			1	310	1	310	1	310	1	310	1	310								
16	3.5×10^3	1	3.5×10^3																		
17	4.5×10^4	1	4.5×10^4	1	4.5×10^4																
18	450	1	450																		
19	450			1	450	1	450	1	450												
20	1.1×10^3	1	1.1×10^3																		
21	1.1×10^3			1	1.1×10^3	1	1.1×10^3														
22	1.2×10^3									1	1.2×10^3	1	1.2×10^3	1	1.2×10^3	1	1.2×10^3				
23	1.2×10^3									1	1.2×10^3			1	1.2×10^3	1	1.2×10^3				
24	2.7×10^3									1	2.7×10^3	3	8.1×10^3								
25	990							1	990	3	3×10^3										
26	39													4	160						
27	930													2	1.9×10^3	2	1.9×10^3				
28	1.1×10^3																	2	2.2×10^3	2	2.2×10^3
29	270	1	270	1	270	1	270	1	270	1	270										
30	10^3	1	10^3	1	10^3	1	10^3	1	10^3	1	10^3	1	10^3	1	10^3						
31	144																			1	144
32	972																			1	972
33	5.9×10^4							1						1	5.9×10^4					1	5.9×10^4
34	23	20	460	20	460	20	460	20	460	20	460	20	460	20	460	20	460	20	460	20	460
35a	9.6×10^5	1	9.6×10^5																		
35b	1.78×10^6																				
35c	6.5×10^4	2	$.3 \times 10^5$																		
Engr	3.4×10^4	1	3.4×10^4	1	3.4×10^4	1	3.4×10^4	1	3.4×10^4	1	3.4×10^4	1	3.4×10^4	1	3.4×10^4	1	3.4×10^4	1	3.4×10^4	1	3.4×10^4
Totals			1.2×10^6		8.1×10^4		4.1×10^4		4.1×10^4		4.2×10^4		4.2×10^4		1.0×10^5		4.4×10^4		4.1×10^4	1	1×10^5

Cumulative total for first 10 days = 1.72×10^6

TABLE 6.3-III

		First 43 Days		First Season		2nd (3rd, 4th) Season		2 Year Totals	
Exp No.	Bits/ Cycle	Cycles	Total	Cycles	Total	Cycles	Total	Cycles	Total
1	55	344	1.9×10^{4}	1.3×10^{3}	7.2×10^{4}	1.3×10^{3}	7.2×10^{4}	5.4×10^{3}	3.0×10^{5}
2	14	430	6.0×10^{3}	1.7×10^{3}	2.4×10^{4}	1.7×10^{3}	2.4×10^{4}	6.7×10^{3}	9.4×10^{4}
3	16	860	1.4×10^{4}	3.3×10^{3}	5.3×10^{4}	3.3×10^{3}	5.3×10^{4}	1.3×10^{4}	2.1×10^{5}
4	192	215	4.1×10^{4}	8.4×10^{2}	1.6×10^{5}	8.4×10^{2}	1.6×10^{5}	3.4×10^{3}	6.5×10^{5}
5	90	6	5.4×10^{2}	18	1.6×10^{3}	18	1.6×10^{3}	72	6.5×10^{3}
6	56	8	4.5×10^{2}	24	1.3×10^{3}	24	1.3×10^{3}	96	5.4×10^{3}
7	1.2×10^{3}	2	2.4×10^{3}	6	7.2×10^{3}	6	7.2×10^{3}	24	2.9×10^{4}
8	565	20	1.1×10^{4}	60	3.4×10^{4}	60	3.4×10^{4}	240	1.4×10^{5}
9	280	1	2.8×10^{2}	1	2.8×10^{2}			1	2.8×10^{2}
10	4.1×10^{3}	1	4.1×10^{3}	1	4.1×10^{3}			1	4.1×10^{3}
11	134	2	2.7×10^{2}	3	4×10^{2}	3	4×10^{2}	12	1.6×10^{3}
12	17	2	34	3	51	3	51	12	2×10^{2}
13	288	10	2.9×10^{3}	15	4.3×10^{3}	15	4.3×10^{3}	60	1.7×10^{4}
14	1.2×10^{3}	2	2.4×10^{3}	3	3.6×10^{3}	3	3.6×10^{3}	12	1.4×10^{4}
15	310	10	3.1×10^{3}	15	4.6×10^{3}	15	4.6×10^{3}	60	1.9×10^{4}
16	3.5×10^{3}	10	3.5×10^{4}	15	5.2×10^{4}	15	5.2×10^{4}	60	2.1×10^{5}
17	4.5×10^{4}	3	1.4×10^{5}	4	1.8×10^{5}	3	1.4×10^{5}	13	5.9×10^{5}
18	450	10	4.5×10^{3}	15	6.8×10^{3}	15	6.8×10^{3}	60	2.7×10^{4}
19	450	10	4.5×10^{3}	15	6.8×10^{3}	15	6.8×10^{3}	60	2.7×10^{4}
20	1.1×10^{3}	12	1.3×10^{4}	21	2.3×10^{4}	21	2.3×10^{4}	84	9.2×10^{4}
21	1.1×10^{3}	12	1.3×10^{4}	21	2.3×10^{4}	21	2.3×10^{4}	84	9.2×10^{4}
22	1.2×10^{3}	12	1.4×10^{4}	21	2.5×10^{4}	21	2.5×10^{4}	84	1.0×10^{4}
23	1.2×10^{3}	12	1.4×10^{4}	21	2.5×10^{4}	21	2.5×10^{4}	84	1.0×10^{5}
24	2.7×10^{3}	12	3.2×10^{4}	21	5.7×10^{4}	21	5.7×10^{4}	84	2.3×10^{5}
25	990	12	1.2×10^{4}	21	2.1×10^{4}	21	2.1×10^{4}	84	8.3×10^{4}
26	39	10	3.9×10^{2}	15	5.9×10^{2}	15	5.9×10^{2}	60	2.3×10^{3}
27	930	10	9.3×10^{3}	15	1.4×10^{4}	15	1.4×10^{4}	60	5.6×10^{4}
28	1.1×10^{3}	10	1.1×10^{4}	15	1.7×10^{4}	15	1.7×10^{4}	60	6.6×10^{4}
29	270	5	1.3×10^{3}	15	4.0×10^{3}	15	4.0×10^{3}	60	1.6×10^{4}
30	103	5	5×10^{3}	15	1.5×10^{4}	15	1.5×10^{4}	60	6×10^{4}
31	144	5	7.2×10^{2}	15	2.2×10^{3}	15	2.2×10^{3}	60	8.6×10^{3}
32	972	5	4.9×10^{3}	15	1.5×10^{4}	15	1.5×10^{4}	60	5.8×10^{4}
33	5.9×10^{4}	2	1.2×10^{5}	3	1.8×10^{5}	3	1.8×10^{5}	12	7.1×10^{5}
34	23	215	4.9×10^{3}	8.4×10^{2}	1.9×10^{4}	8.4×10^{2}	1.9×10^{4}	3.4×10^{3}	7.8×10^{4}
35a	9.6×10^{5}	1	9.6×10^{5}	1	9.6×10^{5}			1	9.6×10^{5}
35b	1.78×10^{6}	3	5.3×10^{6}	8	1.42×10^{7}	6	1.07×10^{7}	26	4.6×10^{7}
35c	6.5×10^{4}	8	5.2×10^{5}	18	1.2×10^{6}	12	7.8×10^{5}	54	3.5×10^{6}
Engr	1.7×10^{4}	43	7.3×10^{5}	167	2.8×10^{6}	167	2.8×10^{6}	669	1.1×10^{7}
Totals			8.1×10^{6}		2.0×10^{7}		1.52×10^{7}		6.7×10^{7}

NOTES:
1. Based on no failures (or alt exp runs of equal data)
2. High res image data (Exp 35b) 1 run for each of low res (Exp 35a).
3. Exp 4 and 34 daily samplings drop to one-fourth that shown for first 10 days.
4. Engrg daily bits drop to one-half that shown for first 10 days.

The cumulative output data values of Table 6.3-III have been plotted along with the ABL transmission capabilities for several cases in Figure 6.2-21 of Paragraph 6.2. In even the most limited case, the total transmission capacity is nearly ten times the data load. The data generated can be transmitted on a daily basis except for the visual imaging data which must be stored and read out over several days.

With use of an orbital relay it is possible to transmit to Earth a much larger amount of data than the indicated ABL data output. The relay link is capable of transmitting 4.3 x 10^6 to 1.7 x 10^7 bits per day, which is large compared to the data outputs of most experiments. However, when it is compared to the data output possible from the imaging equipment, it is apparent that expanded use of this equipment can efficiently utilize even the relay transmission capability. The increased use of the facsimile equipment can include both stereo and multispectral visaul images. It is possible that the use of other experiments and equipments may be expanded, but most of the biological experiments are limited by their reagent, solvent, and gas requirements, and increased data from environmental experiments, other than facsimile, would be of limited value.

b. Processing Requirements. This paragraph discusses the processing requirements for the various functions listed under the preceding Paragraph 6.3.2. The only feasible way to estimate overall processing requirements is to consider the individual processing functions and aggregate their individual requirements into a set of overall requirements. This was done and an overall summary is given in Table 6.3-IV. The uncertainties in estimating at this stage are high. However, they are primarily intended to establish order of magnitude and to determine consistency with the following hardware definition.

In estimating overall processing requirements from individual functions, consideration must be given to the distribution of processing tasks over time. The processor must be able to handle the peak loads. Thus, most emphasis must be given to the processing requirements in the first several days, and on the image data handling.

Table 6.3-IV presents a summary of the estimated data processing requirements. The line entries at the left are the basic processing functions described in Paragraph 6.3.2. Column 1 presents the estimated number of instructions necessary for each function. Column 2 is the estimated number of instruction executions for each operation. Frequently, only a portion of the program is utilized; however, some portions of the program may be executed many times in one operation. Column 3 describes the basic operation involved. Column 4 is an estimate of the operation rate during a peak activity period. Column 5 is the number of executions per second required for each function, assuming the executions are spread over

TABLE 6.3-IV

SUMMARY OF ABL DATA PROCESSING REQUIREMENTS

Processing Functions	Instructions (Words)	Executions* per Operation	Operation	Operation Rate	Executions per Second	Internal Storage Bits	Permanent Core Residence Words	Assumptions
Communication								
Antenna Pointing	600	2,000	Ant shift	1/mth			0	
Communication Control	100	300	Message	1/min	5	0	100	Message = 100 bits
Coding and Decoding	200	6	Character	4/sec	24			Character of 4 bits, 30 bits/sec rate
Formatting	2,500	1,200	Message	1/min	20	1K	100	
Data Buffer	100	2	Character	4/sec	8	100K		Communication buffer in internal memory
ABL Control								
Experiment Scheduling and Allocation	400	2,000	Experiment	2/hr	1			2 exp/hr peak period
Configuration Control	3,500	100,000	Experiment	2/hr	50		200	
Apparatus Control and Sample Handling	800	500	Experiment	2/hr	0.25			
Executive Routine	1,500	25	Program Exit	10/sec	10		1,500	
Input-Output	300	60	I/O Operation	1/min	1		300	
Individual Experiment Control								
Adaptive Control	1,000	500	Experiment	2/hr	0.25			
Sequencing and Timing	4,000	2,000	Experiment	2/hr	1			20 nodes/exp, 5 words/node, 40 exper + 1000
Control Sampling	1,000	1,000	Experiment	4/hr	1			
Servo Controls								Included under Spare
Calibration	600	300	Experiment	15/hr	1			
Special Controls	1,500	1,000	Experiment	2/day				
Data Reduction and Analysis								
Data Compression	2,000	8	Image Point	8 to 6000/sec	60 to 48,000			Image compression during transmission or recording image data stored externally
Process Raw Data	500	1,000	Receive Data	10/hr	3	X		
Artifical Intelligence								Included under Spare below
Transient Buffering	100	10	Sample	50/sec	500	1K	100	Assumes 50 samples per second total
Working Space						40K		About 2000 words of program working space
Spare - For Future Growth						100K		Budgeted for future definition (artificial intelligence)
	20,900					242K		

*Equivalent add operations

the entire interval between operations. This is assumed to determine the peak execution rate required. Actually, most of the functions would be performed in a much shorter time. Column 6 presents estimates of the internal storage space required for other than program storage. Column 7 indicates the number of program words which would remain in the internal memory even if the bulk of the programs were stored externally and read in only as needed. Column 8 presents some of the assumptions used in arriving at these estimates.

Several significant points derived from Table 6.3-IV are discussed in the following paragraphs.

(1) Data Compression. The data processing execution rate is extremely low, except for data compression of image data. Even this rate, 48,000 executions per second, is quite modest, requiring only a 20-microsecond add time or a 10-microsecond cycle time. Furthermore, this rate could be drastically reduced by performing the image data compression as it is being transmitted rather than as it is being recorded. The rate would then be about 60 executions per second, assuming 8 executions per image point for run length coding, 4 bits per image point for gray scale, and 30 bits per second transmission rate. It should also be noted that this function seldom occurs.

(2) Transient Buffering. The predominant continuous processing is for transient buffering. This rate depends directly on the sampling frequency desired, which could perhaps run as high as 5000 samples per second (50,000 executions per second) but it is expected to be much lower, if needed at all.

(3) Peak Period Processing. The data processing rate required during peak periods can be expected to be in the range of from 100 to 1000 executions per second. This is extremely low compared to what reasonable implementation can provide. Thus, it appears desirable to seek design parameters that can be traded for processing speed and to seek useful functions for the large excess processing capacity.

(4) Pattern Recognition. The excess processing speed may be put to effective use by adding a pattern recognition program which would, for example:

(a) Look for certain symmetries and send a small picture back.

(b) Look for a shape sent back to the ABL from Earth and determine the frequency of occurrence of similar shapes.

(c) Improve image data compression, allowing more pictures to be sent to Earth.

Such pattern recognition programs would take up much of the spare storage capacity.

(5) Data Storage. The amount of program storage exceeds the requirement for data storage in the internal memory, even with the data buffer included in the internal memory. Assuming 18 bits per word, the programs require about 400,000 bits of storage. The estimates are believed to be quite liberal, assuming a comprehensive and flexible program capability. It is possible to reduce the number of instructions considerably by reducing the degree of sophistication and adaptive control. It may also be possible to reduce program size by trading space for time wherever possible and by writing "tight" programs.

c. Implementation Considerations.

(1) General. The design analyses of the preceding paragraphs and other studies (1,2,3,4) leading to the definition of processing requirements of the ABL indicate clearly that a stored program, general-purpose computing capability best satisfies those requirements. The advent of integrated circuits and advanced memory techniques has permitted the state of the art in airborne and spaceborne computers to progress rapidly in recent years. These advances can be reasonably expected to provide hardware techniques for implementing the true general-purpose computer in miniature form, with demonstrated reliability, and within severe weight and power restrictions.(5,6,7)

Considering that the requirements of the ABL will require computer flexibility and adaptability beyond the ability of hardware techniques alone to provide, much of this flexibility and adaptability will be afforded by the sophisticated design of the system and software. Recognizing the rapid advance in the state of the hardware art, it is the primary purpose of this paragraph to determine (1) the hardware requirements of the ABL, (2) the techniques which can best be utilized to implement the expected system design, and (3) to assess the implications of externally imposed conditions such as environment, required operating life, power and weight restrictions, and sterilization procedures.

(2) Memory Requirements. The processing characteristics resulting from the data rates and volumes and the processor memory requirements were discussed in Paragraph 6.3.3b, and summarized in Table 6.3-IV. From these analyses, it is apparent that the overriding memory requirement is total storage, consisting primarily of program storage and raw data storage, whereas the processing speeds are very modest. This leads to the division of memory functions into three types; namely, (1) main memory for program and selected raw data buffer storage, (2) auxiliary memory for bulk image

data storage, and (3) permanent residence memory for basic program storage. Within these general limits of memory performance, the various available techniques will be reviewed to determine their applicability to the ABL processor.

Table 6.3-V presents a tabular summary of the major types of memory devices which are presently in existence. From this group of devices can be made the selection of the devices most suitable for the memory functions of the ABL processor.

For the function of main working memory with its program and data storage requirements, nonvolatile operation is mandatory in order to assure retention of the program and data in the event of component failures or power interruptions. For this reason, tunnel diodes, cryogenic devices, and delay lines are ruled out. Permanent memories are not applicable to the main memory, whereas magnetic tape imposes unacceptably long access time. The techniques of thin films, ferrite cores, and magnetic drums then emerge as being the most applicable. However, the severe power limitation and the reliability requirements associated with the two-year operating life of the ABL will probably rule out also magnetic drum memories with their required rotating mechanism. The conclusion then is that a random access memory, constructed with one of the many ferrite core or thin film devices, will best satisfy the ABL processor main memory requirement. Paragraph 6.3.4 discusses and compares the characteristics of these two types of memories as they apply to the design point processor. To satisfy the auxiliary memory requirements outlined in Table 6.3-IV, the clear choice is a magnetic tape, primarily because of its high storage density (bits/in.^{3}) and its very low standby power compared to the other devices. Although the mechanical mechanism and sterilization procedures may present potential problems, these problems can be solved in time for the ABL mission with adequate development effort.

The requirements for a permanent memory, as shown on Table 6.3-IV, may in actuality be satisfied by the other memories. The executive routine and other essential program information could be stored in the main memory, but also held in a tape unit to be loaded into the main memory if this program should be inadvertently lost. Should a separate device for permanent memory be required, any one of several techniques providing a modest amount of storage can be employed.

In summary, the memory storage and speed requirements of the ABL processor are readily satisfied by a variety of available techniques. The major effort for the ABL design will then be to properly utilize the advanced hardware techniques of the early 1970's to fully satisfy the more severe requirements imposed by the mission duration and the severe weight and power restrictions.

TABLE 6.3-V

COMPARISON OF KEY CHARACTERISTICS OF MAJOR MEMORY DEVICES

Item	Device	Performance	Type of Access	Access Time, Average	Bits/ Element	Capacity (Bits)	Remarks	Reference
1.	Tunnel Diodes	Volatile	Random	20 nsec to 1 μsec	1	to 1 x 10^5		
2.	Cryogenic	Volatile	Random	100 nsec to 2 μsec	to 1 x 10^5	to 1 x 10^6		
3.	Thin Films	Nonvolatile	Random	200 nsec to 5 μsec	to 10^4	300 to 3 x 10^6	Linear select presently	21
4.	Ferrite Cores	Nonvolatile	Random	0.5 μsec to 10 μsec	1	5 x 10^4 to 1 x 10^7	Coincident current except NDRO devices as BIAX and other MAD.	13
5.	Delay Lines	Volatile	Cyclic	5 μsec to 5 msec	to 5 x 10^6			
6.	Magnetic Drums (Working)	Nonvolatile	Cyclic	5 x 10^2 μsec to 5 x 10^4μsec	to 10^5 to 10^8	{500 to 5.10^5 10^6 to 10^8	Constant power drain due to continuous rotation.	
7.	Magnetic Tape (Short)	Nonvolatile	Cyclic	10 sec			Low standby power, < 1.0 w	
8.	Permanent and Semipermanent Memories	Not electirc-ally alterable	Random	1 μsec to 100 μsec	to 10^2	to 10^5	Includes rope memory, capacitive devices, permanent magnet twister, etc.	8,9,10

(3) System Implementation with Integrated Electronics. Virtually all aerospace computers under development at this time employ integrated electronic circuits for mechanization of the computer logic.(5,6,7) As a result of this widespread usage of integrated circuits, an unusual degree of standardization of logic functions has resulted. In particular, the logical operation NAND is emerging as the most widely produced logic circuit function simply because it is most universally applicable to the mechanization of Boolean logic functions. The logical design of the processor should, therefore, be based upon the use of this function. The likely requirement of differing processing speeds within various parts of the processor fits this concept well, since different circuit configurations can perform this identical logical operation in times from a few nanoseconds to several hundred nanoseconds, and switching speed can be traded for power. This concept of utilizing circuits, identical except for the operating speed, has been employed successfully in the past, and should be available to the logical designer of the ABL processor. There is no doubt about the applicability of integrated circuits to the ABL computer. A more serious question, however, is whether the processor size, weight, and power consumption will be acceptable, based upon use of the integrated circuits available today. Should the resultant processor be unacceptable for these reasons, it will be necessary to assess the more exotic integrated techniques which are just now emerging from the feasibility stages.

Among these techniques are the inclusion of more functions within a single integrated package (11,12) and the use of new devices (metal-oxide semiconductors) which permit more complex and lower power functions to be implemented.(11) To summarize, it is likely that adequate integrated logic circuit techniques will be available for efficient design of the basic ABL processor. The more likely considerations will be those of reliability, maintainability, and redundancy to permit programmed self-test and repair.

In this discussion of integrated electronics, little has been said about the means for effecting integration of the memories which will be required in the ABL. Most of the integrated circuit techniques expected to be used for logic circuit mechanization are applicable to the electronic circuits of the memories. Less certain, however, is the degree to which improvements in size, weight, and power can be expected in the memory storage media itself. Thin film memories in planar, circular, and other geometrical forms, as well as semiconductor and ferrite batch techniques, provide a step toward integration and batch processing of memories. The gains made thus far in this area have not produced the spectacular improvement that integrated circuits have, however. Since the performance of most general-purpose computers is memory limited, this area will likely require more design effort and judgment than any other in order to select the proper memory hierarchy and to efficiently mechanize each one.

(4) Other System Requirements Affecting Implementation. Other system requirements that are worthy of note arise from the very nature of the mission itself. Some of these are (1) centralization versus decentralization of hardware, (2) the implications of transmission coding upon the hardware, and (3) the effects of reliability upon implementation techniques.

The importance of proper functional design has been emphasized in Paragraph 6.3.2. Because of the use of a general-purpose processor for experiment sequencing and data reduction, the control functions will necessarily emanate from this central source. The hardware to generate these control functions will be an integral part of the central processor. The flow data will likely be treated in a decentralized sense, however, in order to minimize the possibility of total system failure by the loss of one sensor. An example of this hardware decentralization would be to provide the necessary electronics (such as A-D converters, level changers, etc.) at the sensors themselves to make each one independent of the other when communicating with the central processor. This approach requires duplicate hardware, but the relative insignificance of this hardware in the total ABL as compared to the vastly improved probability of some surviving capability more than warrants its inclusion in the system.

Often the equipment required to mechanize and interpret error-correcting codes limits the codes which can be reasonably considered. The Earth-Mars distance combined with limited transmitter power may require a redundant or complex code. (See Appendix 14.) The equipment for generating and interpreting these codes, if mechanized as a discrete entity, can prove restrictive. The presence of a programmed processor in the ABL virtually eliminates the need for additional equipment used to process these codes, since the processor itself can be programmed to perform this task utilizing its own memory and logic. It is anticipated, therefore, that special equipment for code generation would be confined to those circuits necessary for interfacing with the ABL transmitter and command receiver.

The effects of reliability and survival of ABL capability for a two-year period will have far-reaching effects upon the implementation of the ABL processor. Since the processor of the ABL will likely be centralized, special means of implementation will be necessary in order to achieve these reliability objectives. The mere dependence upon failure rate statistics and component derating in the design of the ABL processor will probably not provide confidence in survivability of the processor in the unknown environment. For this reason, the processor design must provide for alternate or duplicate signal paths to preserve system operation in the event of component failures. A common method of providing these alternate paths is to use redundant components, circuits, subassemblies, or even entire systems. Although these techniques have been extensively investigated and successfully employed (14,15,16) they alone may not provide the degree of reliability improvement which is required. To supplement straightforward redundance approaches, much can be done to improve system survivability by using the system program capabilities to detect certain types of failure conditions and select alternate paths as required. It is likely that methods such as this can reduce the required amount of component redundancy in the equipment. A discussion of error diagnosis and control by system and program design is found in Paragraph 6.3.2, and a description of applicable redundancy techniques is found in Paragraph 6.3.4.

6.3.4 DESCRIPTION OF SELECTED DESIGN POINT DATA PROCESSING SYSTEM

a. General Characteristics. The data processing system described here is compatible with the functions described above and the constraints of the ABL mission. A summary of its principal characteristics follows:

(1) 32,000-word internal core memory using a 10-microsecond cycle time.

(2) 20-microsecond add time.

(3) An auxiliary magnetic tape recorder for storing image data.

(4) An auxiliary magnetic tape recorder for backup storage of programs and essential data (may utilize a portion of the unit in (3) above).

(5) A large number of independent input/output channels.

(6) Eight levels of priority interrupt; each channel's interrupt priority under program control.

b. Logical Design. The logical design of almost any of the recently announced small control computers is adequate for the ABL computer. Typical of such computers are the SDS-925, DDP-116, PDP7, DMI-620, and L-304. Although many other computers will certainly be developed and proved before the design must be frozen, any of these designs would be adequate for accomplishing the functions described above. Economy and confidence would be gained in selecting the logical design of a computer that has been well proven, debugged, or has a variety of software available. It may also be desirable to maintain compatibility with computers used on the lunar programs.

The design point computer has the following set of logical characteristics, typical of current control computers:

(1) 18-bit word length.

(2) Addressable down to 4-bit characters.

(3) Flexible instructions for masking, shifting, and packing.

(4) Four index registers

(5) Multilevel indirect addressing.

(6) Parity checking of all input/output and memory transfer operations.

(7) Automatic assembly/disassembly of four bit characters to and from words.

(8) Redundant arithmetic units for reliability.

In addition to the above, the following features are included to trade excess speed for hardware simplicity and reliability:

(1) Subroutined multiply and divide instructions.

(2) Use of memory cells in place of hardware registers for index registers and some arithmetic registers.

(3) Use of serial logic where possible.

c. Equipment. As a result of the analysis of the data loads and control requirements, the general processor requirements have been formulated. It is the purpose of the analysis covered by this section to determine, as realistically as possible, the type of equipment and hardware, which, in the early mid-1970's will most efficiently mechanize the ABL processing functions. In order to properly do this, it is first necessary to define the system requirements in terms of general electronic functions, project the state of the electronic art to the time when hardware commitments must be made, and formulate a mechanization approach which can be expected to satisfy the requirement.

(1) General Hardware Requirements. The hardware requirements in the ABL processor are, to a large degree, dictated by the system organization. In its anticipated form, the processor will consist of a stored program, general purpose computer capable of the flexibility of operation of this class of machine. As such, it possesses the conventional functional areas of memory, arithmetic and control, and input-output interface. The hardware required to implement these functions varies greatly with the total processing requirement. The ABL, because of the severe Earth-communication bandwidth limitation combined with the relatively slow rate of experiment progress (primarily reaction time or mechanical limitations), does not place any severe requirements on processor speed. The primary requirement, therefore, is one of providing storage for the program, and for data which are either required in the computation or are being coded for transmission to Earth. An examination of the total quantity of data which the ABL processor is required to store at any time, (over two million bits) far exceeds the capacity of a reasonable single main computer memory, primarily because of the quantity of data contained in facsimile pictures

(2×10^6 bits per picture), and the requirement that certain raw experiment data from gas chromatographs and mass spectrometers (10^4 to 10^5 bits per run) be retained until its significance has been determined on Earth. These requirements can and should be relegated to an auxiliary memory such as a tape, since these data are not expected to be required as intermediate data in the conduct of experiments, and will be transmitted only as transmission bandwidth permits, or as requested by ground command. With this first assumption made, the remaining memory requirements for the program storage, working data storage, and data for transmission coding fall quite reasonably within the capabilities of a single random access core or thin film memory of 6×10^5 bits capacity and a cycle time of 10 microseconds. Therefore, the entire memory functions of the proposed design point data processor can be accomplished with only two types of memories, although as discussed later, reliability and recovery from malfunctions may dictate the addition of a small, permanent memory for storage of portions of the basic program. Even with this added complication, the total memory storage and performance requirements do not represent major technological problems, thus giving the designer the freedom to effect significant weight, size, and power reductions in the final system.

The hardware implementation of the arithmetic and control functions of the ABL can be done in many ways. The primary factors which must be considered in the selection of circuit techniques are the types of arithmetic processing to be done, the various types in which the functions can be mechanized, and the ways in which circuit speed can be traded for quantities of circuits and power consumption.

To summarize, the processing requirements do not in themselves require development of new circuit techniques since integrated circuits can readily perform the required functions. Rather, most of the development effort in this area should be devoted to applying existing and future techniques to improving the weight, power, and reliability of the entire processor, and utilizing the nonvolatile and more reliable memory cells as extensively as possible in the mechanization of the arithmetic and control functions. The generalized design point processor, therefore, will appear approximately as shown in Figure 6.3-2. The processor will be designed for minimum hardware complexity to yield the greatest reliability, and with the sophisticated functions provided by programming techniques utilizing the excess available speed of the hardware.

(2) Present and Predicted Hardware Development Status. In order to suggest specific hardware techniques for mechanizing the selected design point data processor, it is necessary to determine the current state of the hardware art, and to predict the status of the various memory and logic devices when the ABL processor is committed to hardware. Excluding power, weight, and reliability considerations, all of the electronic functions of the design point data processor can be readily mechanized within the present state of the art. Figures 6.3-3 and 6.3-4 illustrate this

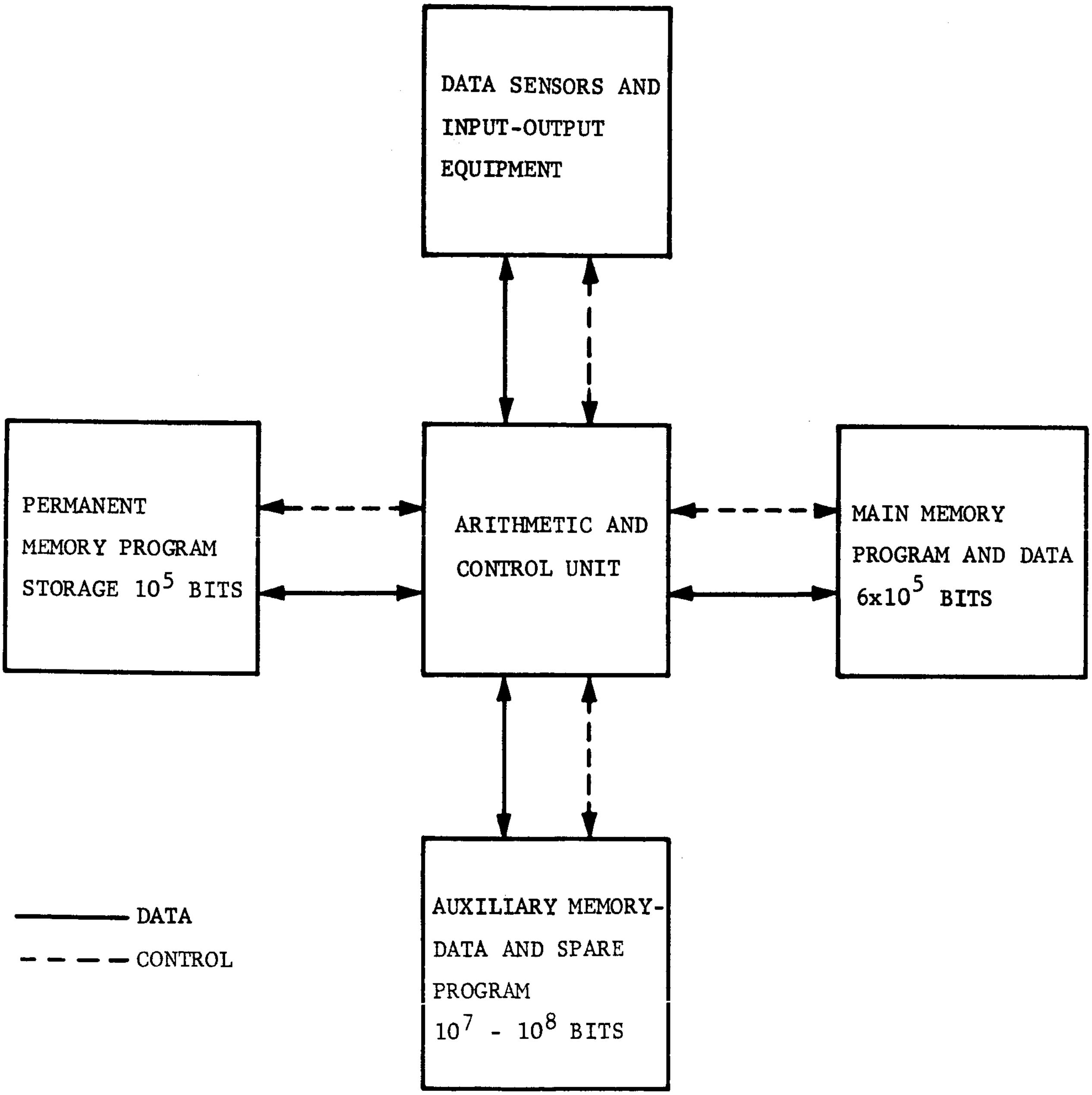

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FIGURE 6.3-2. FUNCTIONAL BLOCK DIAGRAM - DESIGN POINT DATA PROCESSOR

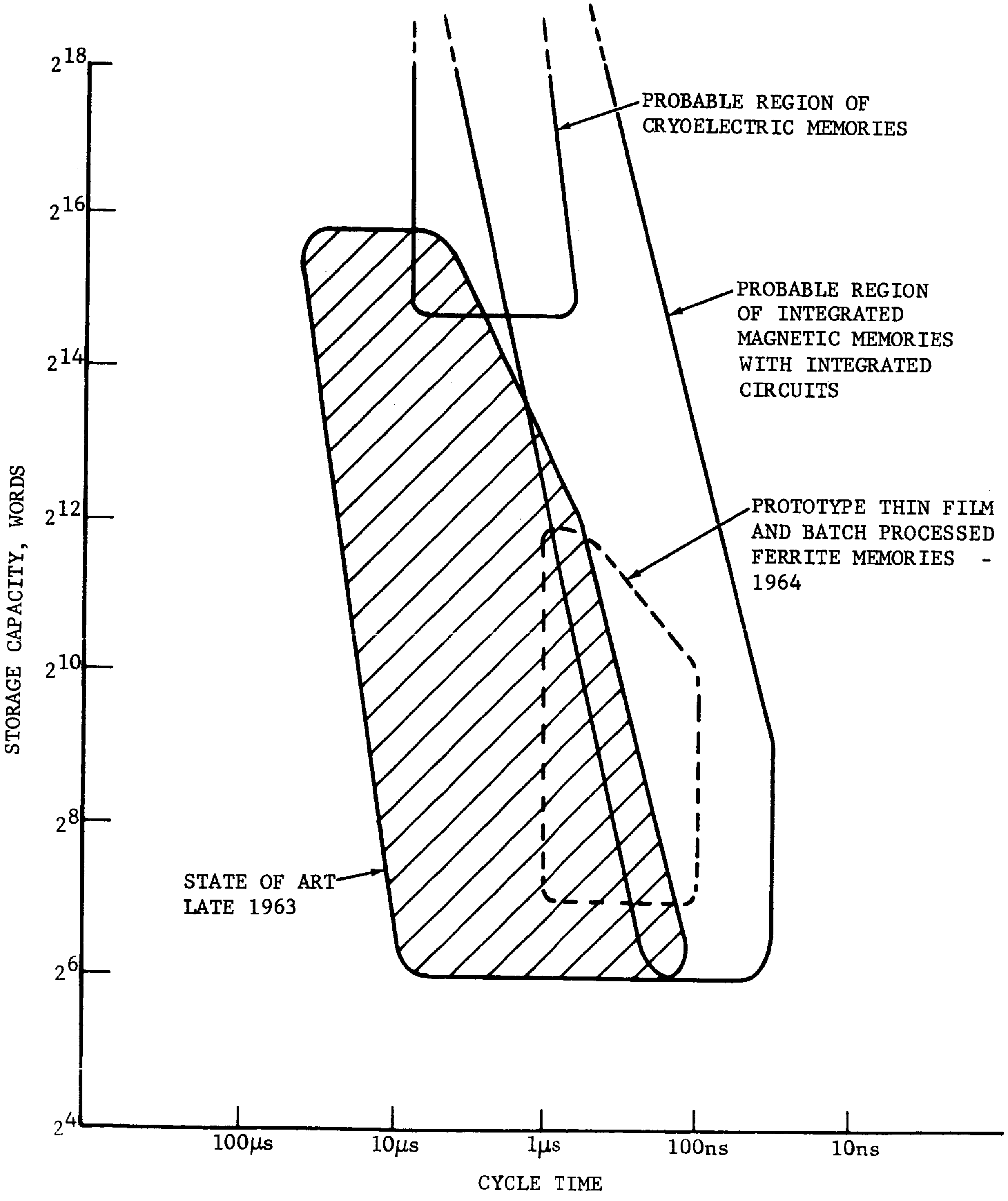

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FIGURE 6.3-3. STORAGE CAPACITY AND CYCLE TIME OF VARIOUS MEMORIES (DATA FROM BURNS, "CRYOELECTRIC MEMORIES," PROC. IEEE, OCT., 1964)

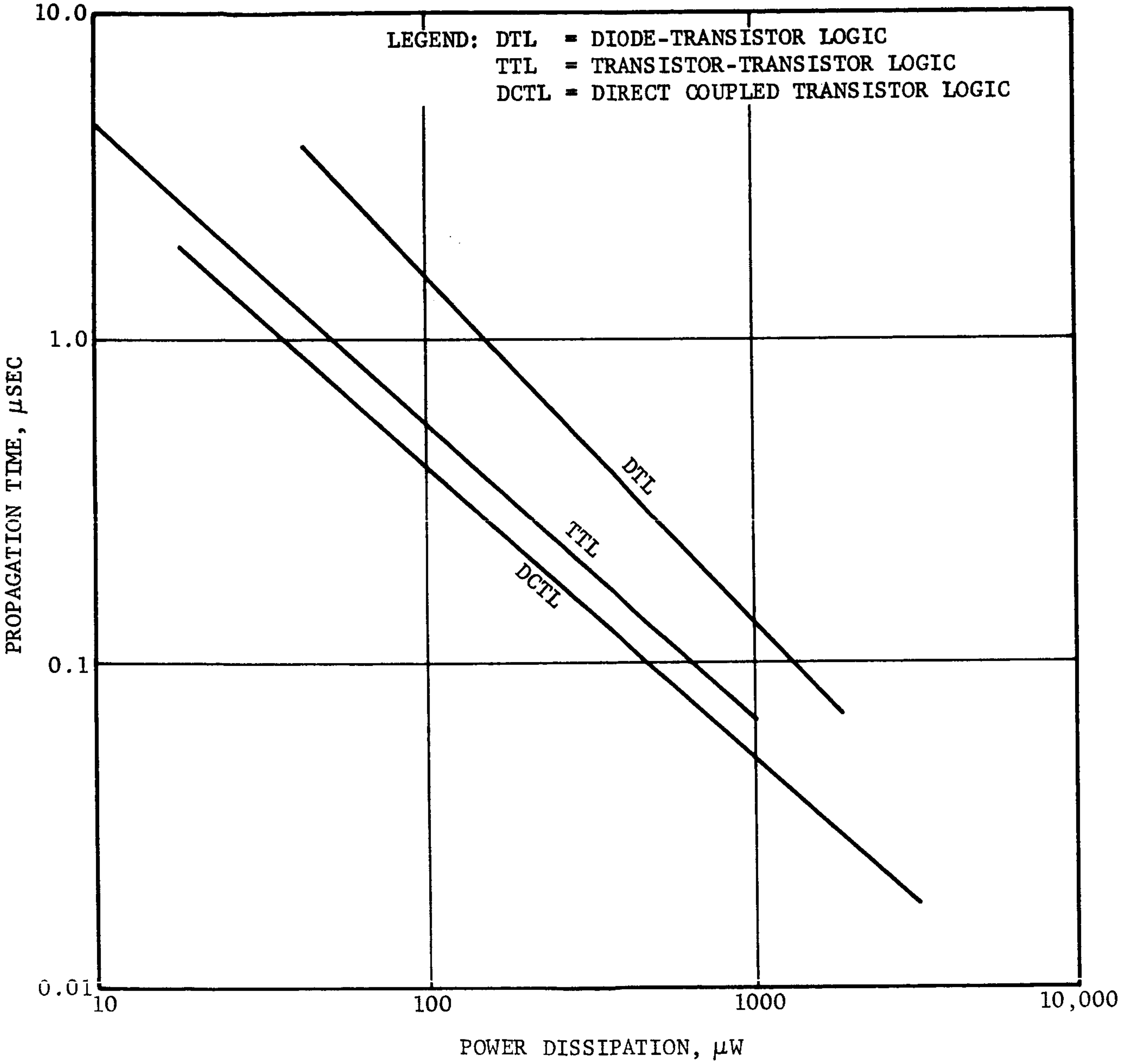

FIGURE 6.3-4. PROPAGATION DELAY VERSUS POWER DRAIN (DATA FROM MEINDL, ET AL, "MICROPOWER TRANSISTOR LOGIC CIRCUITS," PROC. IEEE, DEC., 1964)

capability. For the design point processor, it is anticipated that a main memory containing not more than 2^{15} words will handle the required processing load. Figure 6.3-3 shows that the state of the art in core memories in 1963 was adequate for this purpose if capacity and cycle time along were considered. Similarly, the logic circuit techniques required to mechanize the arithmetic and control functions of the ABL processor are not stringent. From Figure 6.3-4, it can be seen that adequate circuit design techniques exist for mechanizing logic functions with propagation times ranging from less than 0.05 to over 1.0 microseconds per logic level, depending upon the power dissipation permitted, and the techniques used. With little design effort, therefore, as many as 100 logic operations of 0.1 microsecond each could be performed serially during one complete memory cycle, while maintaining the circuit power dissipation at about 1 milliwatt per circuit. Although the preferred design of the equipment is unknown at this time, it does illustrate that circuit speed need not be a limitation in mechanizing the arithmetic and control section of the ABL processor, and further, that considerable reductions in system power dissipation could be expected because of the slower processing rates.

When considering the requirements for the auxiliary memory, the same conclusions are reached as for the main memory; namely, storage capacities of 10^7 and 10^8 bits and required operating speeds are well within existing capabilities. What, then, are the areas in which technological developments are required in order to implement a successful ABL processor? It is felt that three areas must receive major attention: (1) power consumption and size and weight, (2) reliability considerations, and (3) effects of sterilization procedures.

(a) Power Consumption and Size and Weight. The preceding discussions, and, in particular, the data from Figure 6.3-3, did not consider equipment power dissipation and weight since most of the equipment was intended for ground use. Even presently available airborne computers with processor capabilities adequate for the ABL and designed with special integrated circuit and packaging techniques for airborne applications weigh about 13 pounds and consume about 45 watts of power.(17) Clearly this type of burden, particularly power consumption, and the limitations it might impose upon the ABL experiment and transmitter capabilities, is an area in which improvements are mandatory. Similarly, a reduction in weight of the processor will enable more experiments to be run by making weight available for additional reagents, carrier gases, or similar items. It seems clear, therefore, that weight and power considerations will exert far more influence upon the selection of hardware techniques than the logical and memory requirements of the processor.

(b) Reliability Considerations. For reasons of weight, size, and cost as well as general convenience, integrated circuits will be used to mechanize virtually all of the electronic functions of the ABL processor. Integrated circuits should offer better reliability than their discrete component counterpart for several reasons, the most significant is that the interconnection of the components is made under more precisely controlled conditions. Figure 6.3-5 supports this conclusion showing that in recent years a given discrete component circuit exhibits a particular failure rate trend, whereas the single transistor used in this circuit exhibits a rate trend much less than would be expected if all components were no worse than the transistor. Two conclusions are possible from this observation: First, it might be assumed that the components other than the transistor have considerably higher failure rates than the transistor or second, that the discrepancy in failure rate is caused by the cumulative effect of the interconnection of the discrete components. Since the passive components of the circuit normally exhibit lower failure rates than the transistor and the confidence in these figures is high, the only conclusion is that component interconnections account for a substantial part of the total circuit failure rate. In 1964, for example, failure rate of $4x10^{-9}$ per hour (0.0004 percent per 1000 hours) for each component would predict a circuit failure rate of 36×10^{-9} per hour. The measured failure rate of this circuit is 4×10^{-7}. The difference must be the effect of the interconnections giving a failure rate per interconnection of 36×10^{-9} (about 0.0026 percent per 1000 hours), higher than the components themselves. Although such a conclusion may not be numerically precise, since the assumed failure rates depend upon the rather subjective problem of definition of a failure, and the care with which component interconnections are made, it does provide one of the best arguments for expecting dramatic reliability improvement by using integrated circuits. Figure 6.3-6 tends to support this conclusion by showing the trend of failure rate versus calendar time. Assuming that the circuit for this curve (TI series 51) performs a function comparable to the DTL circuit plotted in Figure 3.6-5, the 85°C failure rate for the circuit is approximately 0.04 percent per 1000 hours at 85°C. Correcting to 25°C by multiplying by 0.15(18,19) gives a circuit failure rate of 0.006 percent per 1000 hours. Compared to the discrete component example of 0.04 percent per 1000 hours, an improvement of nearly one order of magnitude is predicted.

As can be seen from the previous discussions, many assumptions and a great deal of testing are necessary to produce meaningful reliability data. Even if the manufacturing process permits the production of integrated circuits with failure rates lower than 0.006 percent per 1000 hours, the operating environment, the confidence level of the data (19), the interconnection of the integrated circuits into a working system for unattended operation must all be considered. The reliability goals will likely still necessitate programmed error detection and correction procedures as well as equipment redundancy at various levels. The benefits of this redundancy upon probability of success as a result of different forms of mechanization is shown in Figure 6.3-7.

(c) Effects of Equipment Sterilization. The entire ABL will be subjected to a severe stress level while undergoing sterilization. Although

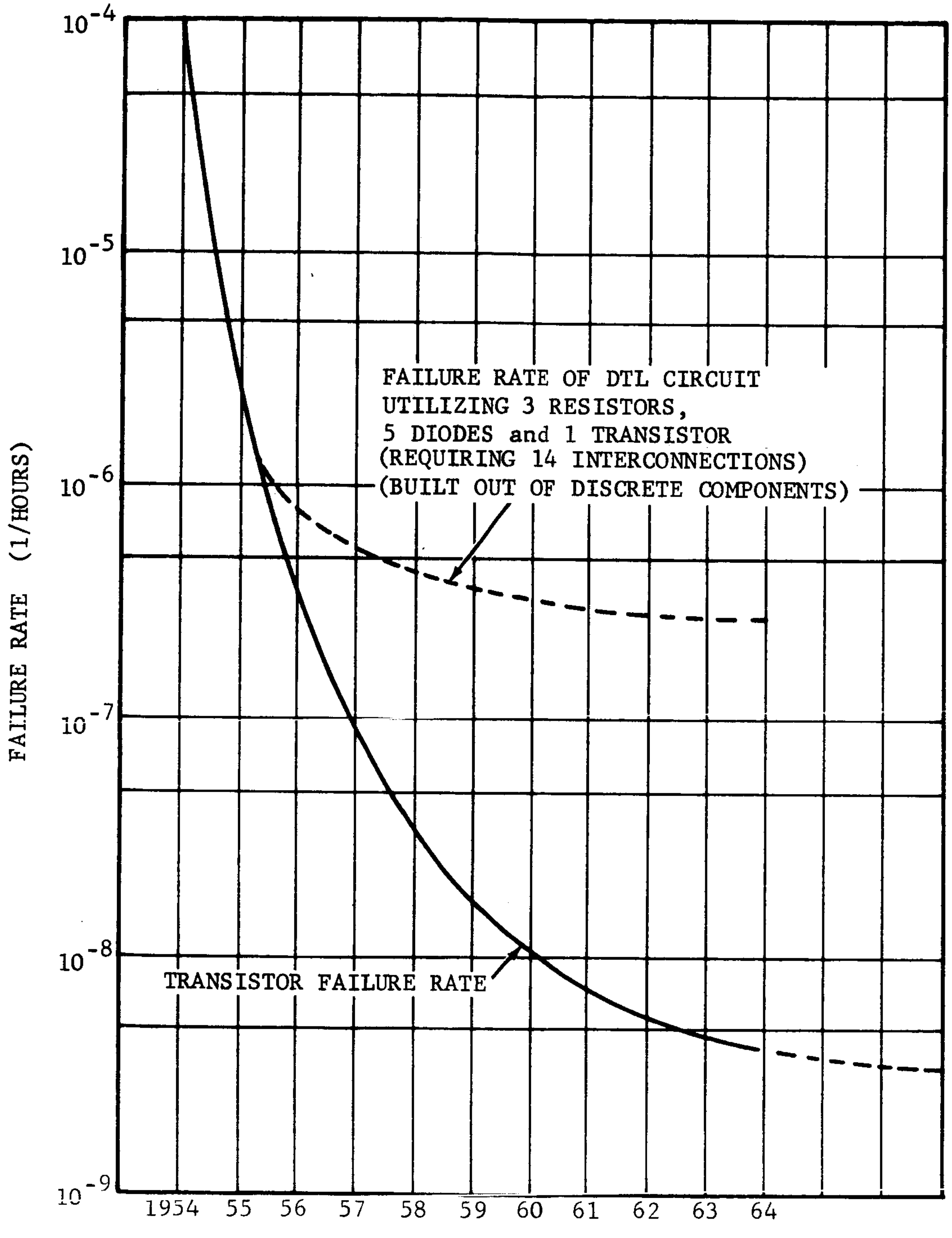

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FIGURE 6.3-5. RELIABILITY IMPROVEMENT IN TRANSISTORS FOR THE PAST TEN YEARS. (DATA FROM NARUD, "MOTOROLA INTEGRATED CIRCUIT DESIGN COURSE," 1964)

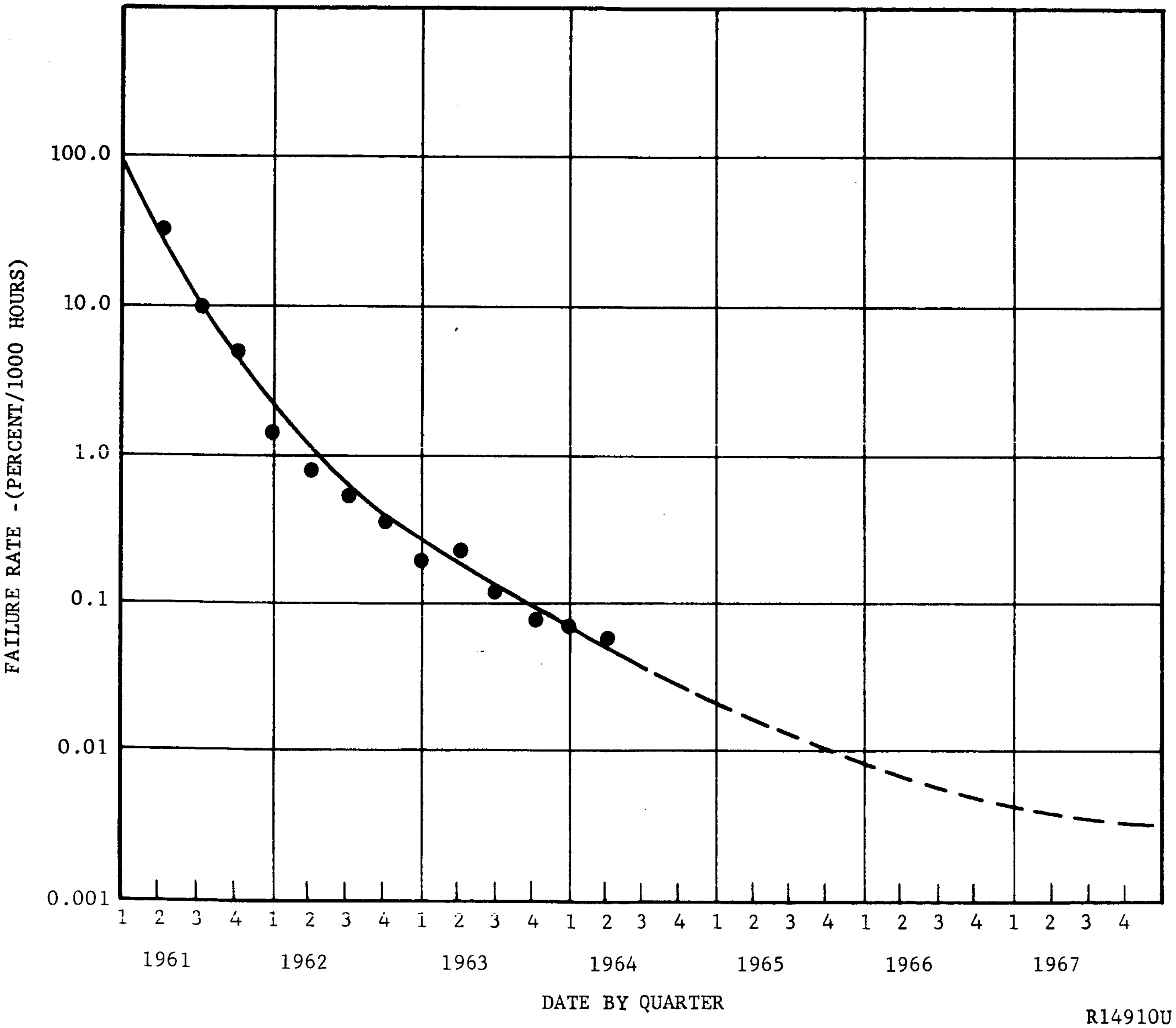

FIGURE 6.3-6. 85° FAILURE RATE TREND
(DATA FROM KILBY, "SILICON FAB TECHNIQUES," PROCEEDINGS OF THE NATIONAL SYMPOSIUM ON THE IMPACT OF BATCH FABRICATION ON FUTURE COMPUTERS, APRIL 1965)

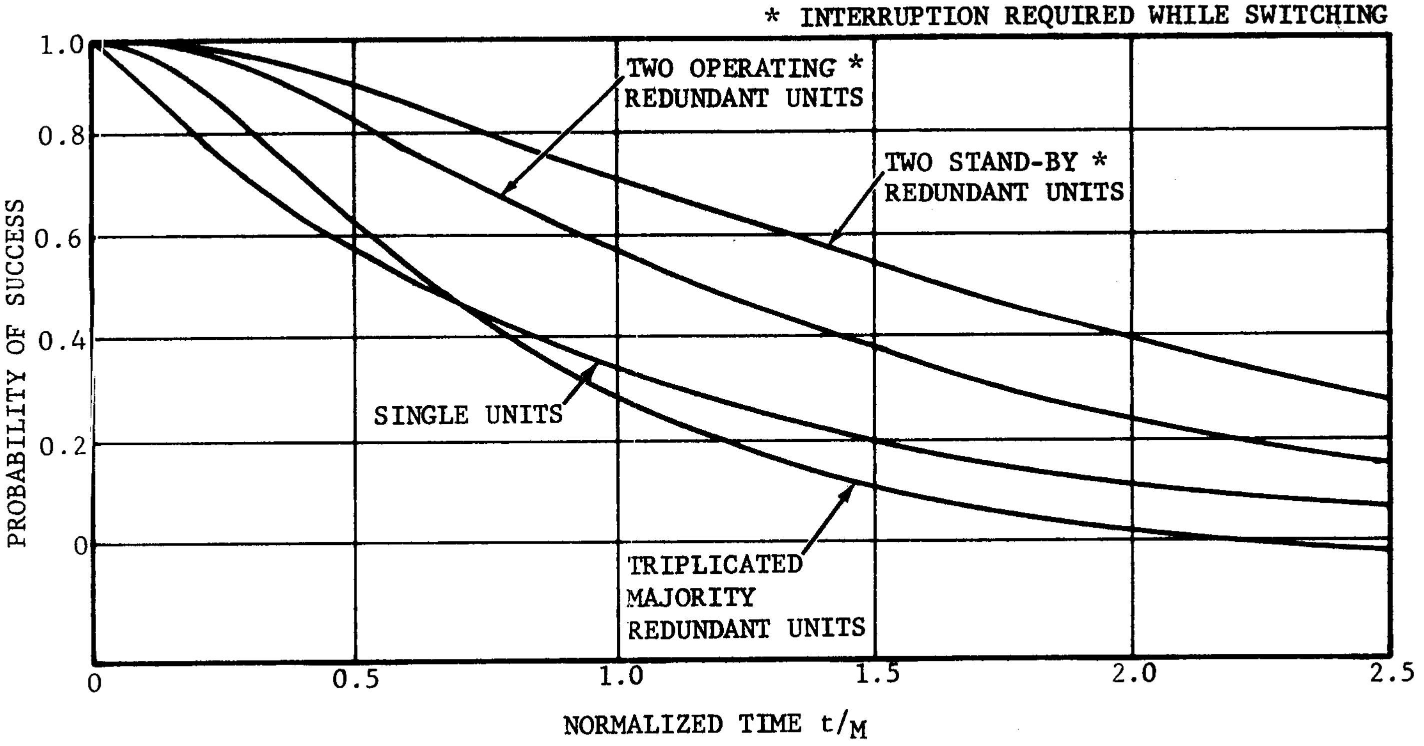

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FIGURE 6.3-7. FORMS OF REDUNDANCY
(ASSUMING PERFECT SWITCHING AND VOTING ELEMENTS)
(DATA FROM WILCOX AND MANN, "REDUNDANCY TECHNIQUES FOR COMPUTING SYSTEMS," 1962 BOOK)

the temperature of 135°C is not expected to cause damage to the circuitry, such a temperature can accelerate the failure process in the equipment even when nonoperating and must, therefore, be considered in the basic selection of circuit techniques. Other equipment, notably the proposed auxiliary memory, are more susceptible to damage however. In particular, the use of conventional plastic-backed tape, coated with a magnetic dispersion may be precluded because of severe deterioration. Similarly, the materials presently utilized for fabrication and encapsulation of the read-record heads is not dimensionally stable at these temperatures and would be unsuitable in their present forms. Solutions to these problems are being actively sought. Metallic tape materials onto which the recording is done directly are under development, and other more stable materials are being investigated. Since the tape unit offers such an attractive solution to the auxiliary memory problem, it will be necessary to ensure that the appropriate improvements in performance have been achieved when required for the ABL processor fabrication schedule. (See Paragraph 5.7 for additional sterilization considerations.)

(3) Design Point Processor Hardware Characteristics. All of the design consideration data presented previously can now be summarized, and a design point processor formulated, which in the early 1970's can satisfy the ABL requirements. It is necessary to make many extrapolations and engineering judgments in arriving at the expected configuration. This is necessary, however, in order that the implications of the processor hardware can be adequately assessed. The proposed processor hardware characteristics are summarized in Table 6.3-VI.

Most critical of all the processor items is the main memory, since most of the ABL functions utilize this memory. The major considerations in this selection are (1) applicable storage and speed capabilities, (2) number of semiconductors required to mechanize it, and (3) power consumption.

Of all the memory techniques expected to be available, the simple, coincident current DRO core memory and anticipated thin film, coincident current DRO memories offer the best apparent choices. The major parameters of these two forms of memories are summarized in Table 6.3-VII. It is assumed that satisfactory coincident current techniques for the thin film memory are available. If not, this choice will likely be eliminated because of the excessive semiconductors required for word selection in the linear select mode (see Figure 6.3-8). Should an electrically alterable coincident current NDRO thin film memory be available, it would be a clear choice because of its lower power consumption, but such a memory is not now available, and it is doubtful that such a development will come soon enough to benefit the ABL. It appears that the final choice will be made primarily on the basis of power, weight, and reliability considerations with neither the core or thin film technique clearly superior at this time.

TABLE 6.3-VI

DESIGN POINT PROCESSOR HARDWARE SUMMARY

Memories:	
Main:	32 K words random access, 6×10^5 bits maximum, CC, DRO Core or CC DRO Film $\geq 10\ \mu$ second cycle, ~ 500 integrated circuits with redundancy.
Permanent:	Few hundred words, wired logic or semipermanent type, slow access.
Auxiliary:	Tape, 10^7 to 10^8 bits, start-stop, search and multispeed capabilities. Redundant unit provided.
Logic Mechanization:	Integrated circuit with integrated functions such as adders, shift registers, or chip, NAND logic, logic propagation delay ~ 200 nanosecond power dissipation ~ 500 μ watts per gate. Multilayer PC board packaging with printed interconnection, built-in thermal paths. Approximately 4000 equivalent gate circuits for arithmetic control unit including redundancy.

Power Dissipation:

Memories		
Main:	10.0 W	
Permanent:	0.5 W	
Auxiliary:	2.0 W	(average)
Standby:	0.5 W	(average)
Logic Circuits	4.0 W	
Miscellaneous Control	3.0 W	
Total Power	20.0 W	

Weight:

Memories	
Main:	5.0 pounds
Permanent:	1.5
Auxiliary:	4.0
Auxiliary Spare:	2.0
Logic Circuits	3.0 pounds
Miscellaneous Control	2.0
Total	17.5 pounds

TABLE 6.3-VII

FERRITE CORE AND THIN FILM MEMORY COMPARISON FOR DESIGN POINT PROCESSOR (600,000 BIT MEMORY, $\geq$ 10-MICROSECOND CYCLE)

		Core Memory	Thin Film Memory
1.	Availability in 1965 (32 K Words)	Good	Not yet available
2.	Estimated Availability in 1970	Good	Good
3.	Word Select Method Presently	Coincident Current (Except BIAX, etc.)	Linear
4.	Selection Circuits for 32 K Words	56 (CCM)	384 (LSM)
5.	Estimated Semiconductor Devices	2,500 (CCM)	129,000 (LSM) 2,500 (CCM)
6.	Possibility of Coincident Current Operation (1970)	Normal Mode	Good
7.	Nondestructive Read Possibilities	Poor or None (Except MAD Devices)	Good
8.	Nondestructive Read Possibilities with Coincident Current Selection	Virtually None	Poor
9.	Estimated 1970 Weight (With Electronics)	$\leq$ 5 Pounds	$\leq$ 5 Pounds
10.	Estimated 1970 Power Consumption	10 - 20 Watts	5 - 15 Watts

Legend: MAD = Multiaperture Device
CCM = Coincident Current Mode
LSM = Linear Select Mode

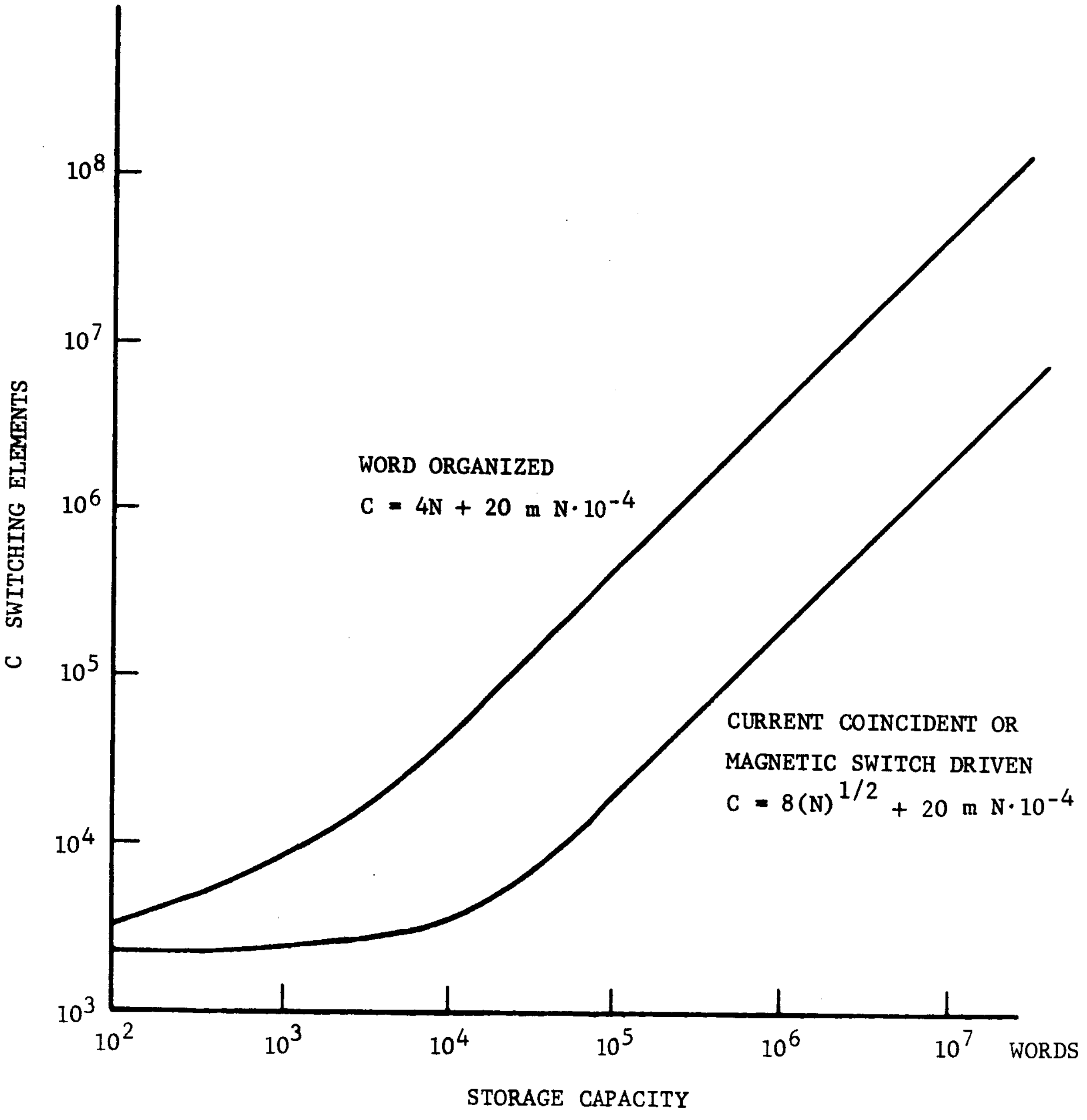

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FIGURE 6.3-8. NUMBER OF SEMICONDUCTOR DEVICES IN MAGNETIC MEMORIES (FROM RAJCHMAN, "MAGNETIC MEMORIES - CAPABILITIES AND LIMITATIONS," J. APPL. PHYSICS, VOL 34, NO. 4 (PART 2), APRIL 1963)

Selection of the appropriate auxiliary memory device will, as for the main memory, be greatly influenced by power, weight, and reliability considerations. From the standpoint of total storage capabilities (10^7 to 10^8 bits) and low standby power, a tape unit offers the only reasonable choice even though the problems of sterilization and physical wearout of parts of the unit are distinct reliability problems. The most likely choice of equipment for this function will be a miniature recorder storing 10^7 to 10^8 bits, with a redundant, or backup unit for reliability improvement. The permanent memory choice is not clear at this time. It is not even certain that such a memory deserves a separate identity in the hierarchy. In its final form, it may be as simple as a block of prewired logic or might be implemented by any of the permanent or semipermanent memory schemes described in References 8, 9, and 10.

Circuits for mechanization of the arithmetic and control functions of the ABL processor will, or course, use integrated techniques, primarily because of the weight, power, and reliability improvements which are readily obtainable. The estimates of Table 6.3-VI assume only a modest extrapolation of the state of the art. The possibility certainly exists that high speed serial arithmetic logic may be possible as higher speed circuits are produced with lower power consumption. If possible, this offers another fruitful area for further reductions in number of components, size, and weight, with improved reliability. Judging from the rapid technological advances in recent years, it is reasonable to expect that more complex functional units such as counters, adders, shift registers, and similar items will have been developed, although the usual lack of reliability data on these items may preclude their extensive use in the ABL.

In spite of the expected improvements in integrated circuit reliability in the next five years, redundancy techniques are still anticipated at the circuit level by means of operating redundancy and at the circuit and unit level under program control (Figure 6.3-7). It is not expected to be necessary to incorporate redundancy of the entire processor to meet the two-year operating life requirement.

d. Software. It is assumed that the logical design of the computer will be chosen to be program-compatible with a well-proved machine. This will facilitate program development and debugging before the ABL computer itself is completed. Also, much of the standard software such as symbolic assemblers, I/O routines, and utility routines should be available and proven. However, the development of the functional programs for the ABL mission must be performed very carefully. There are two main features that will demand special attention. They are providing flexibility and performing exhaustive program checkout and debugging. The flexibility and generality are required for the type of adaptive control demanded by the nature of the mission. The exhaustive checkout and debugging of programs and control procedures is essential to ensure that no combination of circumstances or data are likely to interfere with the normal functioning of successful operation of the ABL mission. Comprehensive means for error checking and diagnostics, as well as error recovery and restart must be provided in order to successfully recover from any program or equipment error. A nondestructive portion of the internal memory, plus the redundant storage of all critical data and programs should allow for adequate backup and restart capability.

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6.4 ELECTRICAL POWER SYSTEMS STUDIES

6.4.1 GENERAL

The ABL power supply is required to operate at an average power level of 70 watts for two years on the Mars surface. It must withstand high-temperature soak during sterilization, followed by a nine month in-orbit transit to Mars. It appears that the system that can best fulfill these requirements is a radioisotope thermoelectric generator for primary power and a storage battery to provide peak power.

Two 70 watt RTG's, that operate continuously from installation, are provided. The storage battery, which also acts as a primary power voltage regulator, is not activated until deployment on Mars surface. The two RTG's provide 100 percent primary power redundancy.

6.4.2 OBJECTIVES

The objectives of the analyses covered by this section were the delineation of realistic electrical power subsystem parameters for ABL-class payloads for the purpose of establishing the principal ABL/power system interfaces. Realistic performance parameters for power systems in the mission times of interest in the 1970's were employed, and realistic power requirements for the ABL were generated from the detailed studies of experiments, processing and system functions resulting from other phases of this study covered by this report. A rigorous optimization of the electrical power system was neither within the scope of this study nor warranted by the objective stated above.

6.4.3 REQUIREMENTS AND CONSTRAINTS

The primary criteria by which the ABL power supply is selected and designed include power requirements, sterilization requirements, mission type and length, and the 1975 mission time period.

a. <u>Power Requirements</u>. ABL experiment and support equipment power requirements for Mars surface operation were tabulated and plotted as functions of time. An average power level of 70 watts is required as determined from the tabulation of the major power loads. Table 6.4-I shows the experimental electrical energy requirements for a typical 43 day cycle. Table 6.4-II presents the individual experimental energy requirements which were used to generate Table 6.4-I. Figure 6.4-1 shows the daily average power for a typical 43 day cycle based on these loads.

TABLE 6.4-I

MAJOR POWER LOADS FOR A 43 DAY CYCLE

Load Description	Average Power (watts)	Time	Energy (w-hr)
1. Experimental Power - 43 day cycle Includes peak powers: Power Time Cycle 1. Soil Sampler 100 W 1 hr 1 2. Soil Processor 15 W 2 hr 1 3. Pyrolysis Oven 400 W 1 min 10 4. Evaporation Oven 100 W 10 min 7	8	Continuous	7,880
2. Transmitter and Receiver	200	3 hr/day	25,800
3. Data Processor	30	Continuous	31,700
4. Tape Recorder	10	3 hr/day	1,490
5. Coolant Pump	25	3 hr/day	3,210
6. Core Drill (Used in first cycle only)	500	1 hr/day for 8 days	4,000
		Total	74,080

TABLE 6.4-II

ITEMIZED ENERGY REQUIREMENTS BY EXPERIMENT
TYPICAL 43 DAY CYCLE

Experiment No.	Watt-Hours
1	214
2	1
3	106
4	1
5	Nil
6	3
7	3
8	36
9	3
10	
11	8
12	Nil
13	224
14	5
15	834
16	92
17	531
18	290
19	833
20	38
21	285
22	524
23	841
24	53
25	19
26	33
27	425
28	209
29	180
30	154
31	48
32	109
33	408
34	1069
35	320
(Round No.) Total	7880

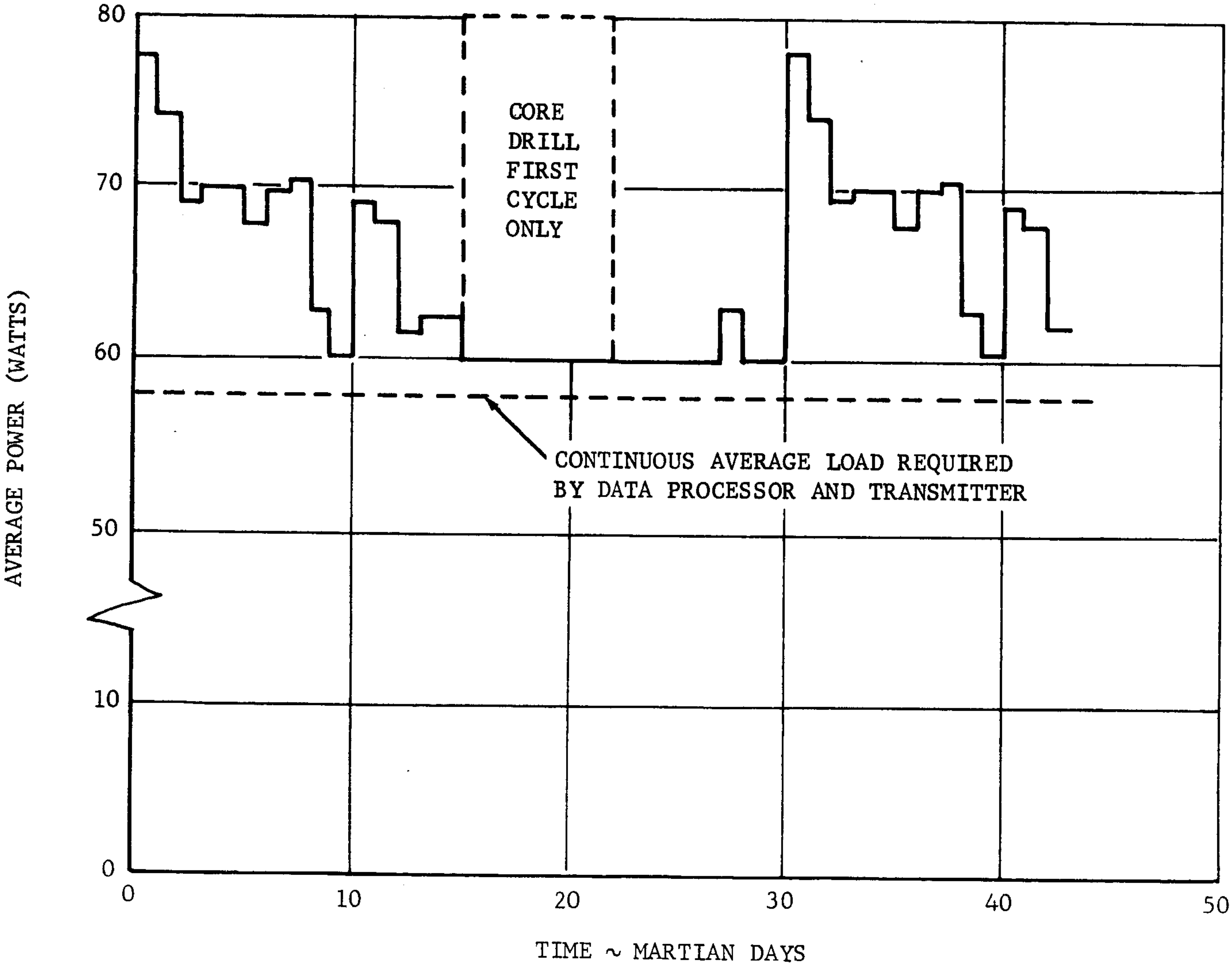

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FIGURE 6.4.1. TYPICAL 43 DAY POWER PROFILE

b. Sterilization Requirements. The power supply must be capable of being sterilized at 145°C for 3 hours (3 cycles proof test) and 135°C for 24 hours (1 cycle terminal sterilization).

c. Mission Type and Length. The mission profile requires the power supply to be encapsulated, sterilized, stored for indefinite period, survive an Earth-Mars transit for approximately nine months, withstand Mars entry and landing, and then operate for two years on Mars. Power is constantly demanded at some level through the two year period.

d. Mission Time Period. The 1972 state-of-the-art was used for power system selection.

6.4.4 POWER SUPPLY SELECTION

The most applicable candidate for the ABL Mission is the Radioisotope Thermoelectric Generator. Figure 6.4-2 shows the 1972 application areas for the major candidate power supplies. This figure is taken from Reference 1. The ABL Mission falls into the Photovoltaic or RTG power supply optimum operation range as shown. The only other possible candidate is the thermionic or dynamic system using an isotope heat source. It does not now appear that either of these systems will be sufficiently reliable for the two year operational period.

The choice between solar cells and the RTG is easily made. Because of the constant power demand, solar cells do not appear feasible since they could have a maximum of only 50 percent of the time in sunlight. The solar cells would have to be deployed and perhaps continuously oriented to reduce the total cell area required. The possible high winds and degrading action of dust are also adverse factors.

The RTG can be sterilized and in fact it operates at a temperature in excess of the sterilization temperatures. The possible three years total operation is within its capabilities. A single 70 watt RTG with shielding should weigh less than 25 pounds in 1972(1). The high heat output of the RTG imposes certain thermal control requirements. However, these can be provided for as discussed in Paragraph 6.5.

6.4.5 ELECTRICAL POWER GENERATION SUBSYSTEM

The subsystem designed to supply ABL electrical power requirements is shown schematically in Figure 6.4-3. The energy source consists of two 70 watt Radioisotope Thermoelectric Generators (RTG's). The power level

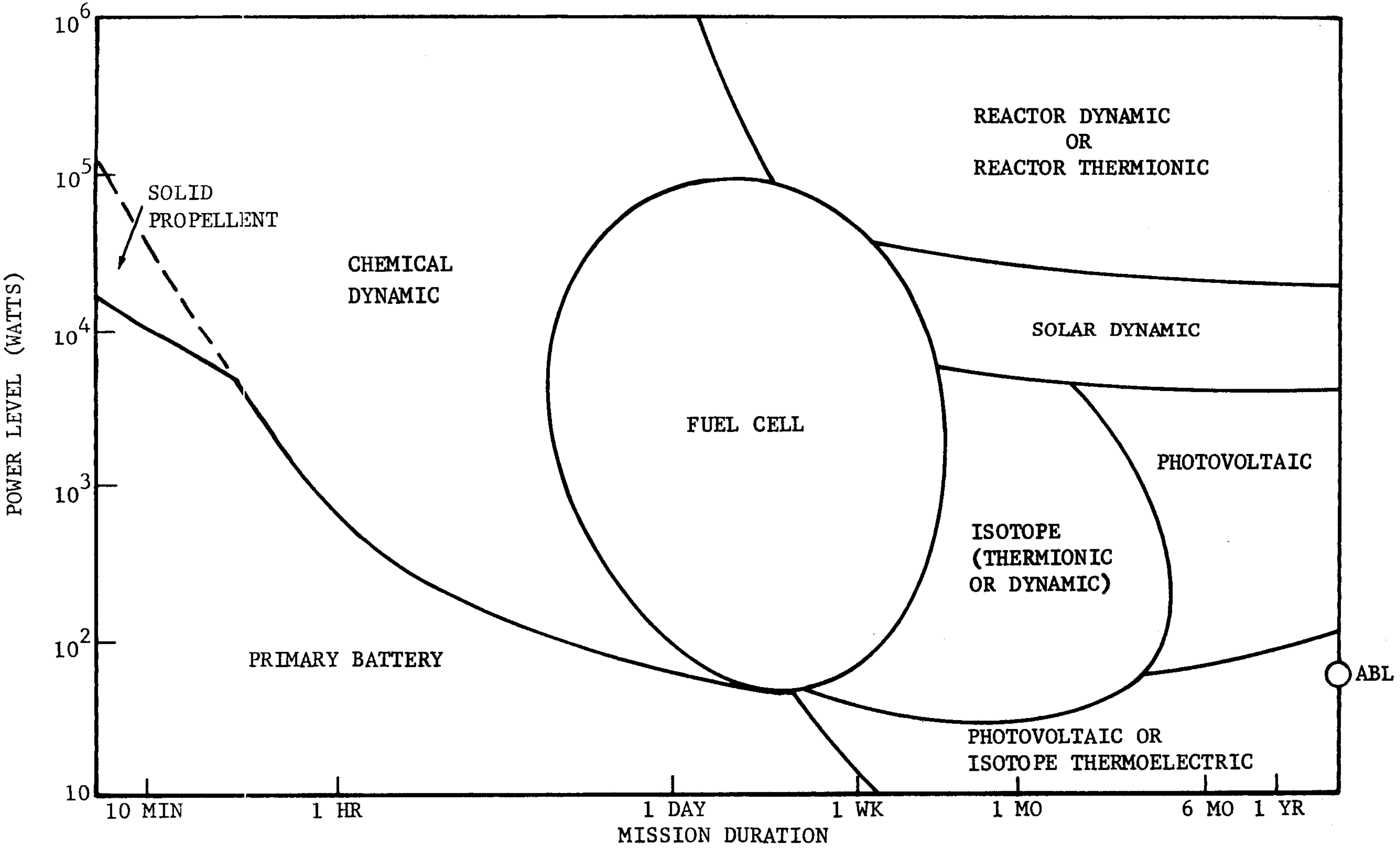

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FIGURE 6.4-2. POWER SUPPLY APPLICATION AREAS, 1972

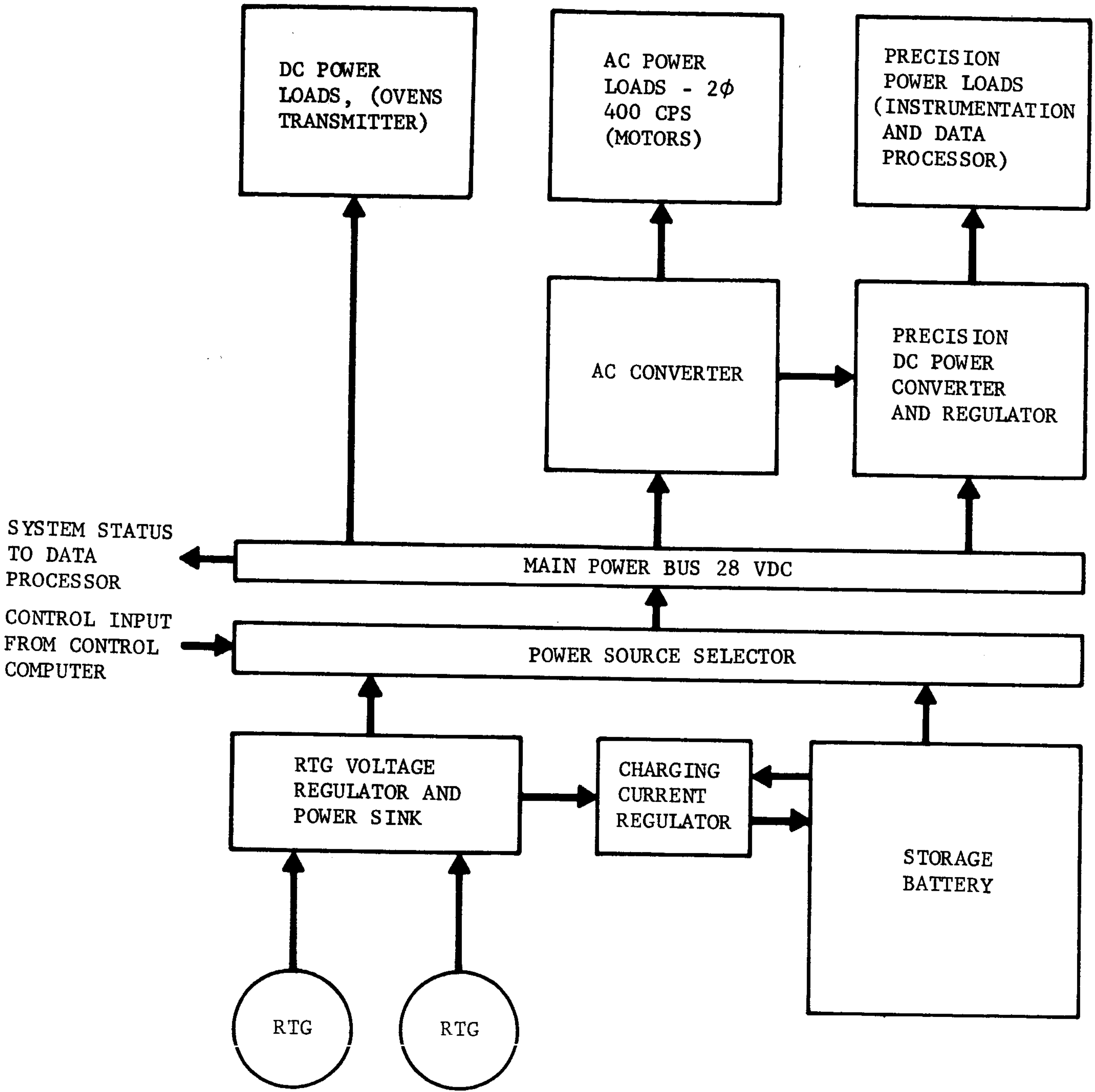

FIGURE 6.4-3. POWER GENERATION SUBSYSTEM

of the RTG's is established by the average power profile of Figure 6.4-1. Two RTG's are provided for redundancy. RTG space and weight is conserved by furnishing RTG capability sufficient only to supply the overall average load. The peak power requirements are supplied by a storage battery system which has a much higher power density than the RTG's.

A second benefit to be derived from the use of a battery is the ability of its low internal impedance to stabilize the load voltages over a wide range of currents. Thus, the battery will be used as a primary power voltage regulator. Secondary regulators are also required to control battery charging current and to supply precision dc voltages: A 2-phase 400 cycle ac power converter is required to complete the complement of power conditioning devices.

a. RTG - Current Regulator and Power Sink. Predictions for RTG performance in the early 1970's indicate that efficiencies of 8 percent will be available(1) thus making it possible to obtain 70 watts from each of the two RTG's shown in the system layout.

Three different Martian power system operating modes will occur:

(1)	Battery and RTG both supply the load	(Figure 6.4-4)
(2)	RTG supplying the load	(Figure 6.4-5)
(3)	RTG supplying the load and recharging the battery	(Figure 6.4-6)

Two of the modes will depend directly upon the power output of the RTG's alone; therefore, voltage regulators will be required to stabilize the voltage during these modes. During the first mode when the RTG's and the battery are both supplying the load, the RTG regulator must convert to a current regulator to permit optimum sharing of the load between the RTG and the battery.

b. Storage Battery and Charger. A storage battery is required to furnish the high power loads that are relatively low in duty cycle. Table 6.4-I identifies the major peak loads. In terms of discrete energy segments the transmitter and the core drill are by far the two largest loads. By scheduling the core drill operations during the lowest average power demand period, the average power is leveled sufficiently to allow the use of the RTG's as designed. Under this condition the peak daily energy segment that must be supplied from the battery is a combined

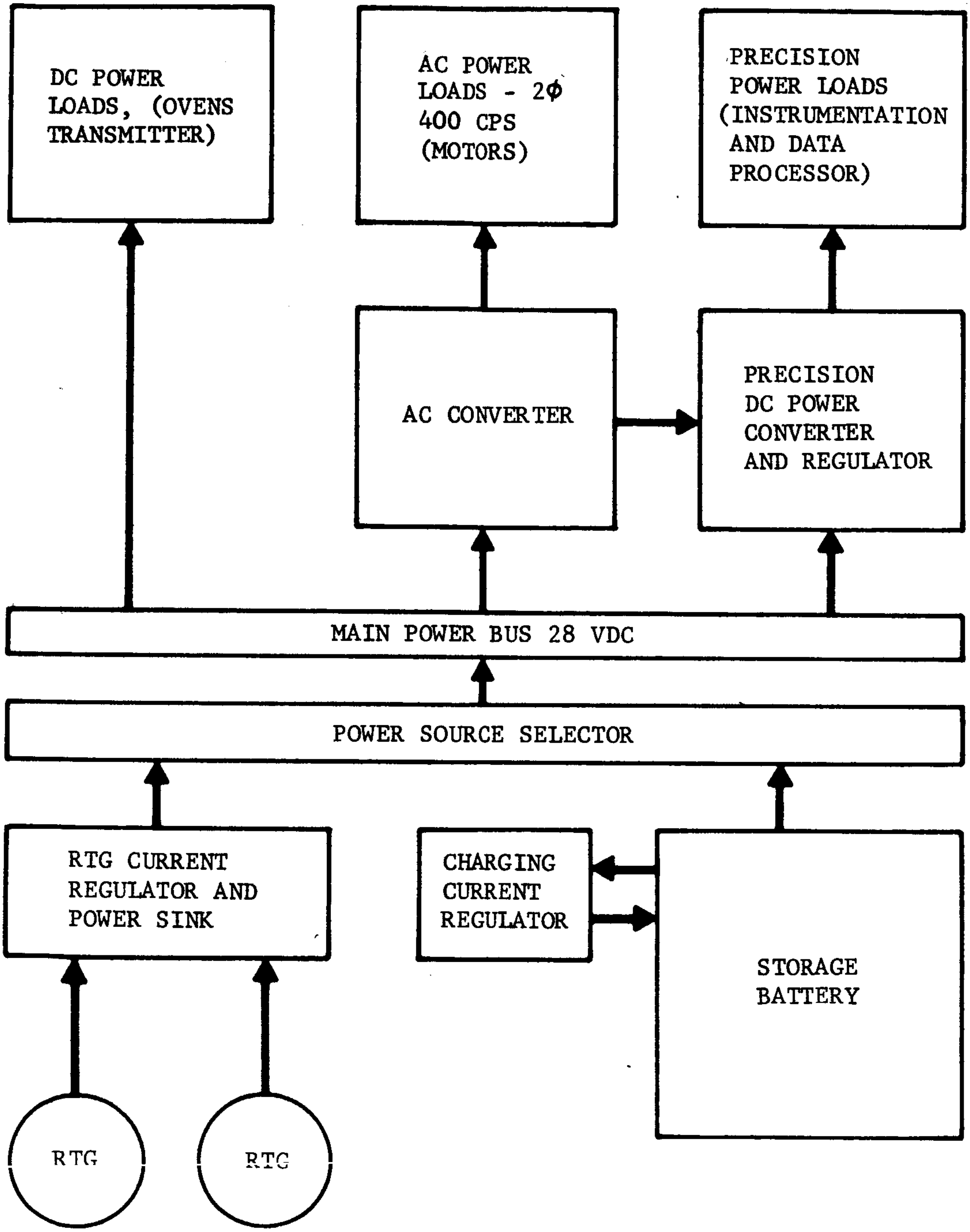

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FIGURE 6.4-4. POWER GENERATION MODE NO. 1, BATTERY AND RTG SUPPLYING LOAD

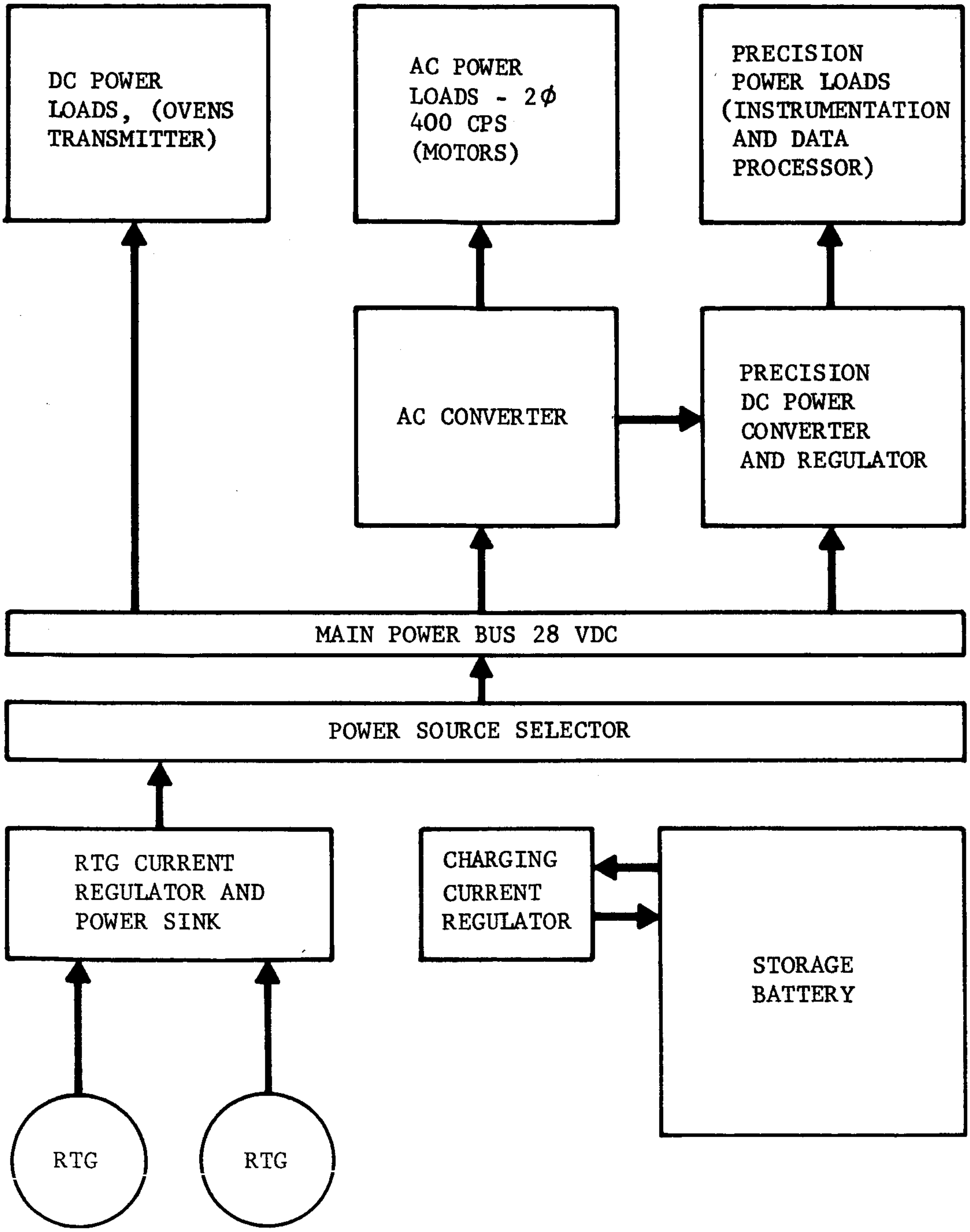

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FIGURE 6.4-5. POWER GENERATION MODE NO. 2, RTG SUPPLYING LOAD

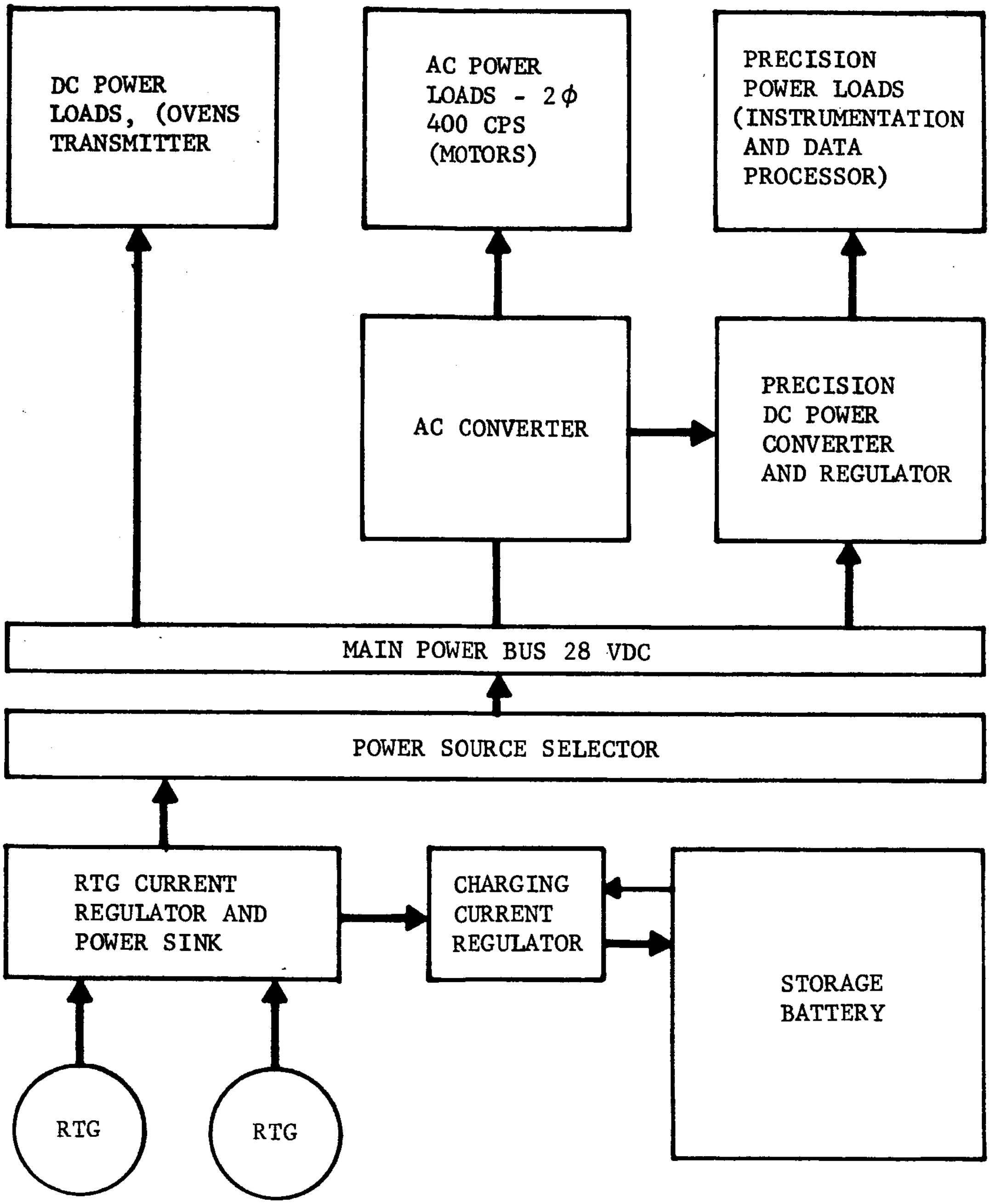

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FIGURE 6.4-6. POWER GENERATION MODE NO. 3, RTG SUPPLYING LOAD AND CHARGING BATTERY

600 watt-hours for the transmitter and 500 watt-hours for the core drill. The battery required to furnish this energy would weigh approximately 30 pounds assuming that the battery density is 60 watt-hours per pound and the depth of discharge is 70 percent. The battery size would be approximately 500 cubic inches.

Recharging the battery requires adequate time to prevent cell deterioration. Current practice requires a nominal charge rate of 1/10 of the rated discharge rate. During core drill operation the discharge to charge ratio is 1/7 based on a depth of discharge of 70 percent. This unfavorable condition occurs approximately eight times during the dirst 43 day cycle and is not expected to cause battery deterioration. Without core drill operation the battery recharge rate is approximately 1/20 of the rated discharge rate.

The charging current regulator provides the necessary charging current control. It limits the current to safe charging levels and terminates the charge when the battery is charged.

c. Power Conditioning Equipment. Raw dc power from the power bus is used directly by large loads such as the core drill, transmitter and heating devices. This permits considerable saving in power conditioning equipment. However,because of motor reliability and efficiency requirements it is necessary to generate 400 cps, two-phase power. This power will be supplied by the ac converter. In addition many instrumentation loads and the data processor will require precision regulated voltages which will be supplied by the precision power converter and regulator.

d. Power Source Selector. a control system must be provided to sense the various system power requirements and the battery charge state. From these observed states the power system operating mode is determined and the appropriate switching is performed. This device must also sense power system states which may require adaptive control from the data processor computer to distribute or schedule loads to permit operation at reduced or power levels compatible with the abailable power subsystem capability.

6.4.4 REFERENCES

1. Stafford, Gene B., "Space Power Subsystem Capabilities ;" AIAA paper 65-468, July 1965.

6.5 THERMAL DESIGN STUDIES

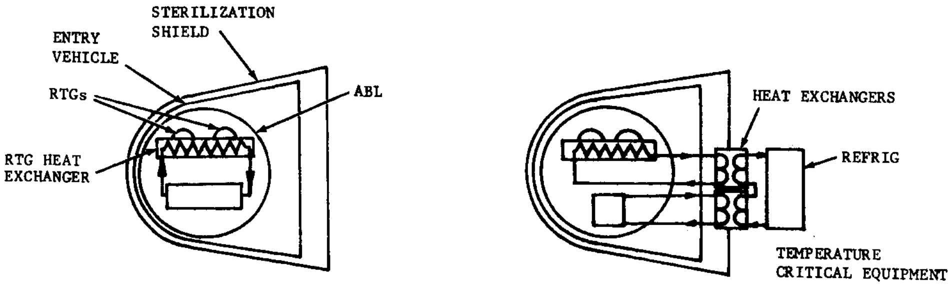
The ABL contains equipment and stored supplies that require a limited temperature environment for operation and for survival during storage. The thermal environment of each mission phase including sterilization has been considered in evaluating thermal control requirements. The two principal factors governing thermal control technique selection and system design are (1) use of the RTG power supply, and (2) the probable extremes of Mars surface thermal environment.

Active thermal control begins at installation of the RTG and continues through the remaining manufacturing operations, through storage, sterilization, and transit, and for two years on Mars' surface. The system provides both cooling and heating as required.

Figure 6.5-1 summarizes thermal control system operation throughout the entire mission. The major operational modes are shown beginning with sterilization when RTG heat is used to heat equipment and structure from the inside thereby reducing the time it takes to bring the ABL up to the sterilization temperature. A closed coolant loop used to reject RTG heat into stored water is used for this purpose. During the sterilization temperature soak, the 600°F RTG temperature is maintained by a circulating coolant. Temperature critical equipment which has been previously sterilized by another method is kept at an acceptable temperature by a separate coolant loop designed for that purpose.

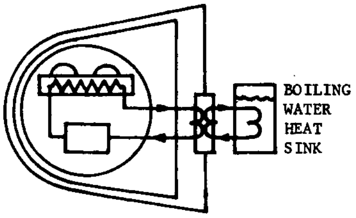
During launch, the external refrigeration unit is replaced by an expendable heat sink. A boiling water system is proposed. RTG and equipment temperatures can be kept at acceptable levels during the launch period using only a small amount of water. After injection into the Earth-Mars transfer orbit, heat is rejected to space via a radiator in the sterilization shield while the assembly is attached to the bus, and via a radiator in the entry vehicle after separation. During entry into the Mars atmosphere and prior to deployment, RTG heat is again dumped into the water stored for laboratory operations.

Two Mars surface operation modes are anticipated, one for high external environment temperatures (daytime) and one for low temperature (night-time). During the day, RTG heat is rejected to space by radiation and to the Mars atmosphere by convection. (At deployment, the RTG is exposed to space and the Mars environment.) Operating equipment is cooled by the circulating coolant which rejects heat to space and to the Mars atmosphere via a combination radiator and convective heat exchanger. The stored water acts as a buffer during high power, high external temperature operations when the heat exchanger is not adequate. At night the stored water is cooled down for this purpose. During low power night operation, thermostatically controlled doors in the insulation separating the RTG's from the capsule open allowing heat to be circulated into the laboratory.

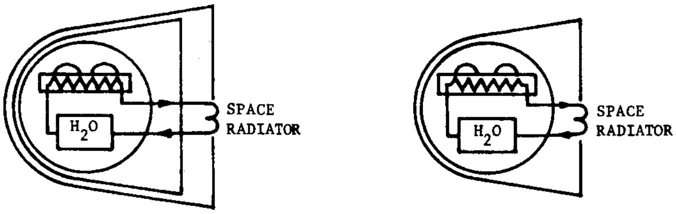


A. PRE-HEAT B. TEMPERATURE CONTROL

1. STERILIZATION

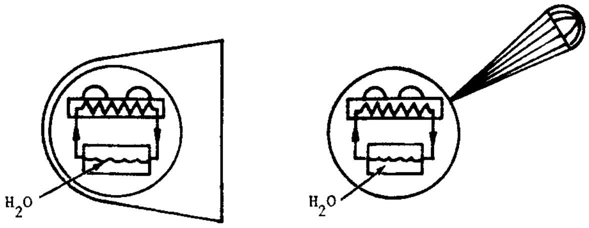


2. LAUNCH



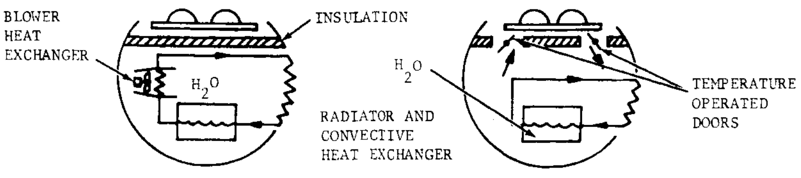
A. ATTACHED TO BUS B. AFTER SEPARATION FROM BUS

3. TRANSIT



A. AERODYNAMIC BRAKING B. PARACHUTE, RETRO, LIMITER C. PRE-DEPLOYMENT

4. ENTRY



A. DAY B. NIGHT

5. MARS SURFACE OPERATION

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FIGURE 6.5-1 SUMMARY OF THERMAL CONTROL MODES

6.5.1 REQUIREMENTS AND CONSTRAINTS

A thermal control system is required to remove waste RTG heat and maintain equipment temperatures between 0 and 75°C beginning with RTG installation. The total operational time period includes manufacture, sterilization, storage, Earth-Mars transit, and Mars surface operation. Some system elements may be required to operate continuously for as long as three years.

The principal requirements and constraints are summarized in Table 6.5-I as functions of mission phase. Nine mission phases are identified. The Mars surface environment parameters are summarized in Table 6.5-II. Two extreme conditions were selected, (1) minimum temperature, no sun, and (2) maximum temperature, subsolar. These represent predawn and noon thermal environments at Mars closest approach to the sun. Colder temperatures appear to exist between 60° and 90° South latitude; however, this region is not a preferred exploration area. The basic atmosphere is the Model 2 NASA MARS ATMOSPHERE* from Reference 1. The specified maximum and minimum ground and air temperatures and wind velocities were arrived at through discussion with Aeronutronic personnel, Reference 2. Density and specific heat were computed using perfect gas relationships. The atmosphere transmission coefficient is from Reference 3. The other parameters are extensively used in the literature.

The RTG power supply imposes some unique operating constraints on the ABL since an RTG emits heat continuously from initial assembly. This characteristic is a drawback in some cases and a benefit in others. The ABL will require cooling from initial assembly through Mars deployment; however, RTG heat is available to heat the ABL from the inside out during sterilization thereby reducing the time it takes to bring the entire assembly up to soak temperature. In addition, RTG waste heat is available during Mars night operation to maintain acceptable equipment temperatures.

The sterilization requirement imposes design constraints on the thermal control system in that some critical equipment cannot withstand the high soak temperatures and must be cooled during sterilization.

To minimize system weight and complexity the system must be designed to use common flow paths, pumps, and heat exchangers where possible. In addition, the wide range of operational requirements and the long time periods indicate the need for redundancy of blowers, pumps, valves, and flow circuits.

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*The recent low atmospheric pressure estimate from Mariner IV data does not significantly change the thermal analysis. See Appendix 15 in Volume VI for a discussion of this point.

TABLE 6.5-I

THERMAL CONTROL REQUIREMENTS AND CONSTRAINTS

Mission Phase	Requirements	Constraints
I. Manufacture and Pre-Sterilization Storage	1. Maintain 0° to 75°C ($32^{\circ}/167^{\circ}$F) in capsule. 2. Maintain RTG radiator temp. at 600°F.	a. RTG waste heat, 1000-2000 watts. b. Undefined time period. c. External heat sink and power available.
II. Sterilization	1. Maintain temperature critical components (already sterilized by other than dry heat bake) at 75°C (167°F) 2. Maintain RTG at 600°F.	a. 145°C (293°F) for 36 hrs (3 cycles) 135°C (275°F) for 24 hrs (1 cycle) b. 1000-2000 watts RTG heat. c. External heat sink and power availabl
III.. Post-Sterilization Storage and Prelaunch	Same as Mission Phase I	
IV. Launch	Same as Mission Phase I	a. 1000-2000 watts RTG heat. b. Launch thermal environment. c. External heat sink available. d. Short time period.
IV. Earth-Mars Orbit - Attached to Bus	Same as Mission Phase I	a. 1000-2000 watts RTG heat. b. Heat sink of outer space (0°R). c. 8-9 months. d. External power available.

TABLE 6.5-I (Continued)

Mission Phase	Requirements	Constraints
VI. Earth-Mars Orbit - Separated from Bus	Same as Mission Phase I	a. 1000-2000 watts RTG heat. b. Heat sink of outer space ($0^{o}R$). c. Several days. d. No external power available.
VII. Mars Entry	Same as Mission Phase I	a. 1000-2000 watts RTG heat. b. No external heat sink. c. Entry thermal environment. d. Short time period.
VIII. Pre-Deployment	Same as Mission Phase I	a. 1000-2000 watts RTG heat. b. Mars surface thermal environment. c. Short time period.
IX. Surface Operations on Mars	1. Maintain capsule at $4^{o}C \pm 3^{o}C$ ($39.2^{o}F \pm 5.4^{o}F$). 2. Battery environment - $50^{o}/100^{o}F$. 3. Gas chromatograph No. 1 requires $-78^{o}C$. ($-108.4^{o}F$) for 5-6 minutes.	a. 1000-2000 watts RTG heat. b. RTG capable of radiating to space. c. Mars surface thermal environment. d. 2 years operation.

TABLE 6.5-II

MARS SURFACE PARAMETERS
FOR
THERMAL CONTROL ANALYSIS

	Parameter	Condition I	Condition II
1	Pressure (atm), Mb	25	25
2	Temperature (atm), ^{o}R	340	450
3	Temperature (ground), ^{o}R	340	558
4	Density (atm), lb/ft^3	$2.95\text{x}10^{-3}$ lb/ft^3	$2.23\text{x}10^{-3}$ lb/ft^3
5	Gas Constant, ft lb/lb-^{o}R	52.1	
6	Ratio of Specific Heats	1.4	
7	Specific Heat - C_p (atm), Btu/lb ^{o}F	0.235	
8	Molecular Weight (atm)	29.7	
	Atmosphere Composition		
9	% by mass	16% CO_2, 84% N_2	
	% by volume	10.8% CO_2, 89.2% N_2	
10	Gravitation Constant, ft/sec^2	12.3	
11	Viscosity (atm) lb/hr-ft	$2.75\text{x}10^{-2}$	$3.69\text{x}10^{-2}$
12	Wind Velocity, m/sec	0 to 60	
13	Thermal Conductivity (atm) Btu/hr-ft^2-^{o}F/ft	$9.5\text{x}10^{-3}$	$1.21\text{x}10^{-2}$
14	Albedo	-	0.15
15	Solar Constant, Btu/ft^2-hr	-	232
16	Vertical Atmosphere Transmission Coefficient	-	0.61
17	Surface Emissivity	0.9	0.9

A completely passive system does not appear to be feasible for any mission phase. During early mission phases, the very high heat rates of the RTG coupled with the requirement that all systems be encapsualted for sterilization dictate use of an active system for heat removal. Also many of the Mars surface experiments require controlled temperature environments which cannot be attained passively, particularly in the wide-range Mars thermal environment.

6.5.2 TECHNICAL DISCUSSION

The objectives of this study have been to determine major thermal control requirements and to define a preliminary system concept so that interfaces between the ABL and the lander could be established.

The Mars surface operational mode is the most critical. Since none of the techniques employed for Earth, space, or Mars surface operation modes require advances in technology, feasibility of the concept depends largely on the correctness of assumptions about the Mars surface thermal environment. The two extreme conditions summarized in Table 6.5.2 are felt to provide a sufficiently wide range to allow for the uncertainties.

Appendix 15 in Volume VI contains the temperature analyses that were made of the ABL on the Mars surface. The basic assumptions, approach, and results of these analyses are summarized here.

A steady-state heat balance analysis of Mars surface operation was made to determine, as functions of insulation thickness, the heat rejection and addition rates necessary to maintain capsule temperature at a nominal 500°R, and the maximum day and minimum night temperatures that would occur with no thermal control. In addition, a first-order transient analysis was made to determine more realistic temperature extremes than are obtained with the steady-state analysis.

Heat transfer modes between the capsule and its environment include radiation, conduction, and convection. The no-wind case was used for the maximum internal heat dissipation noon operation, and the maximum wind velocity was assumed for the minimum external environment temperature case. The payload and the outer wall were each assumed to be isothermal. Heat balance on the RTG was made separately.

The gross analyses show that temperature can be maintained at 500°R using several inches of insulation around the inside wall and by using RTG heat at night.

Thermal control system optimization or a detailed thermal analysis to the level of individual components within the payload were neither within the scope of the present study, nor warranted by the objectives stated above. The results of the analyses performed indicate the probable requirement for an active thermal control system, at least periodically, on Mars and the system description in the following paragraph reflects such a requirement. It is recognized that a detailed design analysis of a specific payload, where thermal characteristics of components are better defined, could result in a feasible passive thermal control system. Requirements for coolant flow rates, pumping power and radiator areas, likewise, did not warrant rigorous optimization at this time.

6.5.3 SYSTEM DESIGN

A single-phase circulating coolant system appears most feasible for removing waste heat and keeping system elements within acceptable temperature limits. The heat sink used for ultimate heat rejection from the ABL varies from a ground refrigeration unit to a space radiator. The principal system elements, shown in Figure 6.5-2, are the circulating coolant, the RTG coldplate heat exchanger, the circulation blower and heat exchanger, the stored water heat sink, the temperature operated doors between the RTGs and the lab, the external heat exchangers, and the insulation surrounding the laboratory. Appropriately located disconnects in coolant lines permit sequential removal of the sterilization shield, the entry vehicle, and the impact limiter as the mission progresses without coolant loss from the inner flow loops. Squib and motor driven valves are provided to properly route coolant flow with changing operational mode. Two completely redundant flow loops are used (only one is schematically shown). Active components such as blowers and pumps are also redundant.

This section discusses system design in light of operational mode. Each of the principal system elements is covered in this way except for the RTG cold-plate heat exchanger. Because power supply cooling begins with manufacture, and because system design is largely based on power supply cooling requirements, the RTG installation is discussed first.

Although Mars surface operation is the most important subject, it is covered last to maintain continuity.

a. RTG Installation. The RTG installation provides for waste heat removal and isolation of the 600°F "cold" junction from the laboratory. The 1000 to 2000 watts of waste heat are removed by the circulating coolant via the cold plate heat exchanger that is integral with the RTGs. Heat transfer into the laboratory (see Figure 6.5-3) is reduced by 2 inches of insulation between the RTGs and the lab and by the triple-pass coldplate heat exchanger that limits the lower RTG surface temperature to between 50° and 200°F. A coolant flow rate of approximately 25 lb/hour is maintained through the heat exchanger (except during sterilization) until deployment on Mars surface from which time RTG heat is rejected by radiation and convection (to space, to the Mars atmosphere, and to the ABL).

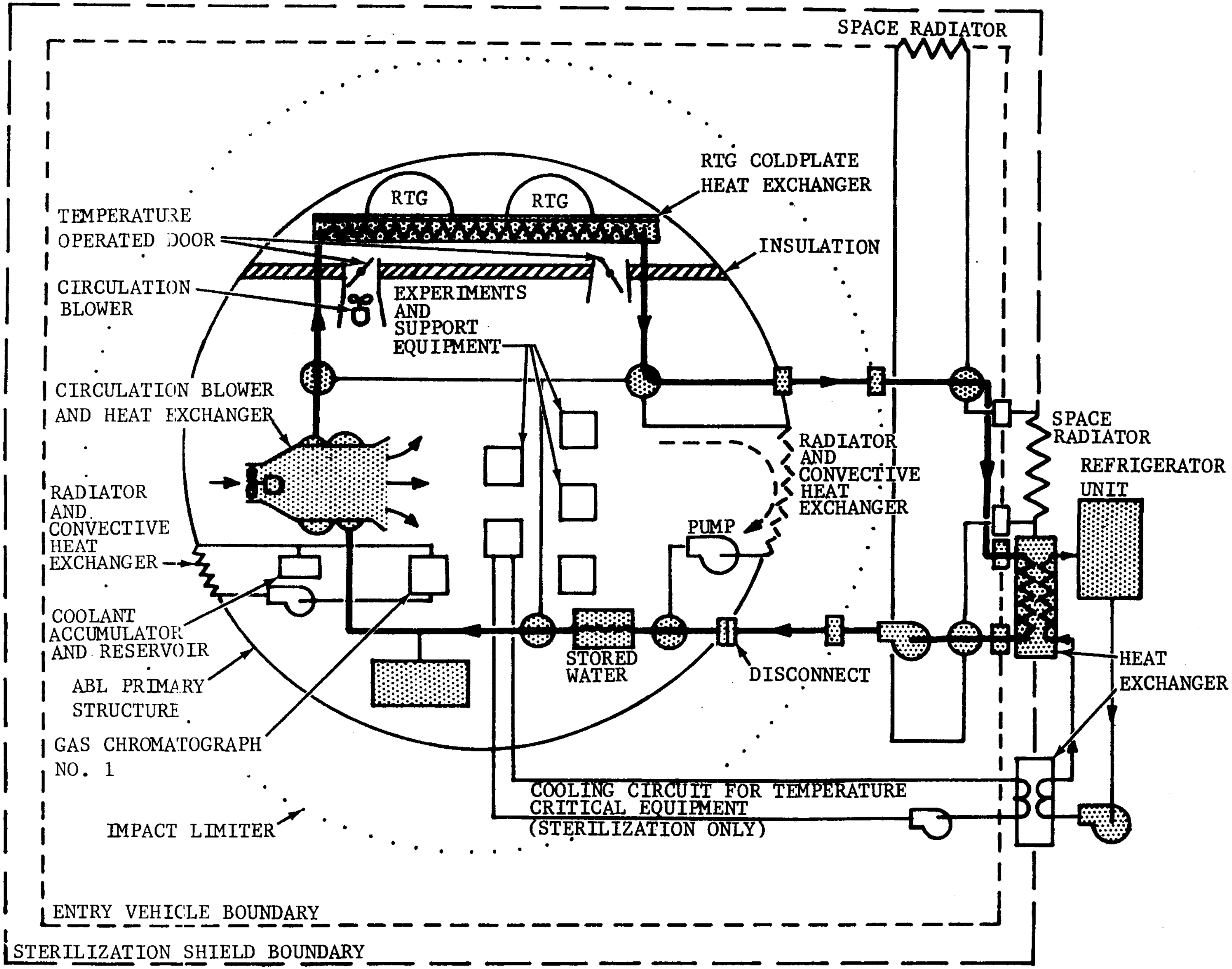

FIGURE 6.5-2. THERMAL CONTROL SYSTEM OPERATION DURING EARLY MISSION PHASES

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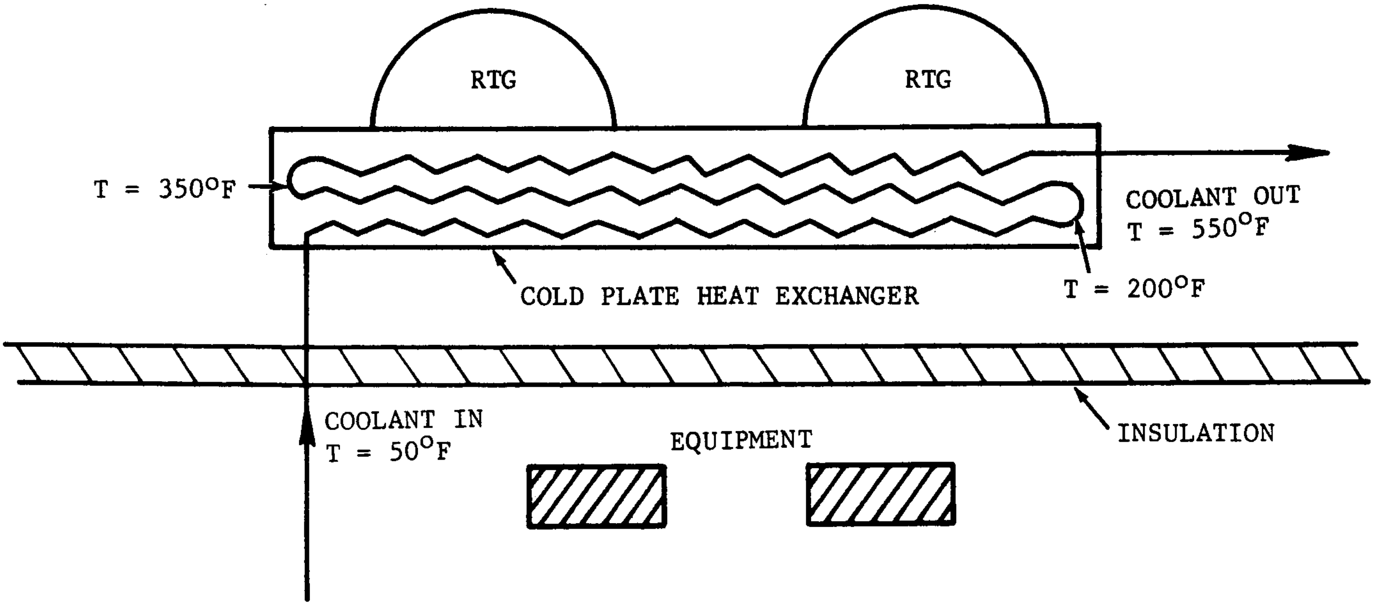

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FIGURE 6.5-3. RTG INSTALLATION

b. Early Mission Phases. During early mission phases the thermal control system removes RTG heat that leaks into the lab by periodic operation of the circulation blower which circulated the dry nitrogen atmosphere through the blower's integral heat exchanger, as shown in Figure 6.5-2. (The coolant flow path is indicated by the heavy solid line). Refrigeration units in storage areas and on the launch pad remove heat from the circulating coolant via a counter flow heat exchanger in the sterilization shield. The coolant is in a closed loop within the shield to meet sterilization requirements. The equipment temperature is kept at approximately 50°F. A coolant accumulator and reservoir provides for coolant expansion and makes up coolant losses which will of necessity be extremely small. RTG power operates valves, blowers, and pumps inside the sterilization shield; however, selection of operational mode is done remotely.

During these phases, coolant temperature varies between approximately 40°F and 550°F.

c. Sterilization. RTG waste heat is used to bring the ABL up to sterilization temperature to reduce the time required for this operation and to minimize internal thermal gradients. Coolant flow is completely or partially diverted as shown by the dashed line in Figure 6.5-2. The flow through this internal circuit is controlled to quickly raise structure and component temperatures to the desired sterilization soak temperature.

When soak temperature is reached the main coolant flow returns to the first mode; however, coolant inlet temperature remains at the required sterilization level and flow rate is increased to approximately 40 lb/hr to maintain the required RTG temperature. In addition a second coolant loop is activated as shown in Figure 6.5-2 to cool temperature critical equipment that has already been sterilized by other means.

d. Launch. During the boost phase RTG heat is removed by a boiling water heat sink that replaces the refrigeration unit used during prelaunch storage and sterilization. An alternate mode of operation that could be used is to dump RTG heat into the laboratory's stored water supply by using the sterilization pre-heat circulation loop. The 75 lb water supply could absorb RTG heat with an accompanying temperature increase of less than 2 degrees Fahrenheit per minute. Coolant temperature during launch will vary between 50°F and 550°F.

e. Earth-Mars Transit. During Earth-Mars transit RTG heat is rejected to space through a space radiator. Two modes of operation are expected, (1) entry vehicle attached to the bus, and (2) entry vehicle separated from the bus. In the first mode the space radiator is in the sterilization shield, in the second it is in the base of the entry vehicle. The coolant circuit, Figure 6.5-4, is similar to that of the early mission phases except for routing through the appropriate radiator.

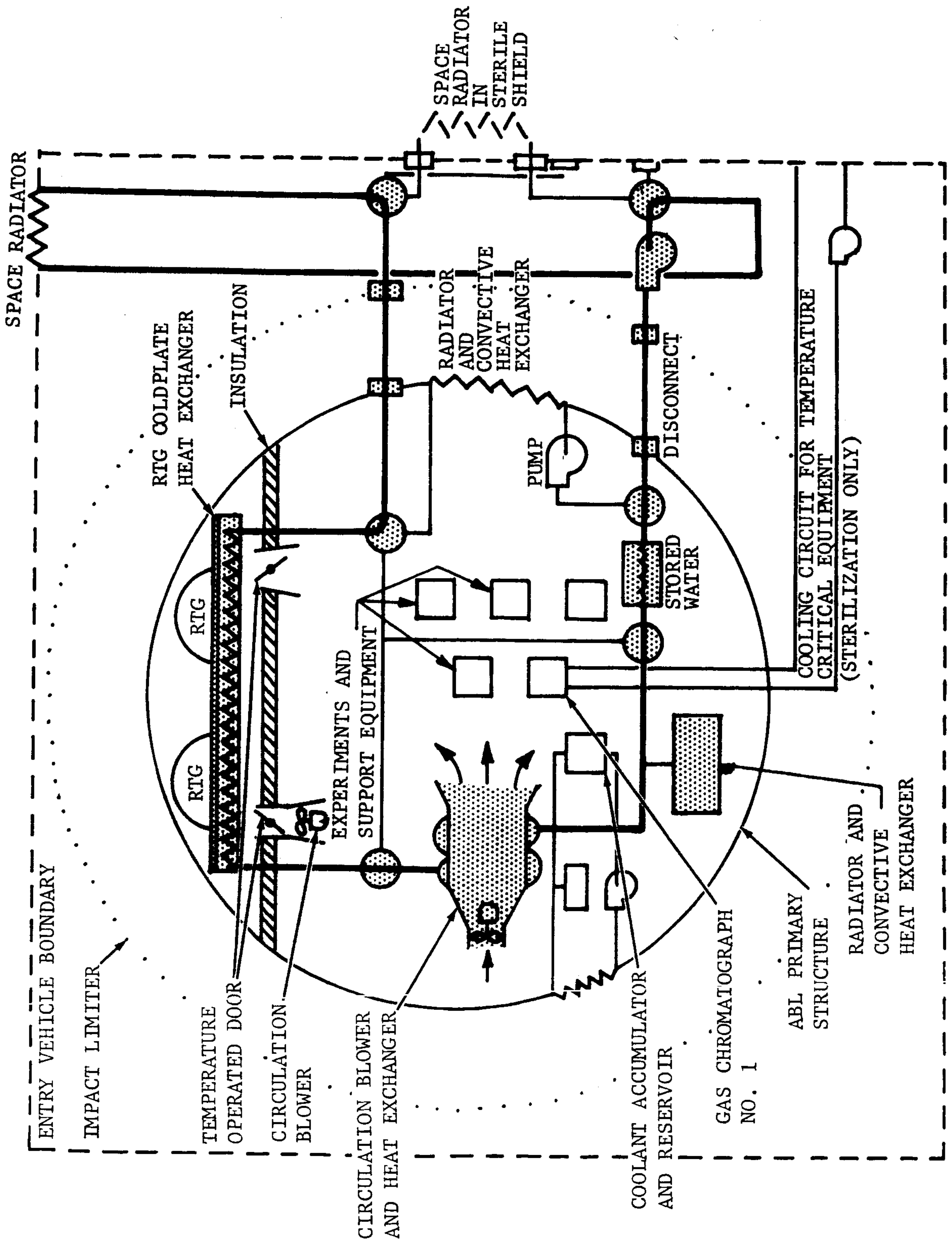

FIGURE 6.5-4. THERMAL CONTROL SYSTEM EARTH-MARS TRANSIT

The low solar absorptivity, high infrared emissivity space radiator coating will degrade during the 9-month transit; however, the solar constant decreases as the spacecraft moves away from the sun, thereby reducing the demand on the radiator, so that the radiator in the sterilization shield will require less than 70 ft^2 of area. The radiator in the entry vehicle is not exposed to the space environment until a few days before entry so no surface coating degradation occurs. Entry vehicle radiator size is less than 30 ft^2. Coolant temperature may drop to as low as 0°F during transit. The high temperature leaving the RTG will be approximately 550°F.

f. Mars Entry. ABL structure and the water heat sink will be at approximately 50°F prior to Mars entry. The total mass will serve as a heat sink until deployment on Mars surface. The water alone limits temperature rise to less than 2°F per minute.

g. Mars Surface Operation. Following deployment, the RTGs reject heat primarily by radiation. Fin root temperature will never exceed 600°F. The processing equipment and storage areas, surrounded by 2 inches of insulation, can be kept within the required temperature limits during day operation by the circulating coolant (Figure 6.5-5) which removes heat from equipment and the circulating atmosphere and rejects it to space and the Mars atmosphere through a radiator and convective heat exchanger in the outer skin of the laboratory. The radiator surface will be either a flame sprayed oxide or the bare metal since conventional pigmented coatings would probably not withstand scouring sandstorms. Temperature excursions during high power noon operations are limited by the stored water (and chemical wastes) that serve as heat sink.

At night the lab temperature is maintained with RTG waste heat (Figure 6.5-6). Heat is transferred into the lab by circulating atmosphere through temperature operated doors between the RTG and the equipment area. The doors and the circulation blower are actuated by a temperature sensor in the equipment.

At night, the circulating coolant is routed as shown in Figure 6.5-6 to remove heat from the water heat sink and reject it via the radiator and convective heat exchanger. The cooled heat sink is then available as a buffer during the following day's operation.

A separate coolant loop is provided for special equipment such as the No. 1 gas chromatograph that requires very low temperature for brief periods. The separate loop is required because the coolant temperature range is much lower than the range required in the primary loop and no coolant was found that fits both ranges. This chromatograph is operated only at night.

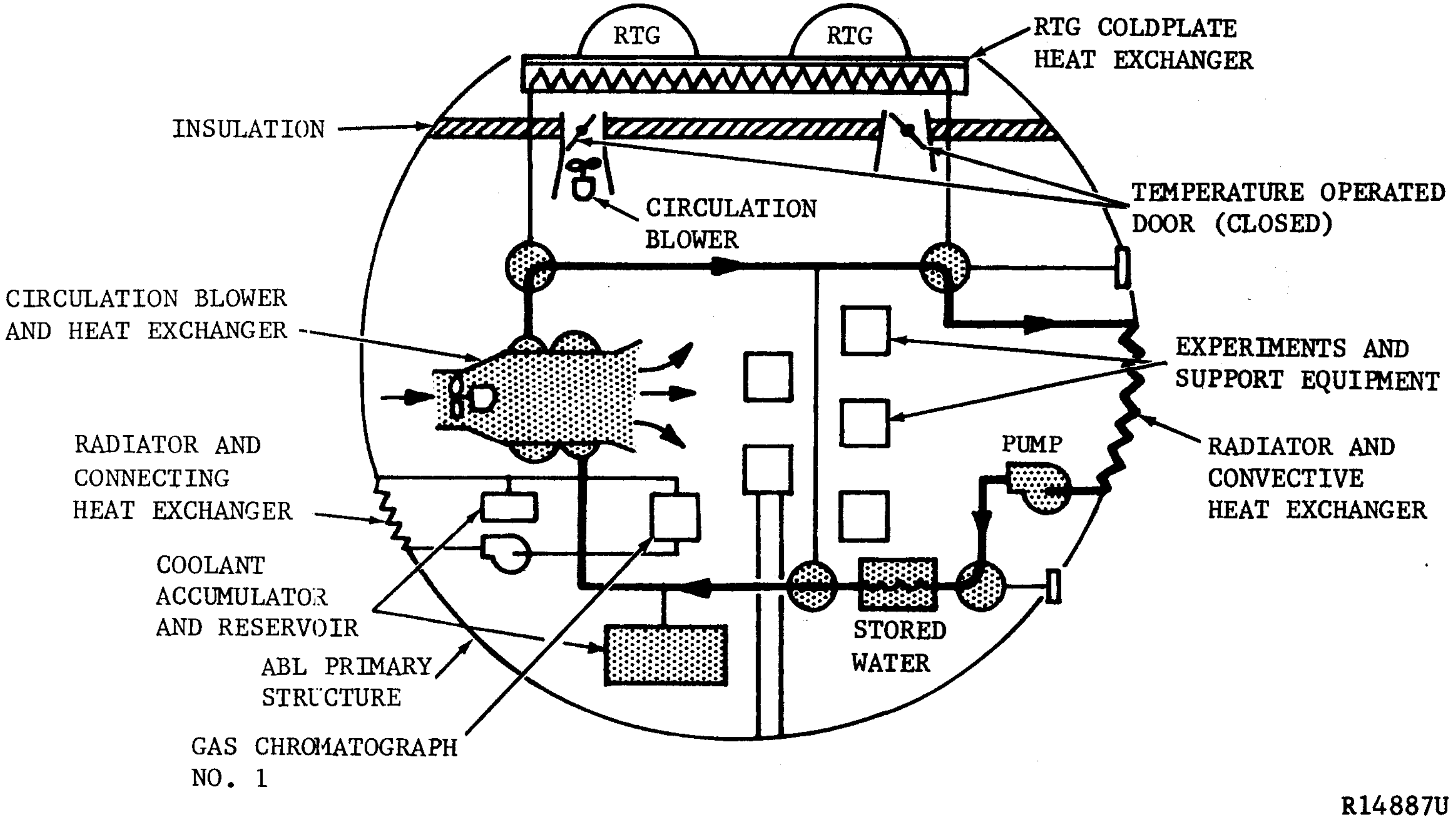

FIGURE 6.5-5. THERMAL CONTROL SYSTEM MARS SURFACE DAY OPERATION

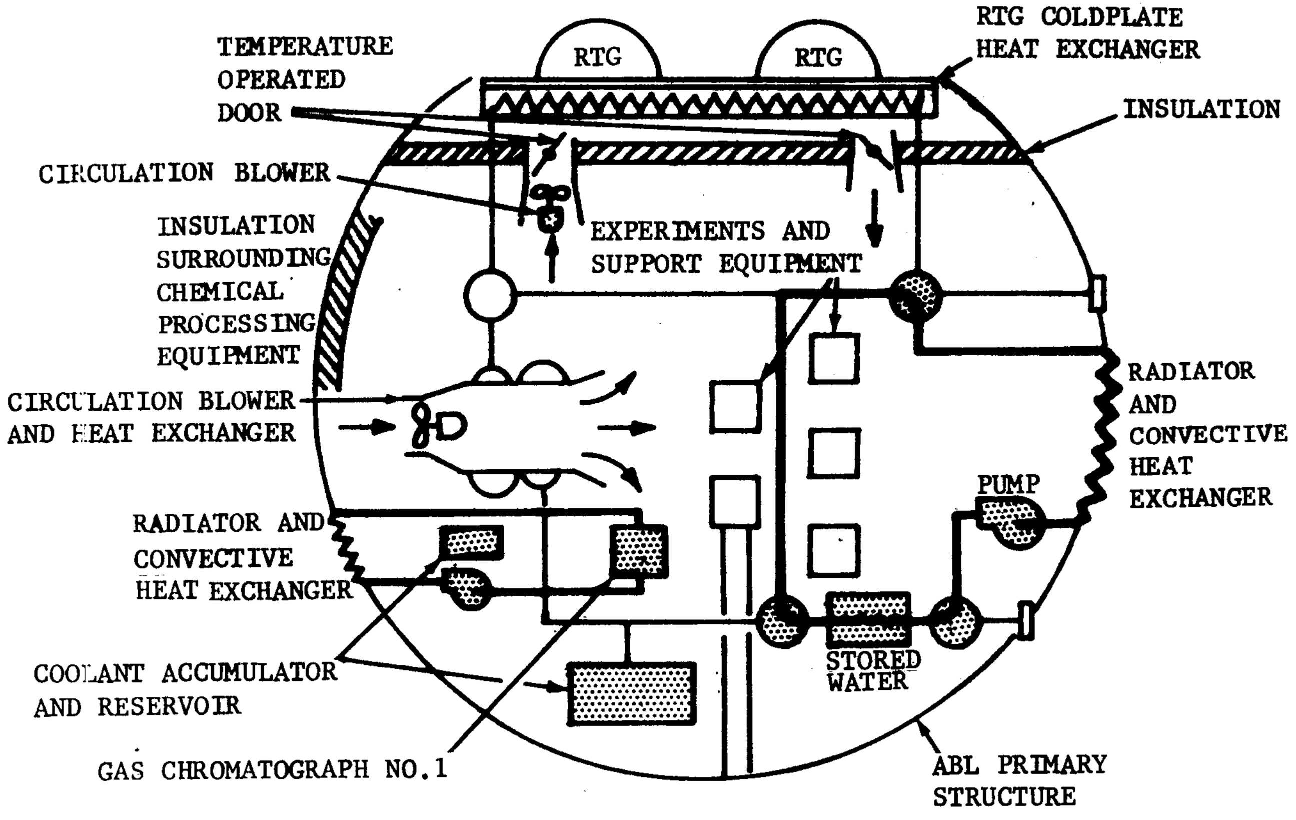

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FIGURE 6.5-6. THERMAL CONTROL SYSTEM MARS SURFACE NIGHT OPERATION

h. Thermal Control during Manufacture. Figure 6.5-7 shows how RTG temperature is maintained during ABL construction. The circulating coolant removes waste heat and is cooled by a refrigeration unit. The coolant can be routed directly through the refrigeration unit until the sterilization shield is installed. From that time the coolant loop is closed and heat is transferred from the assembly through the heat exchanger in the sterilization shield. This design isolates the coolant for sterilization. During assembly operations when the refrigeration unit must be disconnected from the capsule, heat is rejected into the laboratory's stored water as shown in Figure 6.5-7E.

6.5.4 CONCLUSIONS

a. Mars surface operation is the most critical mission phase for the thermal control system.

b. With the assumptions made for this study:

(1) Some form of active thermal control is required during each mission phase.

(2) RTG heat is required during night operation to maintain capsule temperature.

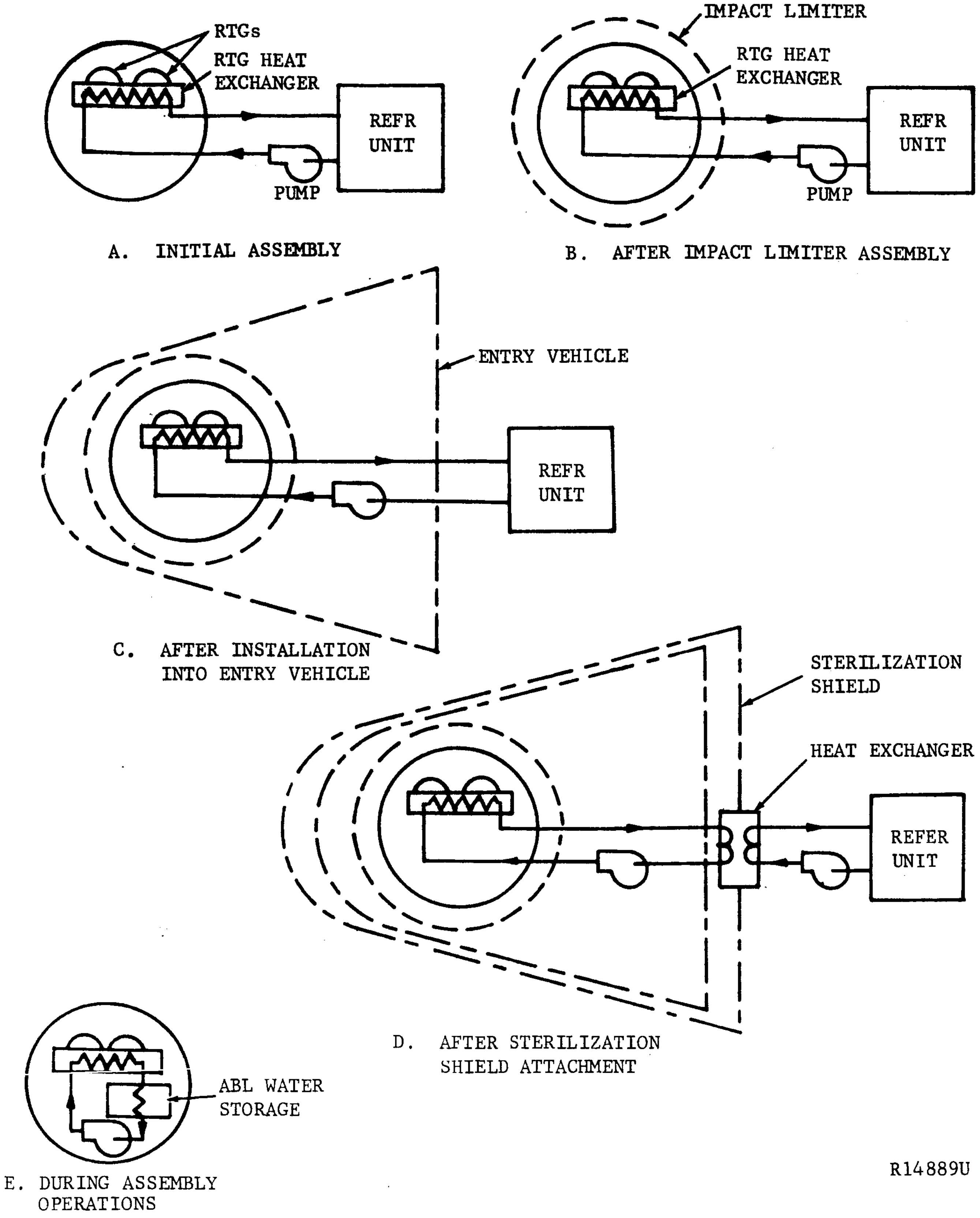
c. A more rigorous analysis may show the feasibility of passive thermal control on Mars surface.

6.5.5 REFERENCES

1. G. M. Levin, D. E. Evans, and V. Stevens, "NASA Engineering Models of the Mars Atmosphere for Entry Vehicle Design," NASA TN d-2525, Nov 1964.

2. Conversation with Aeronutronic's Senior Staff Geologist, George P. Zebal, and Planetary Meteorologist, Richard E. Peterson.

3. "Final Report, Study of a High Resolution Facsimile System Experiment on the Surface of the Planet Mars," Aeronutronic Publication No. U-3034, 25 Feb 1965.



A. INITIAL ASSEMBLY

B. AFTER IMPACT LIMITER ASSEMBLY

C. AFTER INSTALLATION INTO ENTRY VEHICLE

D. AFTER STERILIZATION SHIELD ATTACHMENT

E. DURING ASSEMBLY OPERATIONS

FIGURE 6.5-7. THERMAL CONTROL DURING MANUFACTURE

6.6 ENTRY VEHICLE TECHNOLOGY AND CONCEPTUAL DESIGN STUDIES

6.6.1 GENERAL

The objectives in investigating entry vehicle technology and performing vehicle conceptual design studies as a part of the ABL study were to determine (1) the effects of ABL-class payloads on the entry vehicle, and (2) to establish the essential nature of the principal interface (functional, mechanical, electrical) between the ABL and typical entry vehicles. Inasmuch as these objectives could be accomplished without detailed vehicle preliminary designs, vehicle optimization was not an objective of these studies. However, every effort was made to utilize the latest substantiated environmental data available at the time the study was performed. The analysis also utilized data based upon the latest entry vehicle technology from research and development programs completed or in progress within Aeronutronic and from other government and industrial sources. Conceptual studies of a number of promising vehicle/payload systems were conducted, making every effort to compare alternative approaches on a consistent basis.

6.6.2 SELECTION OF ATMOSPHERIC MODEL

At the initiation of this study effort, the recognized values of the Mars atmospheric parameters for use in entry vehicle design were best represented by the three atmospheric models defined in NASA-TN-D255.(1) Studies of other ABL systems had originally been predicated on the use of the mean atmosphere, Model 2 (25-mb surface pressure) from this reference, as discussed elsewhere in this report. It was recognized, however, that the entry vehicle parameters were extremely sensitive to variations in the atmospheric model, particularly at the lower end of the density range. Therefore, the entry vehicle studies covered by this analysis were scheduled to include a lower limit model of 14-mb surface pressure known to be consistent with studies at the Jet Propulsion Laboratory (JPL). These studies had been underway only a short time when the preliminary results from the occultation experiment on Mariner IV were reported by JPL. These results, 10- to 20-mb surface pressure, appeared to justify the choice of models for this study of 14 to 25 mb. The surface pressure scale heights of 8 to 10 kilometers reported from the occultation data were lower, however, than that of the Model 3 (1) atmosphere (approximately 13 kilometers).

Unfortunately, the analysis covered by this section is being completed approximately one month prior to the scheduled official release of the reduced and analyzed data from the occultation experiment; improved resolution of pressure and scale height beyond the values quoted above is not available. On this basis, it was concluded that the 14-mb surface pressure was an appropriate choice with which to continue the analysis.

Since no definitive data on revised scale height were available, 14 kilometers was retained for this study so that maximum use could be made of the considerable trajectory data and conceptual design work already accomplished with this value. When the final results from the occultation experiment are available, the results of this analysis should be reviewed. If lower densities and lower scale heights are defined by later data, all vehicle systems shown in this section will grow, payload ratios will decrease, and those configurations representing marginal solutions may become untenable. The relative merit of the various approaches will not be affected, however.

6.6.3 PAYLOAD/ENTRY VEHICLE SYSTEMS CONSIDERATIONS

There are many potential systems interfaces between an ABL-class payload and its Mars entry carrier vehicle. The principal ones affecting the system concept to be employed are

(1) Use of separable versus integral payload installation.

(2) Entry vehicle aerodynamic/structural configuration.

(3) Use of active or passive damping and attitude stabilization.

(4) Use of subsonic or supersonic parachute technology.

(5) Use of wind drift cancellation devices.

(6) Landing impact deceleration level (hard or soft).

(7) Use of fixed or deployable impact deceleration technology and/or terminal retropropulsion.

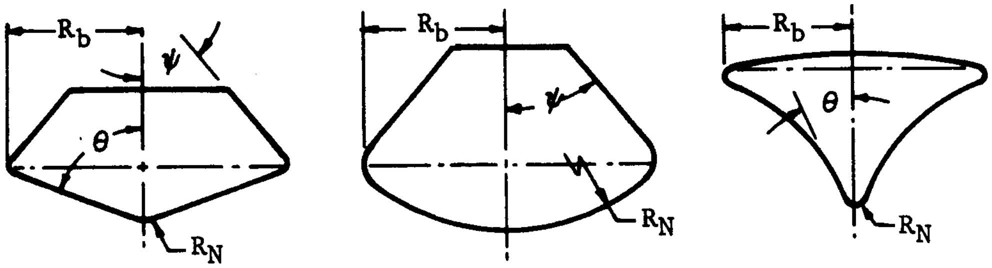
These various concepts will be discussed in the following paragraphs with regard to their principal effects on the entry vehicle and the payload interfaces with it in order to indicate their importance in the conceptual design studies which will be described in Paragraph 6.6.4.

a. Separable versus Integral Payload. The reasons for employing the separable payload concept in the ABL preliminary design study have been reviewed in detail in Paragraph 5.3 of this report from the point of view of optimizing the payload and of maximizing the thoroughness of the payload analysis. There remains a secondary question, however, regarding the functional separation of these two entities. The payload could conceivably remain with the entry vehicle through touchdown and surface operation, or it could be separated in flight and landed independently. Retaining the entry vehicle permits possible use of portions of its structure for landing impact absorption but increases the load to be absorbed by its own added weight; it increases the size of the parachute requirements for a given terminal velocity; and raises questions of the removal of the payload, or the deployment of critical mechanisms, such as samplers, from the crushed entry body. Some entry vehicle structural concepts (e.g., the Langley tension shell(2)) employ very light structural elements in their forward section which are inherently poor energy absorption structures, and further, offer little protection and possibly even some hazard to the payload during crush-up. The probability of tumbling on impact is high, and such structures could deform in such a way as to prevent subsequent deployment of the payload or critical functions in it.

In order to assess this tradeoff in a more quantitative way, a brief study was performed as part of another program at Aeronutronic.(3) This study employed a design point case using the Model 3(1) atmosphere, a terminal velocity on parachute of 80 fps, a design impact velocity of 200 fps, a total lander weight of 2150 pounds, an allowable landing impact of approximately 1100 g's, and used the Langley tension shell entry vehicle configuration. The structures were optimized for each case. Carrying the entry body throughout produced a payload of 344 pounds gross weight. The separable system payload weighed 377 pounds, or roughly a 10 percent improvement in payload. While not representing an outstanding improvement, it is sufficient to indicate that a separable landed payload is probably optimum from a performance as well as a functional standpoint and so was adopted for this study.

b. Entry Vehicle Configurations. The objective of this study, as previously stated, was not to devise optimum entry vehicle concepts, but rather to investigate payload/vehicle interface effects. For this purpose, therefore, it was desired to employ those entry vehicle configurations which have received the most development and which are being most seriously considered for Mars missions. Historically, the configuration which has received the greatest amount of study and development, because of its early utilization in the ballistic missile program, is the blunted- or sphere-cone and its derivatives (such as the sphere-cone-cylinder-flare). This configuration, employing large cone angles, is a satisfactory candidate for Martian entry and has been so considered in Mars mission studies.(4) The entry shape having the next greatest amount of historical precedence and design experience is the so-called Apollo shape employed on Mercury, Gemini, and Apollo, and also considered in a number of Mars mission studies.(5,6) One of the more recent attractive candidates for Mars entry, because of its high drag coefficient, C_D, and its potential structural efficiency, is the tension shell concept developed by the NASA Langley Research Center.(2) In addition to these vehicle configurations, there has been much work done on a large number of other Martian entry vehicle concepts. These have included the spherical configuration investigated by the NASA Ames Research Center,(7) the cone-cylinder-flare configuration under study by the NASA Goddard Space Flight Center,(8) the sharp cone and cone-flare designs(9) and blunted half-cone lifting designs(10) studied by Aeronutronic. These concepts, generally, have been investigated for specific missions in which the objective was considerably different than that for the ABL-Voyager class mission, e.g., nonsurvivable atmospheric probes(7,8,9) and manned lifting entry(10) where range and maneuverability during entry were important considerations. The first three configurations discussed appeared to be the most likely and representative candidates, and were therefore selected for use in this analysis. Each of these configurations actually represents a family of shapes according to the proportions selected for the various parameters such as cone angle, nose radius/base radius ratio, etc. Representative near-optimum values for these principal parameters used in this study are given in Figure 6.6-1.

PARAMETER ENTRY VEHICLE CONFIGURATION



Type	Blunted- or Sphere-Cone	Apollo	Tension Shell
R_N/R_b	0.05	2.4	0.05
θ Cone Angle	70°	-	35°
C_D	1.47	1.37	1.60
ψ After-body Angle	40°	40°	-

FIGURE 6.6-1. BASIC ENTRY BODY PARAMETERS

c. Stablization and Attitude Control. The question of entry body static and dynamic aerodynamic stability has an important influence on the resulting lander size and weight. While the shapes described in Figure 6.6-1 exhibit good stability over a wide range of Mach numbers and static margins at low angles of attack,(11,12) they all suffer from instablity at high angles of attack, particularly if the static stability margin (cg-cp relationship) is low. The static stability margin requirement is the factor having the greatest potential influence on the lander vehicle size and payload interface. If large margins are required, the vehicle must grow for a given size of payload. Figure 6.6-2 illustrates this point. One way to permit the use of small static margins on the selected entry vehicles is to employ some form of attitude control on the vehicle to insure that it enters the atmosphere at a low angle of attack and that large angles do not build up during entry. The latter implies some form of damping as well. There are a number of techniques available for accomplishing these objectives. Some of these are briefly described in the following paragraphs.

(1) Spin-Up. The entry vehicle can be oriented by the spacecraft (bus) and spun up about its longitudinal axis at separation. The spin tends to maintain the vehicle orientation, in the absence of external forces, in the direction in which it was set at separation. If this attitude is chosen to correspond to the entry angle attitude, the vehicle will not experience high angles of attack at entry.

(2) Passive Damping. During entry, angle of attack convergence may not be sufficient to attain the required low angle of attack for stability. One method of attaining this is by passive damping. Such devices consist of passive elements and depend upon the energy dissipation of a viscous medium to damp the angle-of-attack oscillations. Such systems have been analyzed(13) for nonspinning entry bodies appropriate for Mars missions. However, passive damping techniques become excessively heavy when payloads in the class of ABL are considered. Alternative techniques employing active damping then must be considered.

(3) Active Damping and Attitude Control. Substitution of active damping for passive damping has been studied(14) at Aeronutronic and shown to be highly effective in reducing the angle-of-attack envelope. Gas jets are employed to oppose the angle-of-attack oscillations and to reduce them to an acceptably low value. Reference 14 demonstrates the use of proportional and on-off active rate control on both spinning and nonspinning entry bodies. Both are feasible for the ABL-class entry vehicle and can be provided for less than 3 percent of the vehicle weight. A similar system, employing suitable sensors, is also capable of maintaining the vehicle initial orientation so that spin-up may not be required. This would simplify many of the lander/bus interfaces and could remove some constraints on payload design which the spin requirement might impose.

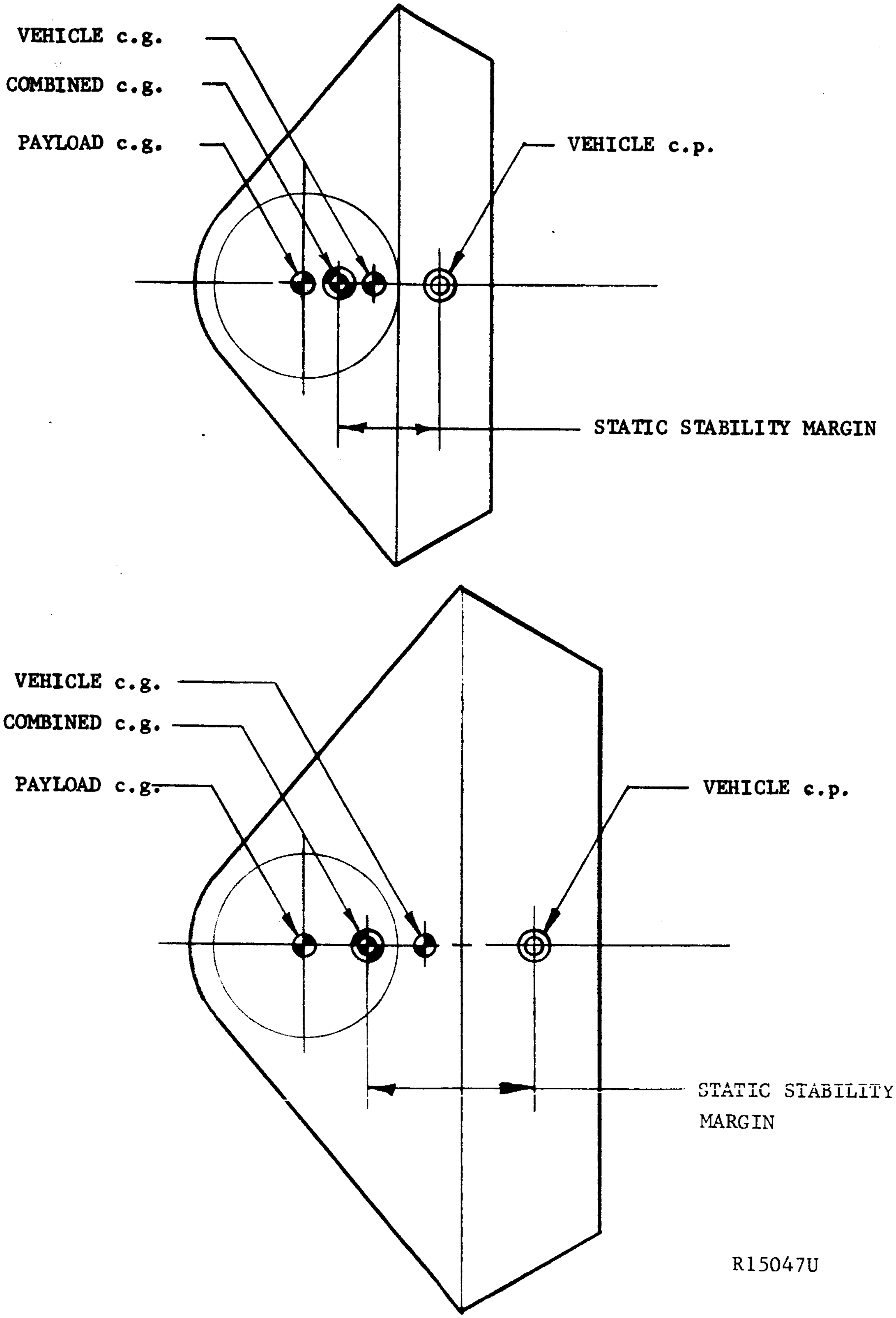


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FIGURE 6.6-2. EFFECT OF STATIC STABILITY MARGIN REQUIREMENTS ON ENTRY VEHICLE SIZE

d. Parachute Technology. The level of technology assumed for the terminal deceleration parachute has an important effect on the entry vehicle because it determines the ballistic coefficient ($\beta = W/C_DA$) required to achieve the parachute deployment velocity at sufficient altitude to permit deceleration before impact. If supersonic parachute deployment is assumed, terminal velocity achievable by the entry vehicle alone can be possibly as high as $M = 4$. If only subsonic parachute technology is assumed, terminal velocity must not exceed $M = 0.9$. Assuming only subsonic parachute technology is, of course, the most conservative approach. It was assumed for one set of conceptual studies. However, it will be shown that in the low density atmosphere, under certain conditions of payload size and weight, entry vehicle technology is not adequate to achieve subsonic speeds before impact, and supersonic deployment is required. Based on this result, a second set of conceptual studies was conducted utilizing supersonic parachute deployment. Supersonic parachute development has progressed far in the past few years, and it is not unrealistic to assume that this approach can be used in the early- to mid-1970's.

e. Wind Drift Cancellation. The largest unknown in the final impact phenomena is the direction of the final velocity vector with respect to the surface. It is possible to predict the vertical component of this velocity with adequate accuracy within the limits of our knowledge of the surface pressure. However, wind drift can add a large unknown horizontal component to this final velocity. The local slope of the surface at point of contact adds still another unknown. If a completely passive landing deceleration system is used, it is necessary to make it nearly orthotropic with respect to the payload in order to adequately protect against the range of variables and the resulting tumbling they are likely to induce. There are techniques for minimizing this variation. Northrop(15) has studied the use of gliding parachutes with $L/D = 2$ and greater which can be employed to cancel all or part of the wind drift (depending on wind velocity and sink rate). This same study also investigates the possibility of a horizontal maneuvering rocket which could be used in connection with gliding parachutes to increase the horizontal velocity cancellation capability. These techniques, of course, require some sensing device to determine the direction of the relative motion over the ground so that correct parachute and/or maneuvering rocket orientation can be achieved. Such a sensing device is currently within the state of the art by either optical or radar techniques. Such an active device represents some risk, but the payoff is substantial in the saving that can be achieved in the terminal landing deceleration system. Conceptual design studies were performed considering the effects both with and without wind drift cancellation and will be discussed in the following paragraphs.

f. Landing Impact Level. The level of landing impact deceleration selected for the final payload touchdown has important ramifications on the payload/lander interface. (A fixed terminal velocity achieved by any combination of parachute) and/or retrorocket near the surface is assumed in this discussion. As the selected terminal impact level increases, of course, payload internal hardening must take place. This frequently results in a smaller net payload volume as parts are miniaturized and compacted to better resist the implied loads. It is interesting to note, however, that this improvement is negligible for payloads in the range of the design point ABL and entry vehicles designed for the low density atmospheres, since vehicle size required to achieve the required ballistic coefficient is adequate to accommodate very low density payloads. (This point is discussed further in Paragraph 6.6.5.)

The more significant effect of the higher impact load level is the decrease in the required stroke of the decelerator. Where a fixed passive orthotropic decelerator is used, the effect on vehicle size becomes particularly apparent. Conceptual design studies were conducted for such a system at two levels of terminal deceleration, approximately 500 g and 1100 g, and the results will be discussed in the following paragraphs.

The question of payload survivability cannot be divorced from the question of landing impact level. The presence of one indispensable item of shock sensitive equipment in the payload is sufficient to outweigh all questions of efficiency of the payload/vehicle system. However, the problem is usually not so unequivocal as this. There are almost always alternative solutions in terms of equipment or constructions that will function as well, but have improved shock resistance. While specific answers can only be obtained after a detailed analysis of a particular payload, Aeronutronic's considerable experience (16,17,18) with high-impact technology tends to give confidence in the possibility of hardening a payload even as complex as ABL. Aeronutronic has developed electrochemical batteries, electronic assemblies (RF transmitters), and other devices to survive 3000-g impacts, and has developed and tested a camera system containing motor-driven, moving, optical elements which have functioned properly after a 4500-g impact. Such technology, because of its emphasis on quality and compactness, often has the additional benefit of producing smaller, better quality equipment with a built-in margin against such things as tumbling on landing. Such high impact levels require additional development effort to produce flight hardware, but such high levels are not necessarily required on ABL. A tradeoff needs to be made in a subsequent study between hardening level and impact limiter, parachute and retrorocket requirements to minimize the size of the payload/lander systems while retaining an adequate safety margin.

g. Form of Terminal Deceleration. The tradeoff just discussed covers means of removing the remaining terminal velocity at touchdown. Studies of such tradeoffs have been made (19) but without the factor of payload hardening considered. However, the object of the present study was not optimization, but a determination of the effects on the resulting payload/vehicle system of the various possible mechanizations. Thus, the conceptual studies reported on have considered both fixed, passive, orthotropic decelerators, and "other" systems. Other systems are lumped here under one case because, from a conceptual vehicle design standpoint, terminal deceleration accomplished by (1) retropropulsion, (2) deployable energy absorbers, or (3) combinations of these, are identical. This is not strictly true, of course, because some efficiency differences exist between these various methods. However, for determining interface influences between payload and entry vehicle, the difference is inconsequential; all three require insignificant volume in comparison to the fixed deceleration, and the weight differences between approaches is small compared to the total system weight. This relationship will be shown in the following conceptual designs.

6.6.4 CONCEPTUAL DESIGN STUDIES

Conceptual design studies were conducted to determine the effect of the foregoing systems considerations on the payload/entry vehicle systems. The principal system parameters just discussed could be lumped into the effective parameters listed in Table 6.6-I for purposes of these studies.

TABLE 6.6-I

PARAMETERS FOR CONCEPTUAL DESIGN STUDIES

Parameter	Values Used In Study
1. Parachute Deployment Velocity	Subsonic Mach 0.9 Supersonic Mach 2.5
2. Required Entry Vehicle Ballistic Coefficient β (in the 14-mb Atmosphere)	Subsonic β = 7.5 lb/ft^2 Supersonic β = 10.0 lb/ft^2
3. Landing Impact Level	500 g 1100 g
4. Landing Decelerator Type	Fixed Orthotropic Other (See Paragraph 6.6.3 g)

The initial objective was to determine the influence of the payload on the entry vehicle system under the most conservative selected conditions of the foregoing parameters. Thus, the study began by assuming subsonic parachute deployment requiring a β of 7.5 lb/ft^2, and a fixed orthotropic decelerator adequate for providing the lower 500-g terminal impact deceleration. An attempt was made to synthesize the three selected vehicle types (Figure 6.6-1) for these conditions. Parametric results from other Aeronutronic studies in the area of structural weight factors, heatshield requirements, parachute sizes and weights, and other elements making up the selected configurations were employed to obtain representative near-optimum solutions under each set of conditions. The results are given in Figure 6.6-3. No solution was found for the case of the blunted cone; the vehicle size increase to achieve the required ballistic coefficient resulted in an accompanying weight increase that increased, rather than decreased, the ballistic coefficient. Thus, no solution was obtained. Solutions were obtained for the Apollo and tension shell designs as indicated. It will be noted, however, that these solutions exceed the Saturn Ib booster shroud limits, so that while feasible entry vehicles are possible, they probably do not represent real solutions.

The results from this set of parameters indicated a need to try other approaches to attain the required low β. This was done in a stepwise fashion, first by increasing landing impact deceleration to 1100 g in order to reduce the size of the entry vehicle by reducing both weight and size of the decelerator. In this case, solutions were again found for the Apollo and tension shell designs, as shown in Figure 6.6.4, but still no solution was found for the blunted cone. The solutions are seen to still exceed the nominal Saturn Ib payload shroud limits and consequently are again probably not valid solutions.

In order to obtain satisfactory solutions in all three cases, the parameter combination of supersonic parachute deployment ($\beta =$ 10 lb/ft^2) and the higher impact limit of 1100 g were subsequently selected, but the fixed orthotropic decelerator system was retained. Solutions were found for this case, and the resulting configurations are shown in Figure 6.6-5.

A fourth combination of parameters was finally selected, employing subsonic parachute deployment and no fixed limiter. The best solutions, in terms of total payload/lander size and weight, were obtained by this combination. The resulting conceptual designs are compared in Figure 6.6-6.

All of the foregoing conceptual designs are listed and compared in Figure 6.6-7.

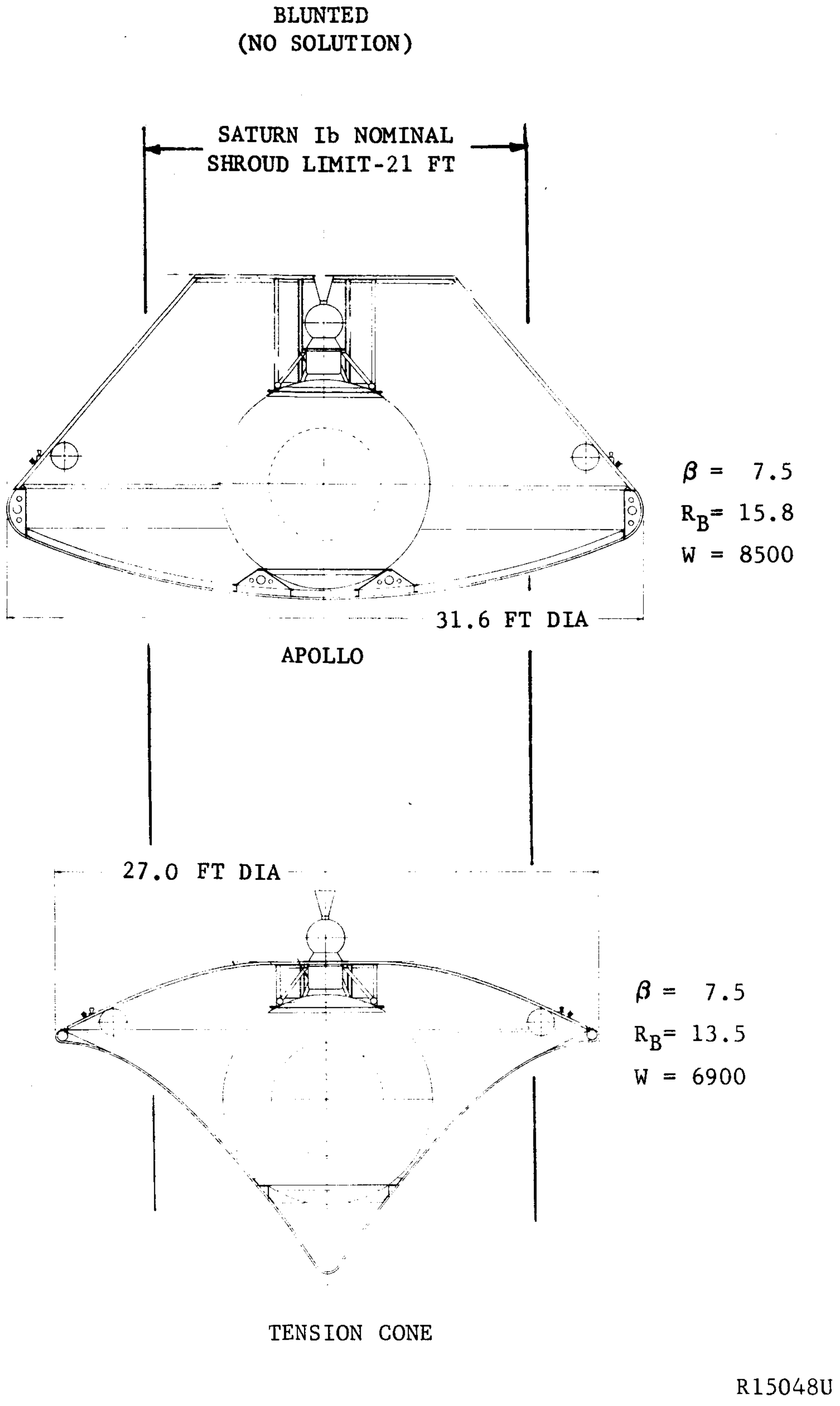


FIGURE 6.6-3 CONCEPTUAL ENTRY VEHICLE DESIGN FOR SUBSONIC PARACHUTE DEPLOYMENT, 500-g IMPACT AND FIXED ORTHOTROPICAL DECELERATOR

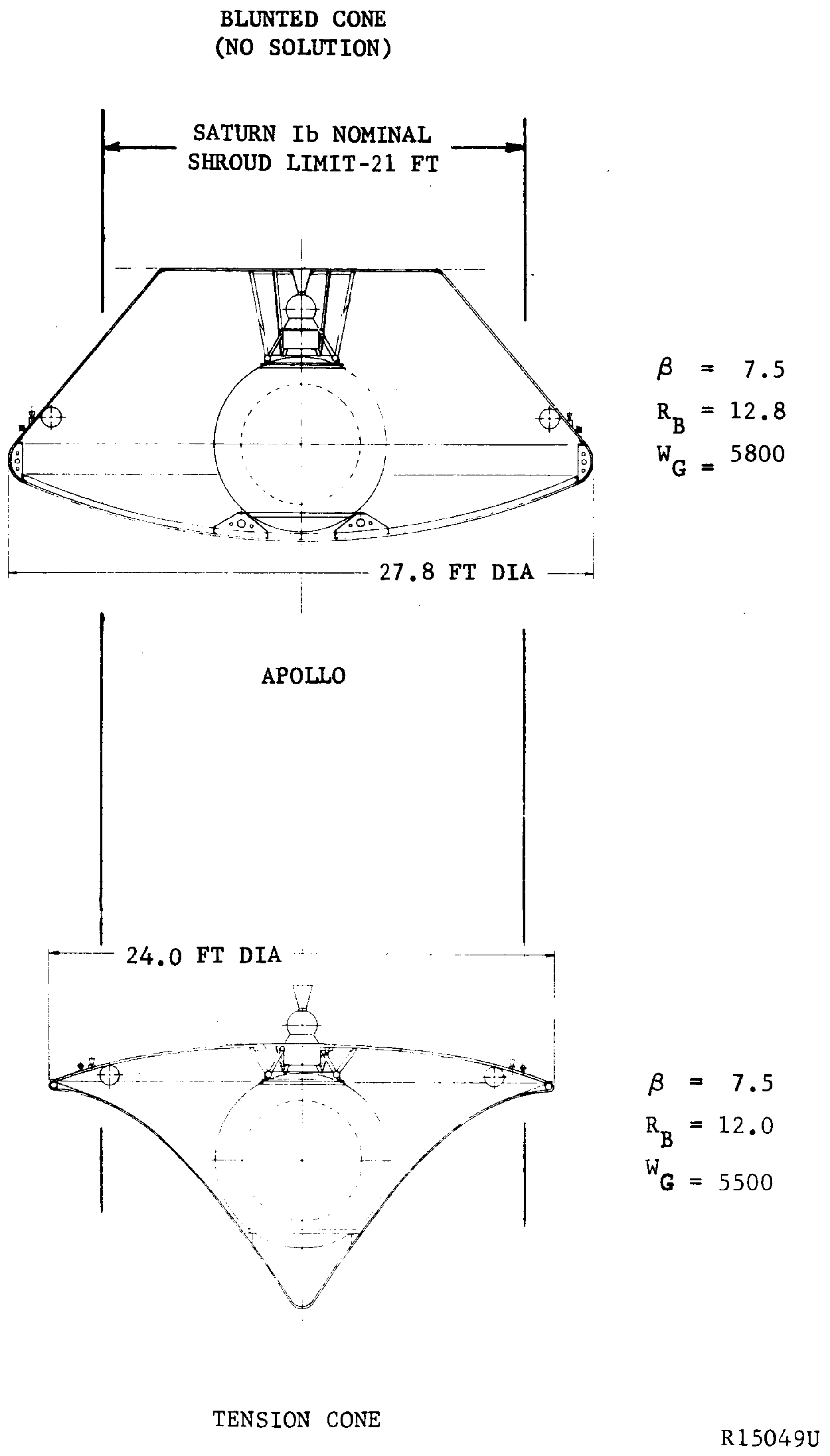


FIGURE 6.6-4 CONCEPTUAL ENTRY VEHICLE DESIGN FOR SUBSONIC PARACHUTE DEPLOYMENT, 1100-g IMPACT AND FIXED ORTHOTROPIC DECELERATOR

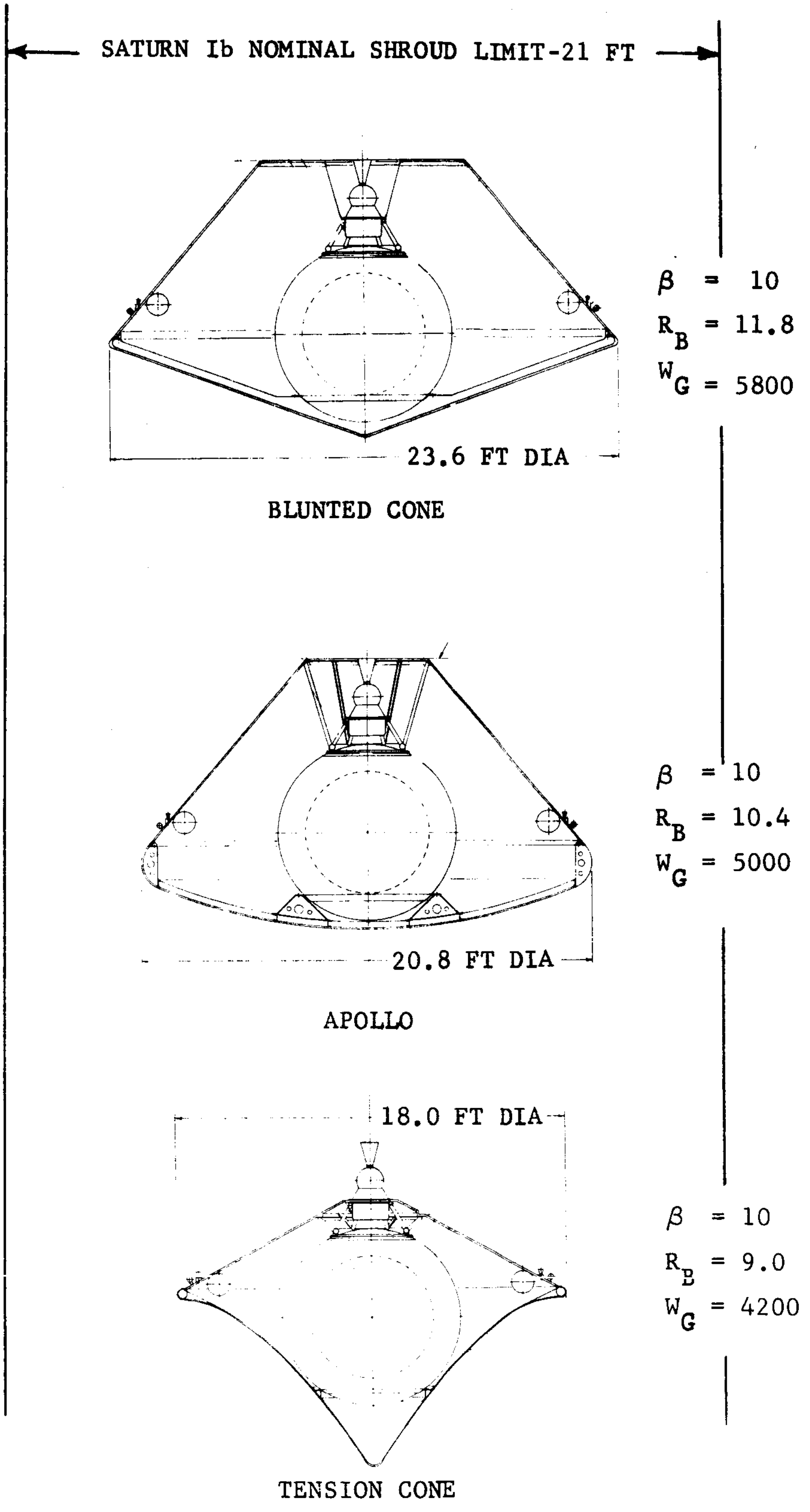


FIGURE 6.6-5 CONCEPTUAL ENTRY VEHICLE DESIGN FOR SUPERSONIC PARACHUTE DEPLOYMENT, 1100-g IMPACT AND FIXED ORTHOTROPIC DECELERATION

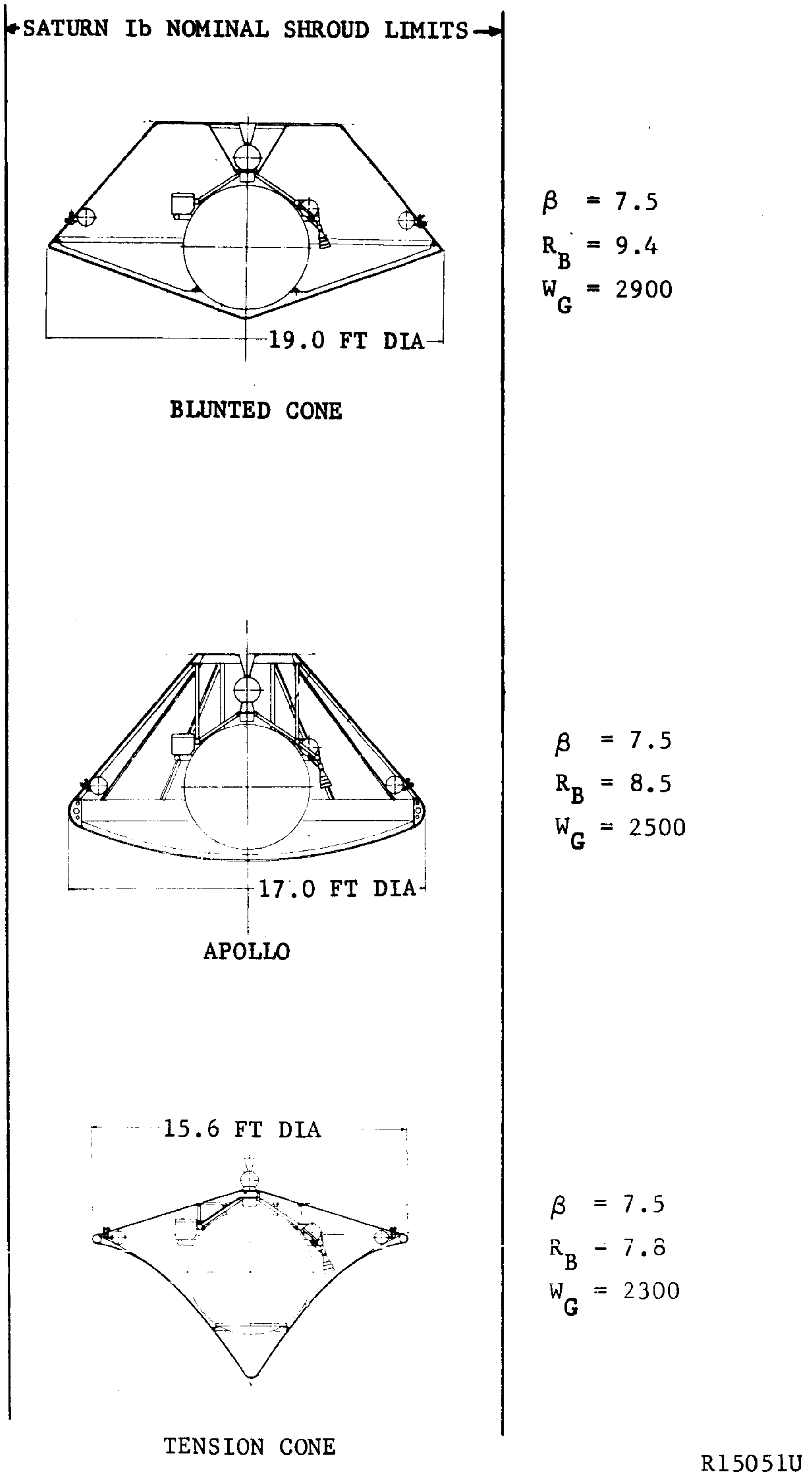


FIGURE 6.6-6 CONCEPTUAL ENTRY VEHICLE DESIGNS FOR SUBSONIC PARACHUTE DEPLOYMENT AND NON-FIXED TERMINAL DECELERATION

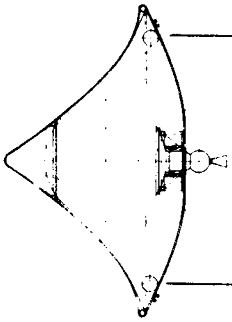
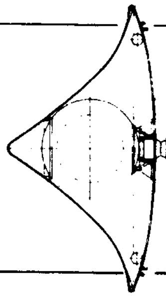
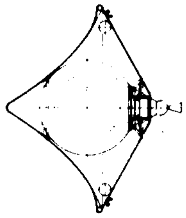
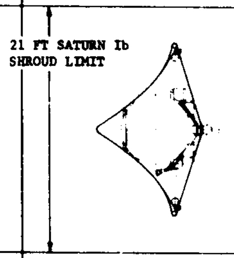
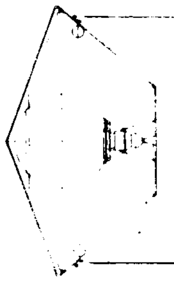
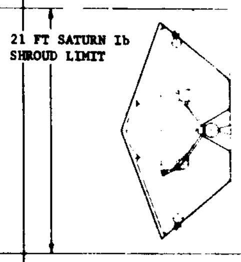
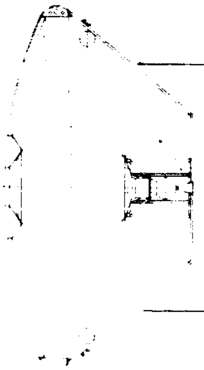
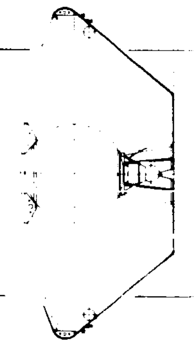
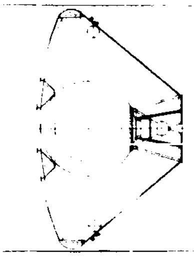
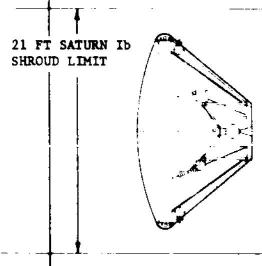
SHAPE	SUBSONIC CHUTE 500g LIMITER β=7.5	SUBSONIC CHUTE 1100g LIMITER β=7.5	SUPERSONIC CHUTE 1100g LIMITER β=10	SUBSONIC CHUTE RETRO-ROCKET β=7.5
PAYLOAD	W=2900 R= 5.25	W=2500 R= 4.1	W=2610 R= 4.1	W=1250 R= 3.0
TENSION CONE	W= 6900 R= 13.5 $W_{PL}/W=$ .420 	W= 5500 R= 12.0 $W_{PL}/W=$ .455 	W= 4200 R= 9.0 $W_{PL}/W=$ .620 	W= 2300 R= 7.8 $W_{PL}/=$ .545  21 FT SATURN Ib SHROUD LIMIT
70% CONE	NO SLOUTION	NO SOLUTION	W= 5800 R= 11.8 $W_{PL}/W=$ .450 	W= 2900 R= 9.4 $W_{PL}/W=$ .432  21 FT SATURN Ib SHROUD LIMIT
APOLLO	W= 8500 R= 15.8 $W_{PL}/W=$ .342 	W= 5800 R= 12.8 $W_{PL}/W=$ .431 	W= 5000 R= 10.4 $W_{PL}/W=$ .520 	W= 2500 R= 8.5 $W_{PL}/W=$ .50  21 FT SATURN Ib SHROUD LIMIT

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FIGURE 6.6-7 COMPARISON OF CONCEPTUAL ENTRY VEHICLE DESIGNS

6.6.5 SUMMARY OF PRINCIPAL PAYLOAD/ENTRY VEHICLE INTERFACES

From the results of the parametric conceptual design studies covered in the previous paragraphs, it is possible to draw significant conclusions with regard to the effect of ABL-class payloads on the entry vehicle and the important interfaces between the two. The principal ones will be discussed.

a. Functional Interfaces

(1) Payload/Vehicle Physical Interface. The discussion of Paragraph 5.3 regarding functional integration of the total payload elements and the analysis of Reference 3 discussed previously in Paragraph 6.6.3a leads to the conclusion that a payload mechanization physically and functionally separable from the entry vehicle is optimum from both the performance and vehicle system design, development, and management standpoint. It is felt that this is a significant conclusion reached in this study.

(2) Payload Hardness. For systems employing fixed orthotropic decelerators, payload hardness (i.e., allowable level of impact) has an important effect on the total payload/vehicle system, as shown in Figure 6.6-7. In some cases (compare results in Figures 6.6-3 and 6.6-4), the difference in level of hardness can be seen to have a significant effect on resulting vehicle size and weight. If other than fixed orthotropic decelerators are employed (Figure 6.6-6) the question of payload hardness, within the limits of this study, is not important. In actual fact, detailed differences will exist in the payload-to-gross-weight ratios attainable with various combinations of retropropulsion and non-fixed orthotropic decelerators as a function of payload hardness. Such a study should be made when more detailed knowledge of the payload is available. Variations that will affect the overall attainable payload ratio are expected to be nominal, however.

(3) Payload Size and Density. In the cases shown on Figure 6.6-6, no improvement would be experienced by a reduction in the payload size (or density) at the fixed payload weight, since all factors considered were independent of these parameters. This fact, as well as the greater ease of incorporation into the entry vehicle, would argue strongly for this approach when large or low-density payloads are considered.

When fixed orthotropic decelerators are employed, payload density has an effect on the size, and therefore the weight, of the decelerator, thereby affecting the size of the entry body required to achieve a given β. Some reduction in parachute weight also contributes to this effect. Consider the case for the tension cone body in Figure 6.6-4. The design point case payload density is 10.6 lb/ft^3 and has a total weight of 1000 pounds. Table 6.6-II shows the improvement possible with increased payload density. The effect is seen to be significant for this case employing a fixed orthotropic decelerator.

TABLE 6.6-II

EFFECT OF PAYLOAD DENSITY ON TOTAL ENTRY SYSTEM
(Based on the Tension Cone Design from Figure 6.6-4)

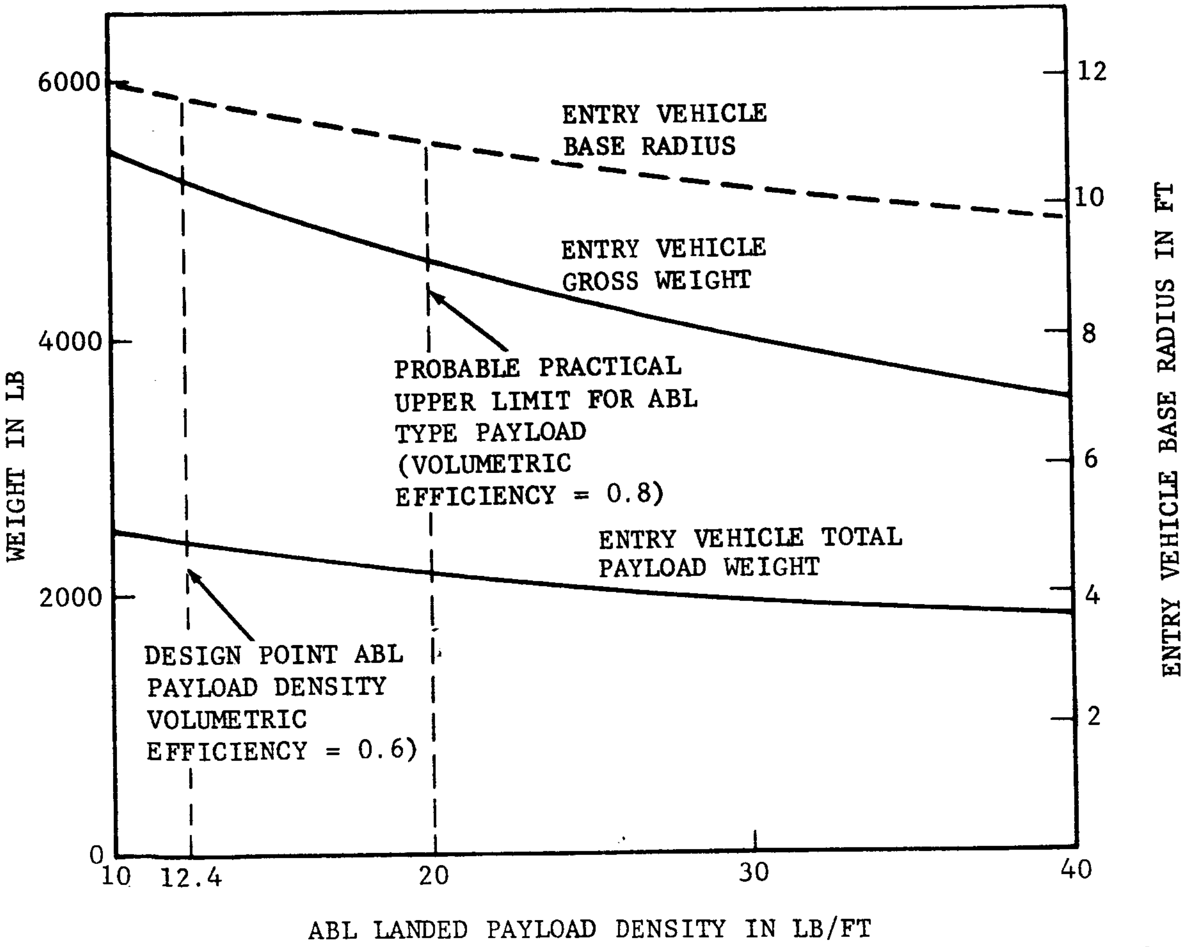
Payload Density (lb/ft^3)	Entry Vehicle Payload Weight (lb)	Entry System Gross Weight (lb)	Entry Vehicle Base Radius (ft)
10.6	2500	5500	12.0
20.0	2200	4600	11.0
40.0	1800	3500	9.7

The indicated four-fold range in density is a significant improvement and the 20 lb/ft^3 valve is probably a more practical limit. These relationships are shown in Figure 6.6-8. Further study is warranted, however, if the fixed decelerator approach is employed.

(4) Effect of Entry Vehicle Performance on Payload Ratio. The interface between the scientific payload and the entry vehicle performance is clearly shown in Figure 6.6-7 by the listed payload ratios ($W_{scientific\ payload}/W_{gross}$). The effect of the high C_D combined with good structural efficiency in the tension cone case is apparent. The attainable scientific payload ratios over the range of vehicle types and parameters selected run from 0.12 to 0.44 and the entry vehicle payload ratios from 0.34 to 0.62. Thus, the selection of efficient entry vehicle concepts is important in maximizing the weight of payload delivered to the surface, and development effort expended toward perfecting attractive approaches appears worthwhile.

b. Mechanical and Electrical Interfaces. If the separable payload concept discussed in the previous paragraph is used, the usual mechanical and electrical interfaces between the payload and the entry vehicle can be kept to an absolute minimum (one of the important reasons for its selection, of course). However, even in this case, at least two important interfaces remain to be considered, beyond the basic mechanical connection securing the two together, and which must allow for their separation at the appropriate velocity and altitude.

(1) Entry Experiments. It will undoubtedly be desirable to instrument the entry vehicle for at least engineering measurements, if not



BASED ON FIXED ORTHOTROPIC LANDING DECELERATOR 1100 g IMPACT, SUBSONIC PARACHUTE DEPLOYMENT AND TENSION SHELL ENTRY BODY DESIGN, 14 MILLIBARS ATMOSPHERE

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FIGURE 6.6-8. EFFECTS OF PAYLOAD PACKAGING DENSITY scientific ones. Such experiments were beyond the scope of the ABL study so no experiment complement has been identified for this purpose. However, it is possible to identify the critical interfaces even without such an experiment complement. These are discussed in the following paragraphs.

(a) Electrical Power. The entry experiments will undoubtedly be mounted physically on the entry body. Rather than providing an electrical power connection to the payload RTG, a separable battery power supply for these experiments appears warranted. This conclusion might have to be modified according to the method of handling the data from these experiments.

(b) Data Handling. If the decision is made to transmit the results of the entry experiments to the bus during entry, an entry vehicle mounted antenna system is required, and the transmitter power could be significantly high so that power sources, suitable for the purpose, become a problem. Alternatively (or in addition), the data could be read into the ABL for transmission after landing, creating an interface at that point. Pull-away connectors have been developed which are probably satisfactory, or a short range RF link could be provided with the ABL, at greater complexity but eliminating the mechanical interface.

(2) Thermal Control. The thermal control requirements of the ABL during each phase of the mission are discussed in detail in Paragraph 6.5 of this report. The principal payload/entry vehicle interface resulting from these requirements is for two pair of fluid transfer lines between the ABL payload and an entry vehicle mounted radiator. For details of the requirements for these items, see Paragraph 6.5.

6.6.6 REFERENCES

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SECTION 7

LANDING SITE SELECTION STUDIES

7.1 LANDING SITE DESIRABILITY

7.1.1 GENERAL

The surface skin and atmospheric environments of Mars have been defined within broad ranges by the application of universal laws of physics, direct astronomical observations, planetary probes, laboratory experiments, terrestrial analogy, theories of recognized planetary authorities, and by a priori reasoning. The representative values for environmental parameters that are ecologically important demonstrate that the planet Mars lies well within the boundary of Strughold's(1) "ecosphere." In order to test the ability of organisms to survive and/or grow in an environment similar to that deduced for Mars, it becomes apparent that a search for extreme terrestrial biotic conditions is warrented and laboratory simulation experiments to define ecological minima are necessitated. Table 7-I lists some of the environmental extremes under which certain types of primitive organisms have survived in controlled laboratory test conditions and some extreme terrestrial conditions to which both primitive and higher orders of organisms have adapted. These brief data serve to illustrate the great range of ecological tolerance of living organisms and to demonstrate the following factors:

(1) Several species of primitive terrestrial organisms can adapt to growth in a Martian environment simulated per the current state of knowledge of the atmospheric composition and pressure, surface skin temperatures, and under conditions of extreme freeze-thaw cycling.

TABLE 7-I

ENVIRONMENTAL EXTREMES FOR THE SURVIVAL AND GROWTH OF PRIMITIVE ORGANISMS

Survival of Bacteria, Fungi, and/or Algae under Laboratory Test Conditions

Factor	Extreme Condition
Gases	80% CO, H_2, N_2, CO_2 Atmospheres
Radiation	10^6 roentgens, gamma rays
Solutes	Concentrated $CuSO_4$; 40% citric acid; 1g phenol/liter
Temperature	5 hours at 140°C; absolute zero
Vacuum	5 days at 10^{-9} mm Hg

Growth of Bacteria and/or Fungi under Extreme Terrestrial Conditions

Factor	Lower Limit	Upper Limit
Hydrostatic pressure	Essentially zero	1400 atmospheres
pH	Zero	13
Salinity	Double distilled H_2O	Supersaturated brines
Temperature	-18°C	104°C
Total environment	Ocean bottoms	Top of Mt. Everest

After Young, Richard S., "Survial and Growth of Organisms in Simulated Planetary Environments - A Review of 'Martian Biology'," Exobiology Lecture, University of California, 1964.

(2) The two most critical parameters essential to organic survival and reproduction appear to be the existence of water and tolerable temperatures.

The first factor is being investigated by a number of workers.(2,3) Studies of the origin of life(4) have contributed to an evaluation of the importance of temperature and liquid water.

The overall purpose of the analysis described in this section was to examine the characteristics of the Mars surface over a broad range of parameters in order to define landing sites in terms of potentially desirable thermal and liquid water ecology zones. These parameters are defined within the range of values denoted by Table 7-II, Basic Geophysical* Parameters of Mars; Table 7-III, Ranges and Representative Values for Atmospheric Parameters of Mars; and Table 7-IV, Observed Astronomical Factors on Mars.

7.1.2 THERMAL ECOLOGY ZONES ON MARS

a. Surface Skin Temperatures. Many thousands of radiometric measurements of the surface skin of Mars have been recorded and reduced to useable and conformable temperature data. The reduced values of temperatures reported for Mars vary through a wide range as to be expected because of variations in methods of measurement and data reduction, latitude, diurnal time, cloud cover, surface topography, the orbital position of Mars, the influence of bright versus dark areas, and the effect of many more minor factors. The absolute upper and lower temperature limits reported in the responsible literature are +45°C and -125°C, respectively. Figure 7-1, modified after Vaucouleurs(5) presents annual variations in the mean surface skin temperatures of Mars at various latitudes, seasons, and at perihelion and aphelion. Minimum temperatures occur at sunrise and the maximum near noon. The maximum temperature shows a lag, varying with the investigator, of from 15 minutes to 1.5 hours. The diurnal range of Martian temperatures is denoted in Figure 7-2 for a midsummer equatorial day or low latitude subsolar point. The temperatures quoted for the Mars surface are herein termed surface skin temperatures to prevent confusion with standard meteorological temperatures reported for the Earth. The latter are obtained in meteorological shelters and represent air temperatures at elevations at least 2 meters above the surface. Mars surface skin measurements are properly compared to surface skin temperatures recorded for terrestrial deserts, e.g., the 45°C maximum equatorial noon lag temperature recorded for Mars is comparable to a 75°C

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*The correct terminologies for studies of the composition, structure, and physics of Mars are areology and areophysics; however, familiar usage warrants the continued use of geology and geophysics and their many derivatives.

TABLE 7-II

BASIC GEOPHYSICAL PARAMETERS OF MARS

Parameter	Lower Limit	Representative Value	Upper Limit
1. Mass (gm)	6.34×10^{26}	6.433×10^{26}	6.46×10^{26}
2. Density (gm/cm^3)	3.75	3.97	4.25
3. Surface gravity (gal or cm/sec^2)	358	372	392
4. Velocity of escape (km/sec)	4.95	5.02	5.10
5. Solar radiation (cal/min-cm^2)	0.710 (aphelion)	0.840 (mean)	1.02 (perihelion)
6. Physical shape parameters:			
Equatorial radius (km)	3,320	3,388	3,450
Mean radius (km)		3,382	
Dynamical ellipticity (ϵ_d)		0.005209	
Optical ellipticity (ϵ_o)		0.013	
Clairaut's constant for ϵ_d		1.145	
Clairaut's constant for ϵ_o		2.86	
Height of equatorial bulge (km)		26.4	
7. Pertinent orbital characteristics:			
Period of axial rotation	$24^h37^m22.1^s$	$24^h37^m22.67^s$	$24^h37^m22.8^s$
Sidereal period (earth days)		686.96	
Length of seasons (earth days):			

Northern	Southern	Earth Days
Spring	Autumn	199
Summer	Winter	182
Autumn	Spring	146
Winter	Summer	160

Inclination of equator from orbital plane 25^o

TABLE 7-III

RANGES AND REPRESENTATIVE VALUES FOR ATMOSPHERIC PARAMETERS OF MARS

Factor or Assumption		Lower Limit	Representative Value	Upper Limit
Atmospheric factors:				
Composition (% by volume)				
N_2 mol wt	28	65	94	99
A	40	0.5	4	20
CO_2	44	0.3	2	15
O_2	32	0.01	0.05	0.15
H_2O	18		0.004	
Ne	20	probable trace	0.002	
Xe	131			
Kr	84			
Rn	222			
O_3	48	possible trace	0.001	
SO_2	64			
N_2O	44			
CH_4	16			
C_2H_6	30			
NH_3	17			
H_2	2	total escape	escaping	trace
He	4			
Molecular weight		28.1	28.8	32.8
Surface pressure (mb)				
Equatorial elevation		11	30	45
Mean			65	
Polar elevation		47	129	194
Adiabatic lapse rate (°K/Km)		-3.714	-3.720	-3.790
Near surface temperature: (°C at 2m above surface)				
Equatorial maximum (noon lag)			-23°	+27°
Equatorial minimum (sunrise)			-68°	
Polar maximum			-46°	
Polar minimum		-93°		

TABLE 7-IV

OBSERVED ASTRONOMICAL FACTORS

Factor	Lower Limit	Representative Value	Upper Limit
1. Resolution (maximum)			
a. Optical (in, km)			
Linear			28
Circular			85
b. Photographic (km)			
Linear			42
Circular			127
2. Albedo			
a. Bright areas	0.150	0.200	0.300
b. Dark areas	0.050	0.080	0.097
c. Mean	0.145	0.150	0.154
3. Surface skin temperatures (°C)			
a. Equator, bright areas			
Sunrise	-48°		-30°
Noon lag	-15°		+25°
Sunset	-30°		+5°
b. Equator, dark areas			
Sunrise	-65°		-50°
Noon lag	-5°		+43°
Sunset	-50°		-18°
c. Latitude 25°, bright areas			
Sunrise	-50°		-35°
Noon lag	-40°		+10°
Sunset	-50°		-10°
d. Latitude 25°, dark areas			
Sunrise	-60°		-25°
Noon lag	-15°		+30°
Sunset	-60°		0°
4. Wind Velocity, frontal movement (km/hr)			
Peak	45	60	90
Average	8	10	18
Gusts, frontal or cyclonic	90	100	200
5. Yellow cloud data			
Height in atmosphere (km)	5	7	30
Velocity of frontal movement (km/hr)	8	10	90
Duration as a finite cloud (days)	1	7	35

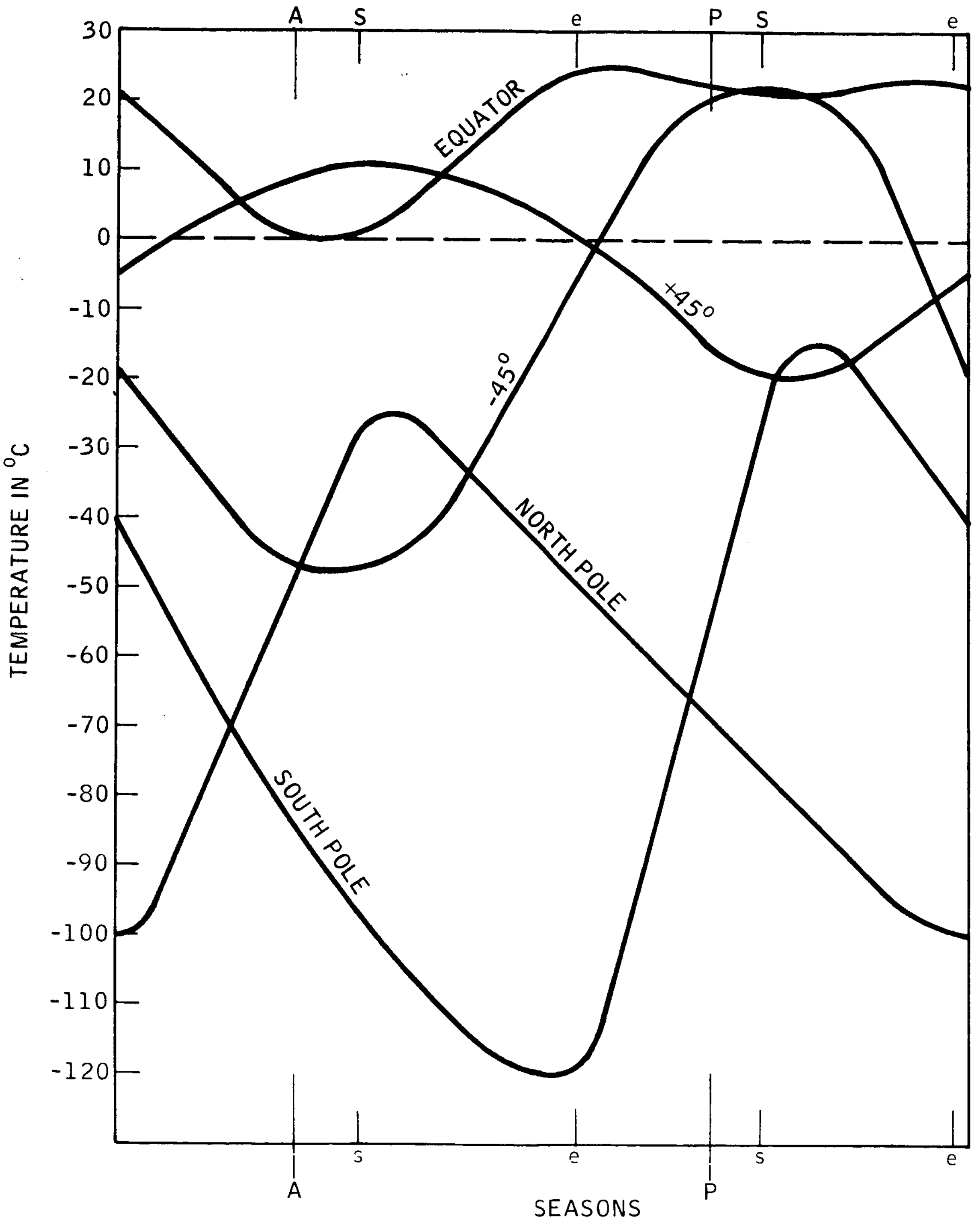

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FIGURE 7-1. ANNUAL VARIATIONS OF THE MEAN SURFACE TEMPERATURES OF MARS AT VARIOUS LATITUDES

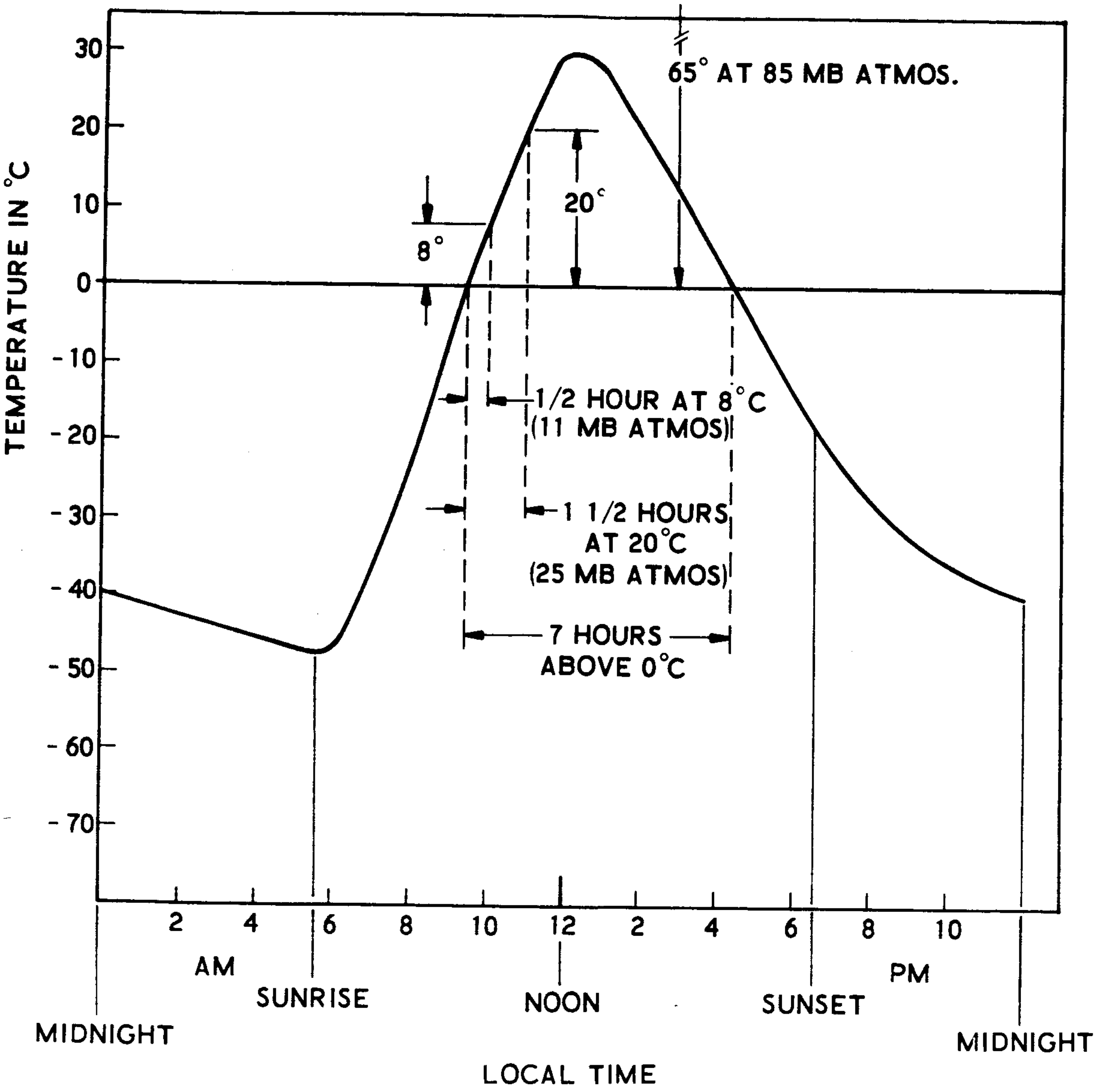

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FIGURE 7-2. DIURNAL TEMPERATURE RANGE AT THE MARTIAN EQUATOR OR LOW LATITUDE SUBSOLAR POINT temperature measured on the surface of a terrestrial tradewind desert. On Mars, there is also a temperature differential between dark areas and bright areas. Vaucouleurs(5) and Sinton(6) have analyzed this difference both theoretically and radiometrically. For a minimum difference in albedo of 0.10 (for noon lag equatorial temperatures), the computed difference for a gray body is 9°C; for a mean difference of 0.15 under the same conditions, it is 12.7°C. Sinton has determined that the temperature differential between light and dark areas in equatorial regions is directly proportional to albedo differences and at a maximum is 8°C. The weighted mean of the maximum values expressed in the literature is 13.8°, therefore, all of the quoted values reasonably agree and demonstrate that the maximum local temperature difference between near equatorial bright and dark areas is 10.8°C, while the average is slightly less than 8°C. This factor is important to the overall temperature regime of the planet. Where there is a concentration of dark areas, the regional surface temperature will tend to be higher than that for regions containing a minimum number or a complete lack of dark areas. The existence of equatorial and low latitude thermal highs and lows are related to slit resolution and, therefore, will represent respectively, an average measurement for the dark areas plus bright areas versus that for bright areas alone.

The most complete and best displayed temperature data assembled for Mars are those developed by Gifford.(7) These data are presented in the form of seasonal isotherm maps of the Mars surface. The temperature values from which the isotherms were drawn were obtained from Gifford's reduction of 1300 radiometric observations made by Lampland during oppositions from 1926 to 1943. The surface resolution of these measurements varied from 500 to 850 kilometers at favorable oppositions to the relatively useless figure of 3400 kilometers at the least favorable. Gifford's maps should not be construed to represent the absolute surface skin temperatures obtained at any specific point in any area less in size than the minimum slit resolution. Rather, they represent variations in the average thermal regime of the surface over large increments of latitude and longitude.

b. Thermal Ecology Concept. An analysis of the thermal regime within which organisms can grow or survive led to the concept of defining thermal ecology zones for Mars. Figure 7-3 demonstrates the geographical limits for these zones in terms of the surface skin temperatures deduced by Gifford(7) and subject to the resolution limit discussed previously. The zones are defined as follows:

(1) Growth Zone. An area on the surface of Mars where the surface skin temperature remains above 0°C for from 2 to 7 (theoretical maximum) hours per day per one season per year, where one season is represented by 160 to 180 Earth days.

(2) Survival Zone. That area where the surface temperature remains above 0°C less than 2 hours per day per one season per year.

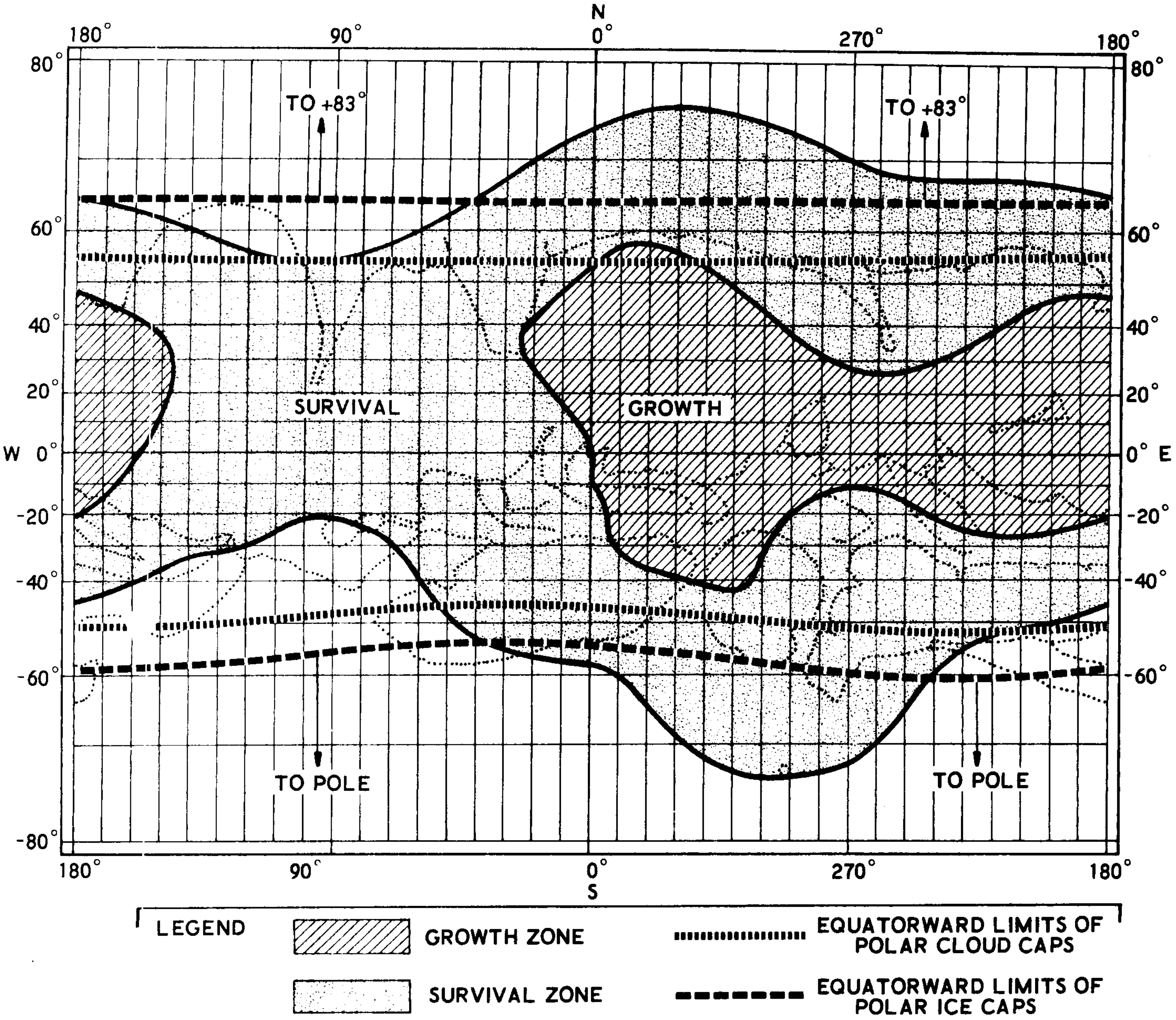

FIGURE 7-3. MARS THERMAL ECOLOGY ZONES

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(3) Subzero (^{o}C) Zone. Figure 7-3 was constructed from the isotherm maps representing the surface temperatures for the extreme seasons, northern and southern hemisphere winter and summer, in order to define the overall area included within the maximum extent of the 0^{o}C isotherm during the course of a Martian year. The limiting time value of two hours per day for one season above 0^{o}C chosen for the separation between growth and survival zones was based on the work of Young et al,(2) who experimented with the growth and survivability of organisms related to freeze-thaw cycles. Under freeze-thaw cycling conditions ranging from +25^{o}C to -70^{o}C wherein 4-1/2 hours per 24 hour day were actually spent above 0^{o}C, several organisms (cultivated under simulated moisture-rich microenvironment conditions) exhibited growth. Young(3) has also described an experiment where the thaw cycle was reduced to 15 minutes per day above freezing. This extreme condition did not inhibit the growth of the facultative anaerobe Aerobacter aerogenes. As a result, it was concluded that the possibility of certain organisms adapting to growth in an extreme freeze-thaw cycle condition was highly likely but that a flourishing multispecies population would probably be encountered only in a less extreme environment. A mean time of two hours was, therefore, arbitrarily selected as a realistic limiting thaw time separating the growth and survival zones.

The resulting growth zone is depicted in Figure 7-3 as an incomplete band spanning the Martian equator from approximately +45^{o} to -30^{o} of latitude. It is truncated between longitudes 20 to 150 degrees. This discontinuity is related to a thermal low created by a general lack of dark areas. Conversely, the prominent poleward bulges in the growth zone are a function of summertime isothermal closures (highs) and a seasonal temperature lag which projects the minimum temperatures into the equinox seasons rather than occurring at the time of the winter solstice as shown in Figure 7-1.

7.1.3 SURFACE MOISTURE, PERMAFROST, AND GROUND WATER ON MARS

a. General. The existence of water on or adjacent to the surface of Mars is a second critical parameter for the origin and development of life on the planet. Water is known to occur on the surface of Mars in the form of polar cap ice deposits and within the atmosphere as vapor and cloud particles. It is believed to be the causitive agent for morning limb whitening phenomena and transient bright area dark patches that follow the passage of some white clouds. It is suspected that the dark fringe that retreats with the subliming ice caps, and possibly the general waves of darkening, are water-related phenomena. These effects all appear to be rather precisely latitudinally controlled. The wave of darkening is the only phenomenon that can be traced to, and across, the equator. The reasons for geographic restrictions to the presence of surface skin water and a theoretical restriction to the presence of subsurface water are discussed below.

b. Geological Background. A measure of geological background is necessary to introduce a series of new concepts upon which the existence of permafrost and ground water in this analysis is based. These geological concepts, discussed in detail in Reference (8) and Appendix 16, Volume VI, are briefly outlined in Table 7-V. The following paragraphs amplify significant features which bear on the water problem.

The internal and surface structures of Mars are directly associated with the figure of the planet. Two values can be determined for Mars, a dynamical ellipticity figure, 0.005209, and an optical ellipticity value of 0.013. The former is analytically determined from the perturbations of the natural Martian satellites. The optical ellipticity has been measured by several methods including filar micrometer and surface spot geometry. If it is assumed that the optical oblateness represents the true physical shape of the planet, then a differentiated crust concept will obtain and a degree of tectonic activity can be inferred. Albedo differences, localized atmospheric phenomena, and the seasonal effects observed on Mars agree more favorably with the concept of large differences in elevation than with a featureless, base-leveled surface of dynamical ellipticity. However, the surface of Mars has to be relatively smooth, for any abrupt isolated mountain mass over two kilometers in height would have been observed as a shadow changing dimensions with phase angle or as a projection on the planetary disk. This condition is also consistent with the early interpretations of the Mariner IV photo data just completed.

Assuming, for the above reasons, that a significant measure of smoothly sloping surface elevation differences exist on the planet Mars, it is of interest to determine how this relief is distributed. If the crust of Mars is homogeneous and yet conforms to the surface of optical ellipticity, then the dynamical ellipticity figure will be incorrect or the surface of the planet will be remarkably unstable. However, since the latter figure is based on perturbations of the Martian moons, it cannot vary to this required degree. In order for the values of these figures to be compatible, it is necessary for the purpose of this explanation to represent the dynamical ellipticity figure as the surface of the Mars geoid (the surface of equal gravity potential). Superimposed on the geoid will be a wedge of crustal material, thick and light at the equator and thin and heavy at the poles. Furthermore, the wedge should smoothly taper from the equator to the poles. Figure 7-4 denotes the manner in which this can be geologically accomplished.

In Figure 7-4, Mars is represented as an Earth-type planet with a high degree of internal differentiation compared to the Moon but far less than the degree required to develop a large liquid Fe-Ni core. The Mars crust is separated from the mantle by a density discontinuity, and the crust above this discontinuity is denoted by three progressively thinner and heavier units. The units, in turn, are identified with permanent

TABLE 7-V

GEOLOGICAL CONCEPTS

Factor	Concept
1. Internal structure	Optical ellipticity value represents topographic shape of the surface. Isosatic compensation is achieved by thickness variations in the crust. Compensation is obtained by abrupt discontinuities at base of crust. Asymmetrical crustal wedging is maintained by: a. Structural ramps, tectonically differentiated into bolsons b. Loess deposits
2. Surface structure	Near-equatorial craton or mobile diastrophic belt. Low to moderate latitude, asymmetrical, taphrogenic structural ramps. Polar basins.
3. Topography	Near-equatorial east-west highland belt of dark area plateaus and plains. Asymmetrical belts of consecutively lower bolson basins. Polar basins.
4. Surface composition	Craton or mobile diastrophic belt may be composed of sub-diorite phase: a. Differentiated hypabyssal, migmatitic or primary plutonic rocks. b. High grade migmatitic to low grade diastrophic metamorphic rocks. c. Plateau basalts. d. Intermontane sedimentary-filled basins. Asymmetrical ramp belts are covered by: a. Dune-veneered bolsons structurally defined by linear to serrated tectonic or rounded impact-rim divides; other linear features may be related to dune chains, desert pavements, dikes or possibly crater rays. Polar dust sinks are basins of loess deposition.
5. Erosion and sedimentation	Highland dark areas are plateaus and high plains of constant deflation. Bolsons are basins containing well-winnowed sand deposits. Polar basins are dust sinks.
6. Moisture	Surface liquid phase waters are essentially nonexistent: Wholly related to short-lived, surface skin moisture films. Subsurface waters are tied up in polar basin permafrost deposits. Escape of water necessitates constant influx of magmatic water.

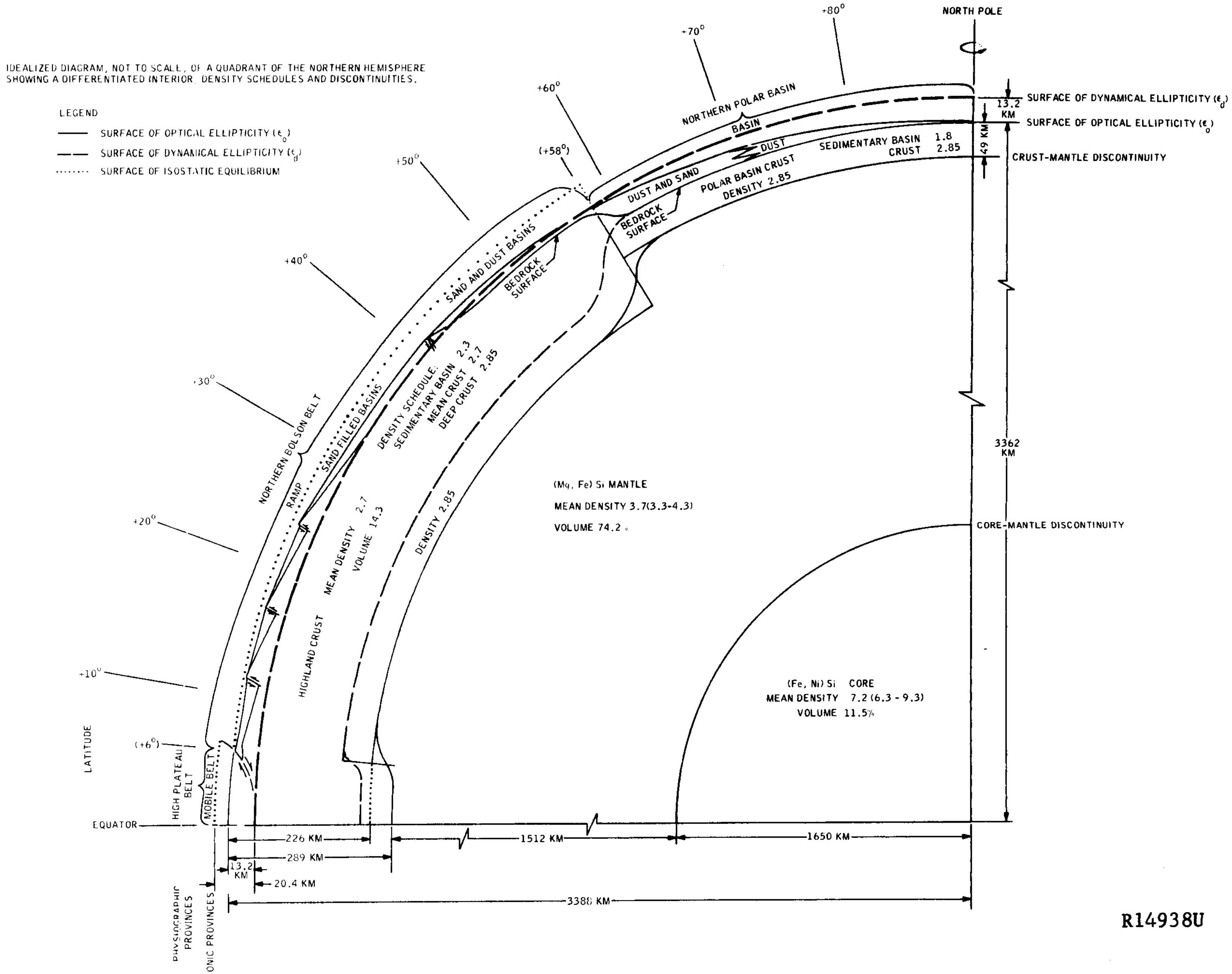

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FIGURE 7-4. INTERNAL STRUCTURE OF MARS

astronomically described albedo differences on the surface of the planet (bright and dark areas). The thickness of the crust is greater than that of the Earth, but it is based on thermal-pressure curves that relate the terrestrial phase change from basalt → eclogite (that theoretically occurs at the level of the Mohorovicic Discontinuity) to Martian gravitational and density schedules. Three surfaces are designated in Figure 7-4. The surface of optical ellipticity (thin solid line) defines the actual surface of the planet. The surface of dynamical ellipticity (thick dashed line) denotes the Mars geoid or isogravity surface (for the sake of this discussion). The surface of isostatic equilibrium (dotted line representing an elevation constant that would exist relative to the crust-mantle discontinuity were it not for erosion) that accounts for the constant rise of the "high plateau belt" in equilibrium with the constant depression of the sedimentary basins of the "ramps" and the "polar basins."

The thickest unit of the crust is related in Figure 7-4 to the near equatorial belt of more or less east-west trending dark areas that extend from latitudes +19 to -49 degrees on Slipher's(9) map of Mars. On the basis of this distribution, the dark area belt is believed to represent a nuclear shield mass (cf. terrestrial Canadian or Fenno-Scandian shields) or a mobile diastrophic belt (cf. Himalaya-Alpine diastrophic belt) that constantly rises as erosion proceeds. This high plateau belt or smoothly sloping mountainous mass is deemed to represent the highest elevations (very positive relative to the geoid) on the Mars surface and may be underlain by a depression in the crust-mantle discontinuity similar to the "roots of mountains" anomalies that exist on Earth. The broadest belt, labeled "ramp" or "northern bolson belt" in Figure 7-4, contains the bright areas of Mars. This belt is represented to be slightly positive or equal to the elevation of the surface of the Mars geoid. The northern and southern ramps are believed to be the sites of a number of intraramp basins formed by faulting, synclinal downwarping, and asteroid impact. The linear (so-called canals), circular (oases) and irregularly-shaped dark areas represented by many observers(5,9) as populating the broad ramp areas and extending into or bounding the high plateau belt are interpreted to be higher elevation remnants of the basin rims rising above the level of sand deposited within the basins. Their origin is interpreted to result from:

(1) Normal or gravity dip-slip faults (linear dark areas and "canals" having an angular relationship to the trend of the high plateau belt) or strike-slip faults (linear dark areas trending parallel to the high plateau belt) representing many periods of marsquake activity and boundary blocks or masses having opposed lithologies (e.g., igneous:sedimentary).

(2) Horsts (large scale dark area masses and broad linear "canals"), composed of uplifted masses bounded by normal faults, and grabens (long, relatively narrow, bright area basins), consisting of down-dropped areas bounded by normal faults.

(3) Impact crater rims (sharply curved boundaries between dark and bright areas).

Finally, the thinnest and heaviest portion of the Mars crust underlies the polar basins whose surface elevations are interpreted to be very negative in relation to the Mars geoid.

The remaining factors that round out the geological setting attributed to Mars are erosion and sedimentation. The basic requirement for long-term erosion is an initial and thereafter more or less continuous renewal of igneous or metamorphic parent material. The mechanism of continuous isostatic readjustment by sporadic but essentially continual uplift has been described previously (nuclear shield uplift or thrust mass).

The mechanical disintegration of fresh rock can be accomplished by tectonic fracturing (marsquakes), volcanism, crushing and fracturing by the impact and shock wave propagation effects of asteroids and meteorites and fatigue spalling and wedging created by temperature changes and ice. Chemical weathering can be accomplished by oxidation and hydration, as the almost ubiquitous presence of limonite would indicate. The existence of life would augment the role of chemical weathering and, depending upon evolutionary status, mechanical disintegration.

The dominant erosive device, however, will be wind abrasion. Abrasion effectiveness is a function of wind velocity, relative hardness of the lithified surface and the amount of resistant grains available in a proper size range for use as cutting tools. Abrasive erosion operates by selective removal of soft crystals, grains, matricies or layers thereby releasing particles from boulder-($>$25.5 cm) to dust-size ($<$10μ) by grain removal, etching, and undermining. In this manner, a large range in particle size distribution is immediately obtained. Sediment transport is a function of dust movement within the atmosphere and sand grain movement by near surface saltation and creep. Direct transportation of particles by wind is basically related to wind velocity operating within known or assumed atmospheric pressure-viscosity-density-temperature schedules. A secondary function is the degree of surface roughness expressed in grain diameters of the particles making up the surface skin. The type of sedimentary material filling the basins and the environment of deposition relative to grain diameter are designated in Table 7-VI.

TABLE 7-VI

SEDEMENTARY MATERIAL FILLING BASINS

Type of Material	Grain Diameter	Environment
Fragmental, tectonically or impact derived	2 mm -> 25.6 cm	Intermontane basins and desert pavements
Sand, abrasively derived	62μ - 2 mm	Bolson basins
Dust and silt, abrasively derived	$>1\mu$- 62μ	Polar dust sinks
Limonite, chemically derived	Microcrystalline	Ubiquitous

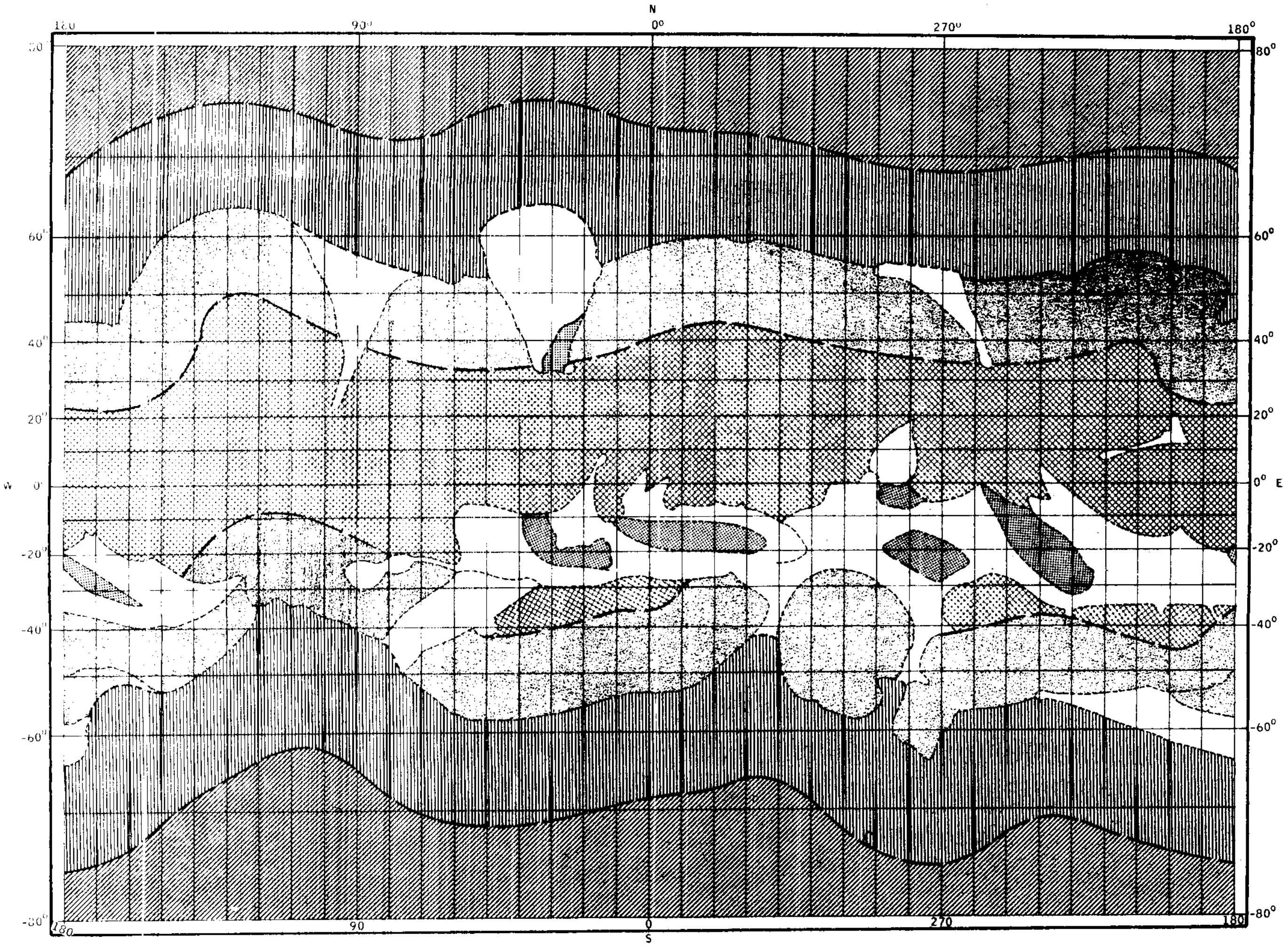
If hemispheric exchange winds are the dominant wind system on Mars, loose sands will be subjected to tradewind conditions during two seasons of the year, high pressure calms during another, and occasional localized thermal cyclonic storms during a fourth. The end result should be one of gradually spreading a blanket of well winnowed sand through 40 degrees or more of latitude. The geographic location of parent igneous or metamorphic rock masses and the bounding sand blankets are shown in Figure 7-5. The basins will continually fill with sand until the divides exist as more or less linear strings of slightly positive summits. As each basin reaches its individual base level, the major sediment load will be drifted into adjacent basins that have not been filled to a base level of deposition. Sedimentation of this type should extend at least to the limits of the "ramps" where the blanket deposition of suspended materials will become increasingly more important. In this manner the "ramps" will eventually become broad, almost flat, but tapering (in terms of elevation and crustal thickness) plains of sand deposition. As sands are transported into and across the ramp basins, they are constantly being winnowed, and the small diameter particles are removed and transported in many directions. Ultimately, however, the area of major dust deposition will be the "polar basins." Dust sedimentation is related to three factors:

(1) Distance from source of material

(2) Reduction in wind velocity

(3) Permafrost anchoring

The first factor is rather obvious from the preceding discussion. The second is related to both observed and theoretical weather regimes; for instance, yellow clouds have never been initiated in this region (±40 degrees to poles) although they often spread over portions of it. The third is based on the cycle of events leading to the formation and



EXPLANATION

		MATERIAL	INTERPRETATION
SEDIMENTS	▩	COARSE SAND, FRAGMENTAL IGNEOUS MATERIAL AND ASH.	FORMS DUNES AND DESERT PAVEMENTS COMPOSED OF THE SLIGHTLY WEATHERED PRODUCTS OF SAND BLASTING, DIASTROPHIC TALUS AND CRUSHED IMPACT DEBRIS.
	░	COARSE SAND, PARTICLE SIZE 225μ - >2mm; SAND COMPOSED OF HARD RESISTANT MINERAL GRAINS.	WELL-WINNOWED SAND DUNES AND LOCAL DESERT PAVEMENTS IN PROCESS OF BEING DEVELOPED.
	░	COARSE TO FINE SAND, PARTICLE SIZE 62-350 μ, AND DUST +10 μ.	WELL- TO POORLY-SORTED SAND DUNES AND DRIFTING DUST. DUST CONTENT VARIES FROM A TRACE TO ≤ 50 PERCENT.
	▥	DUST, PARTICLE SIZE ±10 μ, AND FINE SAND, 62-225 μ.	ARENACEOUS DUST DRIFTS AND DUST BLANKET; SAND CONTENT VARIES FROM A TRACE TO ≤ 50 PERCENT.
	▨	DUST, PARTICLE SIZE ≤ 10μ DUST COMPOSED OF FINELY COMMINUTED PARTICLES OF SOFT MINERALS, HARD MINERAL FLOUR AND FINE ASH.	DUST BLANKET FORMED FROM SETTLING PARTICLES.
IGNEOUS ROCKS	☐	SEE TABLE 2-I	SEE TABLE 2-II

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FIGURE 7-5. PRELIMINARY STRATIGRAPHIC MAP OF MARS sublimation of the polar caps as carefully treated by Focas(10). Dollfus(11) has reported that the albedo of the polar ice cap decreases from about 0.7 at its first disclosure to 0.3 by the end of summer. He relates this dirtying effect to dust deposits being sifted onto the ice. If dust can reduce the albedo more than half in approximately one-third of a Mars year, then the total amount of material being deposited must be large and constant. The concept that sedimentation within the polar basin areas is dominantly dust is thereby introduced. Gradation will exist, as denoted in Figure 7-5; hence, for purposes of presenting an approximate series of surface stratigraphic zones, the following gradation has been assumed to exist in a pole to equator direction:

(1) Sedimentation at the poles of rotation will be exclusively wind lofted dust and silt. (Mean latitude range: +72° to +90° and -70° to -90°).

(2) From a line assumed to lie half the distance between a pole and a hinge line, denoting the boundary between "ramp" and "polar basin" units, deposition will vary from dust with a trace of sand to dust with <50 percent sand at the hinge line. (Mean latitude range: +55° to +72° and -50° to -70°.)

(3) From the hinge line to a line that is equal in width to that defined in Item (2) above, deposition will vary from sand with <50 percent dust at the hinge line to exclusively sand. (Mean latitude range: +38° to +55° and -30° to -50°.)

c. Precipitation and Sublimation. The manner in which surface moisture is precipitated or sublimated can be treated by relating basic meteorological principles to the atmospheric parameters tentatively defined for Mars.

The composition, pressure and temperature of the atmosphere of Mars is based on theoretically and indirectly calculated or assumed parameters. Table 7-III briefly lists these factors and the range of parametric values derived from the responsible literature. The observations of Kaplan et al(12) applied to prior spectral measurements by Kuiper and Sinton yield the surface atmospheric pressure schedule shown in Table 7-VII when modified by topographical relief.

Utilizing the water vapor content defined by Kaplan et al(12), the manner in which precipitation or sublimation occurs on the Mars surface and the geographic areas in which precipitation or sublimation will be at a minimum can be defined.

TABLE 7-VII

SURFACE ATMOSPHERIC PRESSURE CORRECTED FOR TOPOGRAPHICAL RELIEF

Location and Elevation ± (in. km)	Surface Pressure (in. mb)	
	Nominal Range	Minimum Range
Crest of equatorial bulge		
(+13.2)	29	11
+10	35	13
+5	48	18
Mean altitude pressure	65	25
-5	86	34
-10	107	43
Poles of rotation		
(-13.2)	129	47

The minimum partial pressure for water vapor in the Martian atmosphere lies between approximately 0.0005 and 0.0015 g/cm^2 (12). At the atmospheric temperatures on Mars, -23° to -73°C (from nominal values, Table 7-VII), the saturation vapor pressure over ice varies from 0.786 to 0.0000565 g/cm^2 (13). On Mars, if $e_s < e$, where e_s is the saturation vapor pressure and e is the partial pressure of water vapor in the Martian atmosphere, then the water vapor must freeze or sublimate. If $e \leqq e_s$, the water vapor must remain in a gaseous state. In the equatorial regions of Mars, the critical temperature for the sublimation of water vapor is -60° to -65°C. During summer seasons, this minimum temperature is rarely achieved. Therefore, the equatorial regions of Mars, ± 20° - 40° of latitude, (excepting the Tharsis area thermal low) may be prohibited areas for the formation of clouds and subsequent precipitation or sublimation. The minimum water vapor content within tropical latitudes, especially during summer seasons, is probably related to a greater height distribution or vertical mixing of water vapor accompanying cyclonic and thermal convection activity.

Over the remainder of the Mars surface, the formation of clouds and surface hoarfrost will occur according to relative humidity values based on the amount of water vapor present, temperature and pressure.(14) When the relative humidity approaches 100 percent, clouds will be formed if an adequate number of condensation nuclei are present to prevent supersaturation. If moisture content and temperature alone are consisered, dew point sublimation will occur when $e = e_s$. Terrestrial condensation nuclei include sea salt, organic dusts, combustion products (industrial, forest fires and volcanism), and various ions. These nuclei range in size from 0.01 to 1μ and are hygroscopic. On nuclei of the hygroscopic type, condensation can commence at relative humidities well below 100 percent. Other types of particles, such as finely divided silicates, serve as freezing nuclei by absorbing a film of super-cooled water which is immediately frozen. These particles form condensation nuclei at relative humidities very close to 100 percent at temperatures from -10°C to -30°C(14). From these considerations and the discussion on the size and amounts of dust particles in the Martian atmosphere, the concept of cloud seeding by organic and mineral dust particles is advanced.

The above discussion of geological structure, sedimentation, atmospheric parameters, and meteorological applications serves to outline the factors that enter into the following paragraphs describing the nature of tenuous surface water deposits and the development of permafrost and ground water on Mars.

d. Surface Moisture. Surface water is defined as the water present on the surface skin of Mars regardless of phase. It will include polar hoarfrost deposits, high latitude limb whitening phenomena, temporary darkening phenomena following the passage of white clouds and other possible moisture-related effects that have been observed astronomically (for detailed descriptions of these phenomena see Vaucouleurs(5), Slipher(9), and Focas(10)). The existence of surface water will be governed by the thermodynamic pressure-temperature relation for H_2O. Figure 7-6 demonstrates this relationship and denotes the temperature range through which water can exist as a surface skin liquid, e.g.:

(1) At 11-mb surface pressure, water exists as a liquid only from 0° to 8°C.

(2) At 25-mb pressure, water will exist in the liquid state through 20°C.

(3) Above 50-mb, water will exist as a liquid beyond the upper limit of Mars surface skin temperatures.

Where the temperature regime remains below 0°C, direct sublimation of ice will take place regardless of the atmospheric pressure. At low pressures, the time during which a moisture film will pass from melting to evaporation will range from a minimum of one-half hour (11-mb pressure at the equator) to two hours (65-mb pressure at middle latitude temperature conditions or 25-mb at the equator). The relationship between the effect of temperature, pressure, and time on the presence of surface skin water in the liquid phase is illustrated by a series of maps identifying the areas where

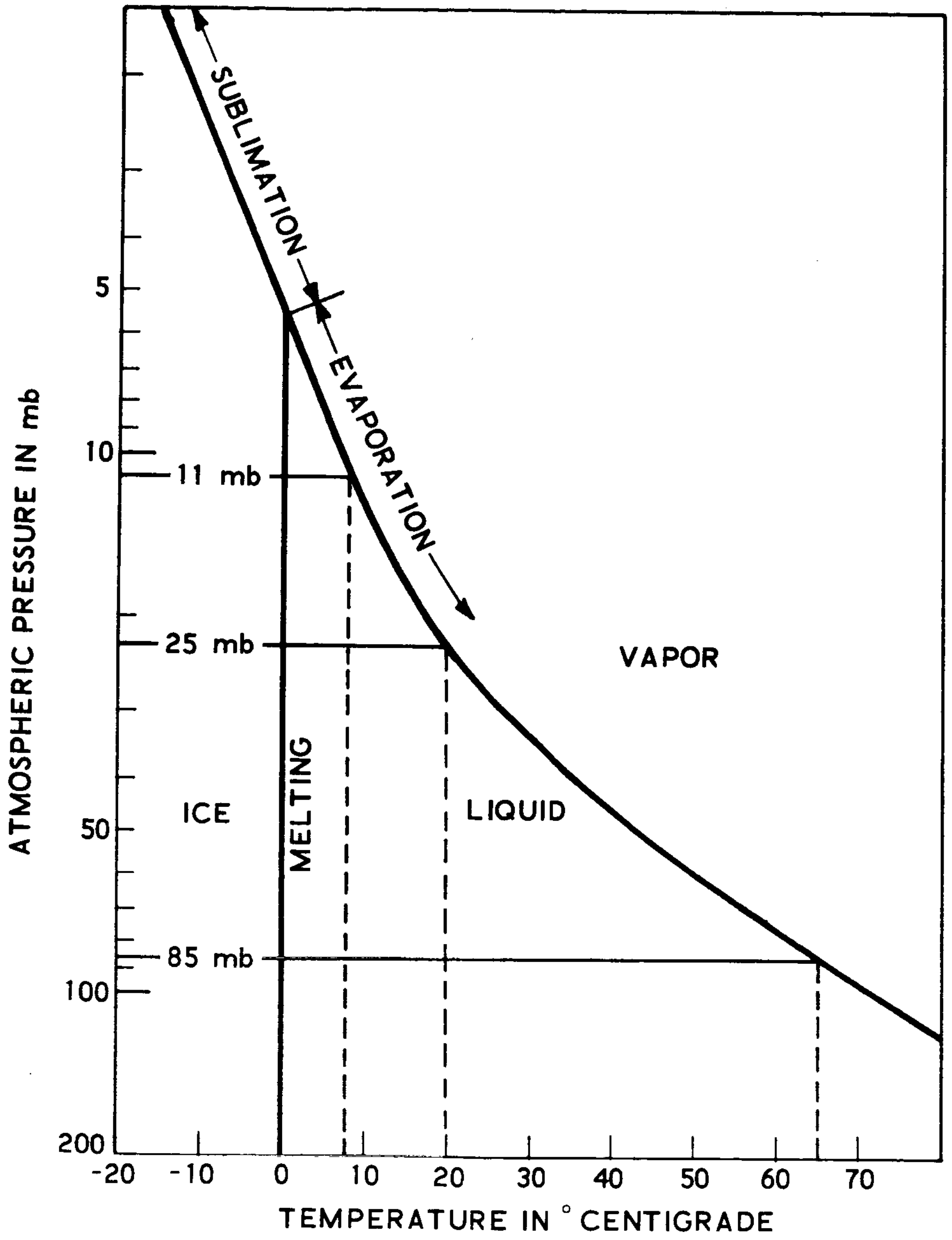

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FIGURE 7-6. THERMODYNAMIC PRESSURE - TEMPERATURE RELATION FOR H_2O

liquid water will exist on the surface of Mars for maximum periods of time under various atmospheric pressures during summer and winter seasons. These maps were constructed from functions of two factors:

(1) The thaw to evaporation time increment in equatorial or low latitude subsolar point areas as expressed in Figure 7-6.

(2) The total duration of thaw time at middle latitudes.

The following figures illustrate optimum areas for the existence of surface skin water in the liquid phase at a uniform atmospheric pressure of 11-mb:

(1) Figure 7-7: Southern hemisphere summer.

(2) Figure 7-8: Southern hemisphere winter.

The maps denoting optimum moisture conditions at an atmospheric pressure of 25-mb are:

(1) Figure 7-9: Southern hemisphere summer.

(2) Figure 7-10: Southern hemisphere winter.

On each map, the closed areas are associated with thermal highs wherein rapid evaporation will take place; outside of the optimum band, sublimation only will occur because of subzero surface skin temperatures. A final map, Figure 7-11, portrays the overall limits for the occurrence of water in the liquid phase during the course of a Martian year. The equatorward limits of the dark fringe surrounding the polar ice caps is also shown. Noteworthy, is the fact that for a short period of time each year, the temperature regime in the Hellas and Arabia-Moab areas appears to be sufficiently high to allow liquid water to be present at the distal fringe of the polar caps. This analysis of the limits to the existence surface moisture demonstrates the tenuous nature of water on the surface skin environment of Mars. Figure 7-12 (right-hand legend) correlates the limited occurrence of surface skin water with other hydrothermal phenomena.

e. Permafrost. The ice crystal nucleation capabilities and moisture binding capacities of very fine dust particles sifting through the polar cloud caps will serve to develop permafrost deposits in the polar dust sinks. Surface dust deposits surrounding the poles should therefore consist of a ratio of dust and silt to ice that is greater than one. Tremendous permafrost masses will result. At lower latitudes, but still within the polar basin, the mixture of sand and dust will increase the

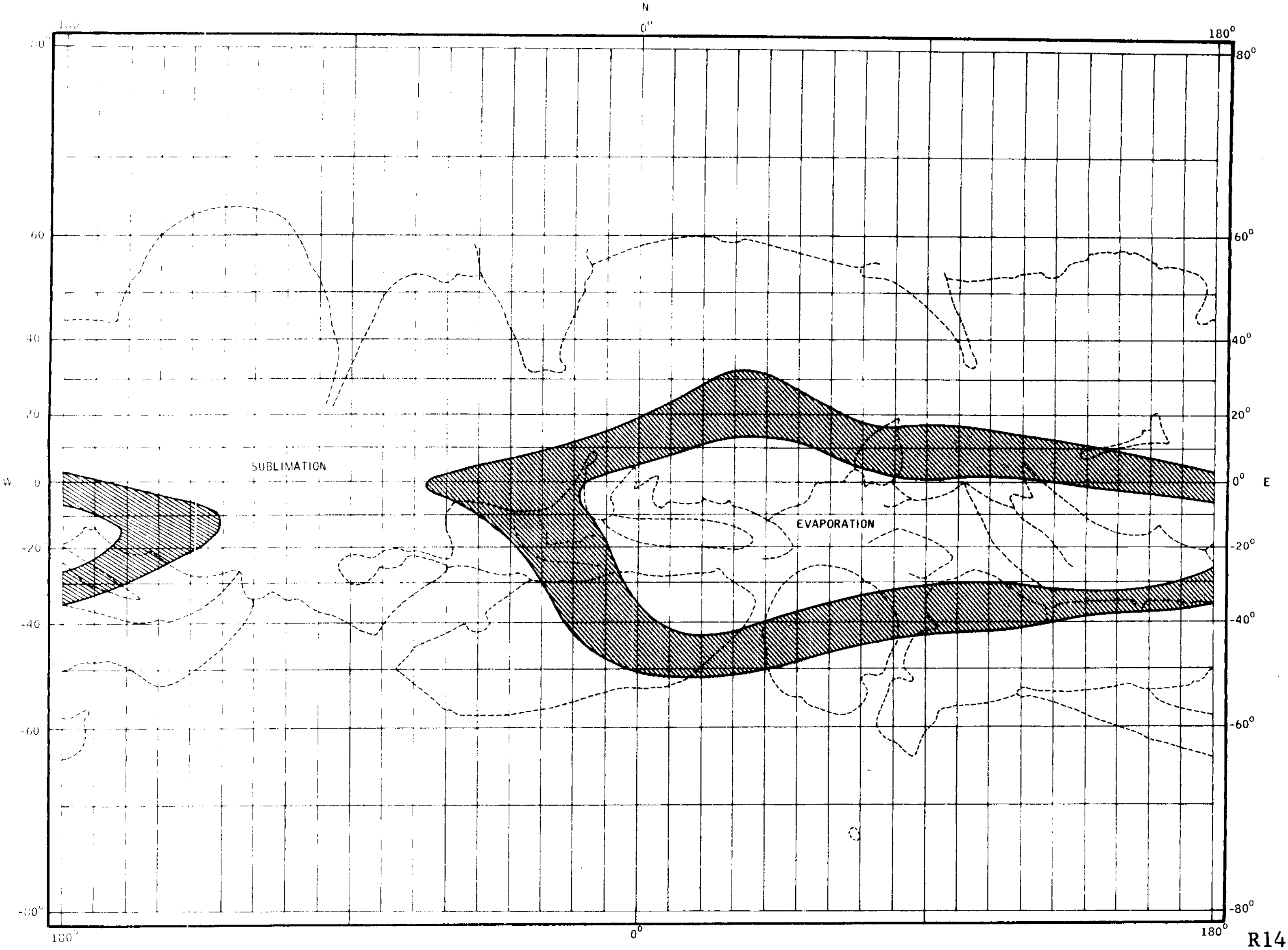

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FIGURE 7-7. OPTIMUM AREA FOR EXISTENCE OF LIQUID WATER AT AN ATMOSPHERIC PRESSURE OF 11 MB DURING SOUTHERN HEMISPHERE SUMMER

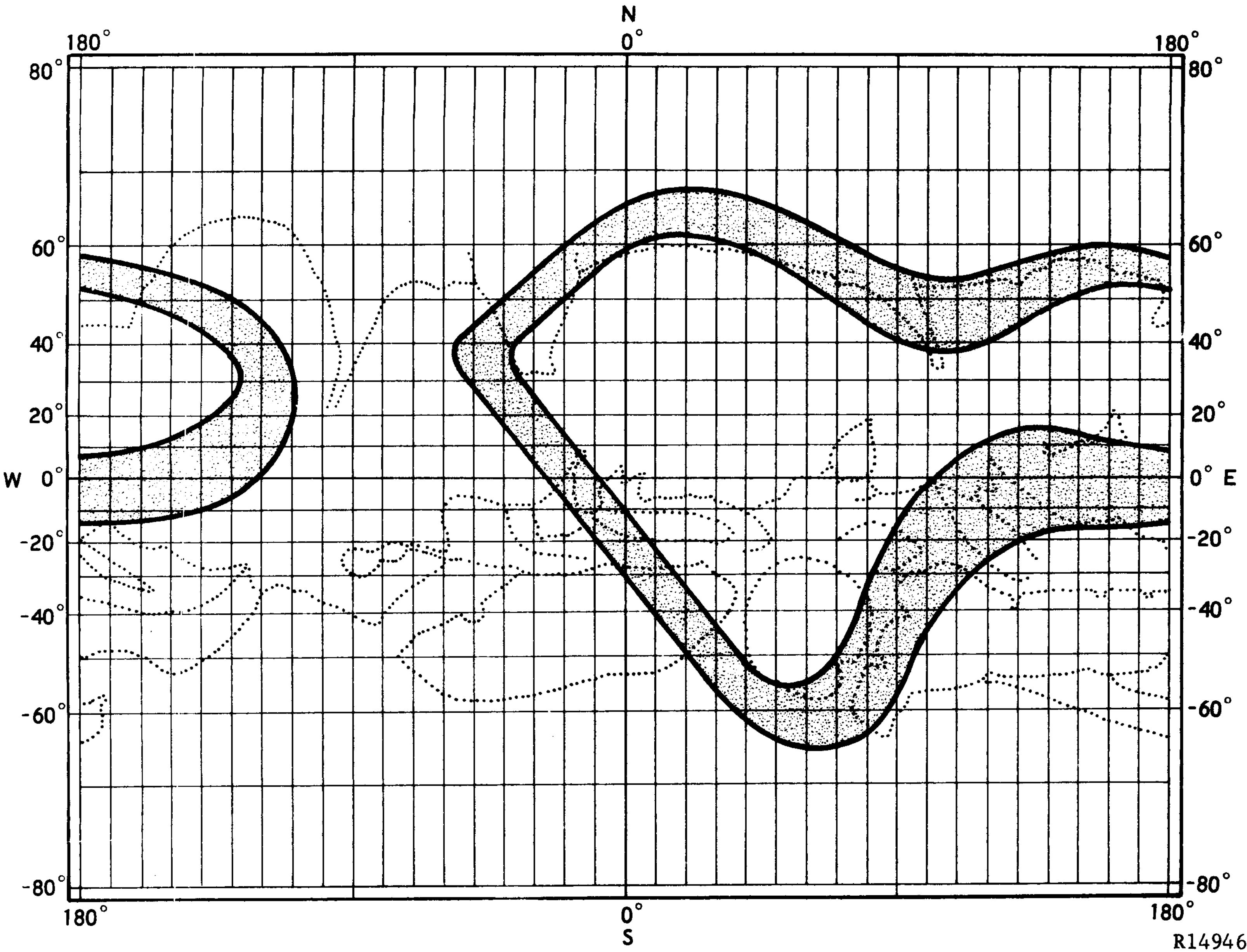

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FIGURE 7-8. OPTIMUM AREA FOR EXISTENCE OF LIQUID WATER AT AN ATMOSPHERIC PRESSURE OF 11 MB DURING SOUTHERN HEMISPHERE WINTER

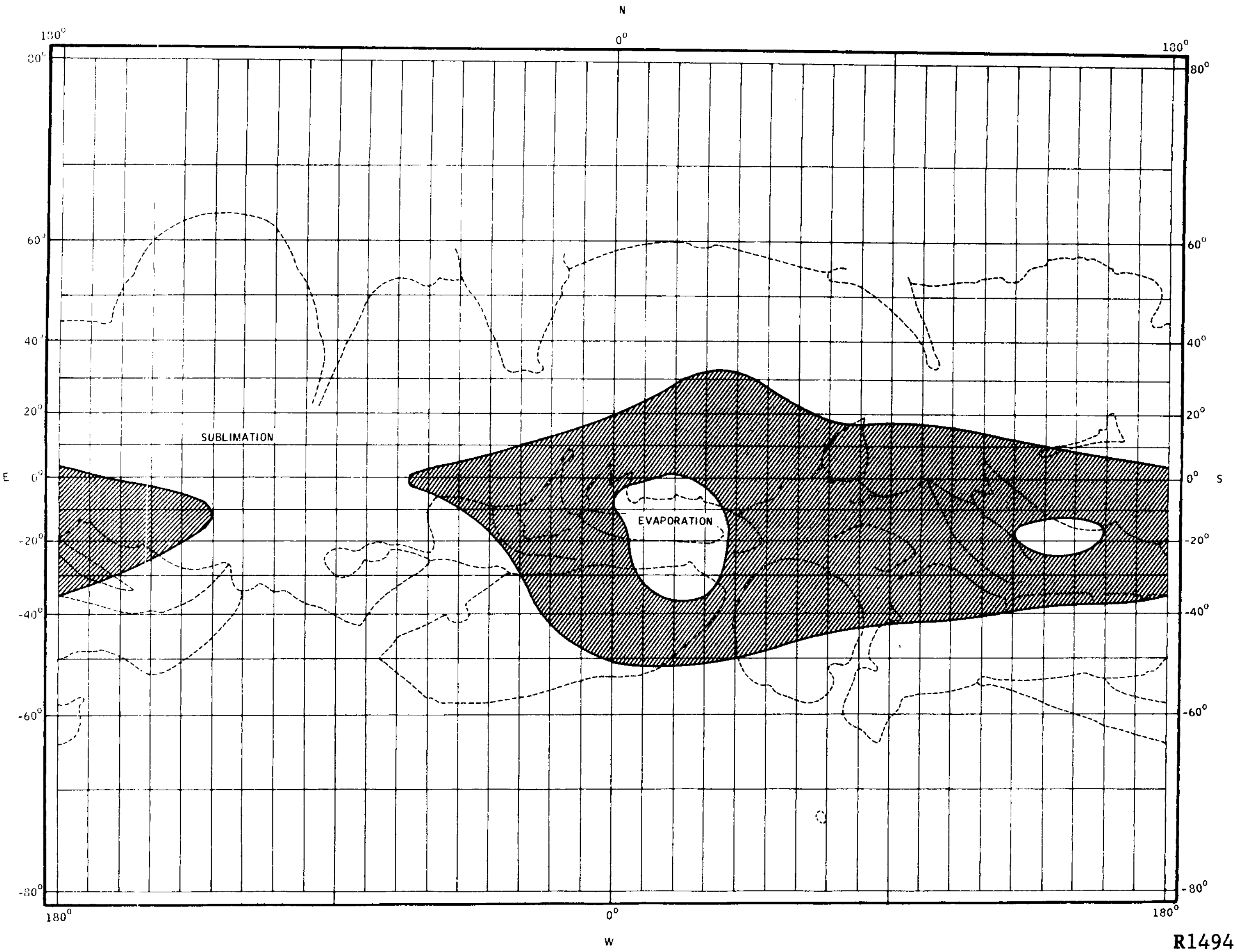

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FIGURE 7-9. OPTIMUM AREA FOR EXISTENCE OF LIQUID WATER AT AN ATMOSPHERIC PRESSURE OF 25 MB DURING SOUTHERN HEMISPHERE SUMMER

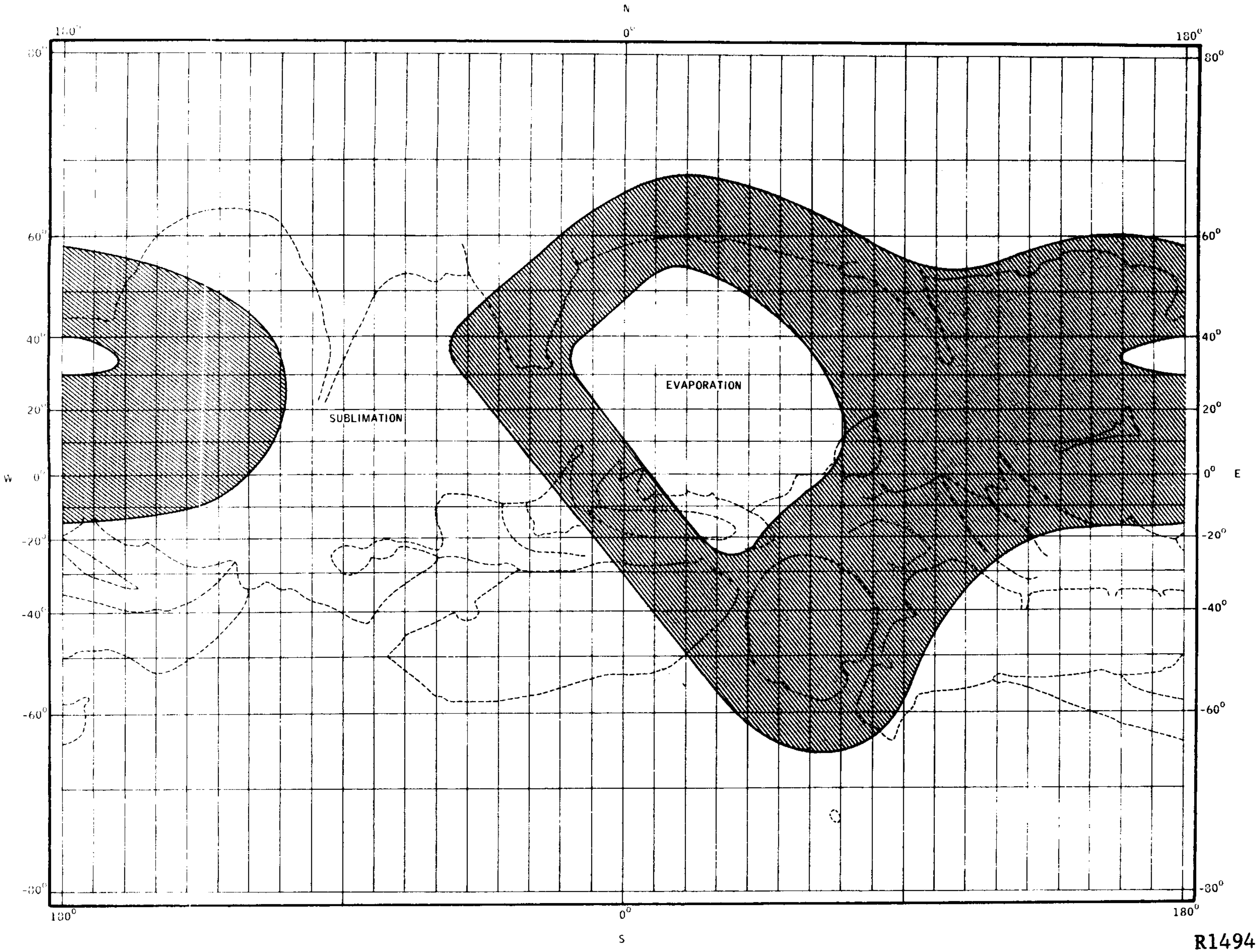

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FIGURE 7-10. OPTIMUM AREA FOR EXISTENCE OF LIQUID WATER AT AN ATMOSPHERIC PRESSURE OF 25 MB DURING SOUTHERN WINTER

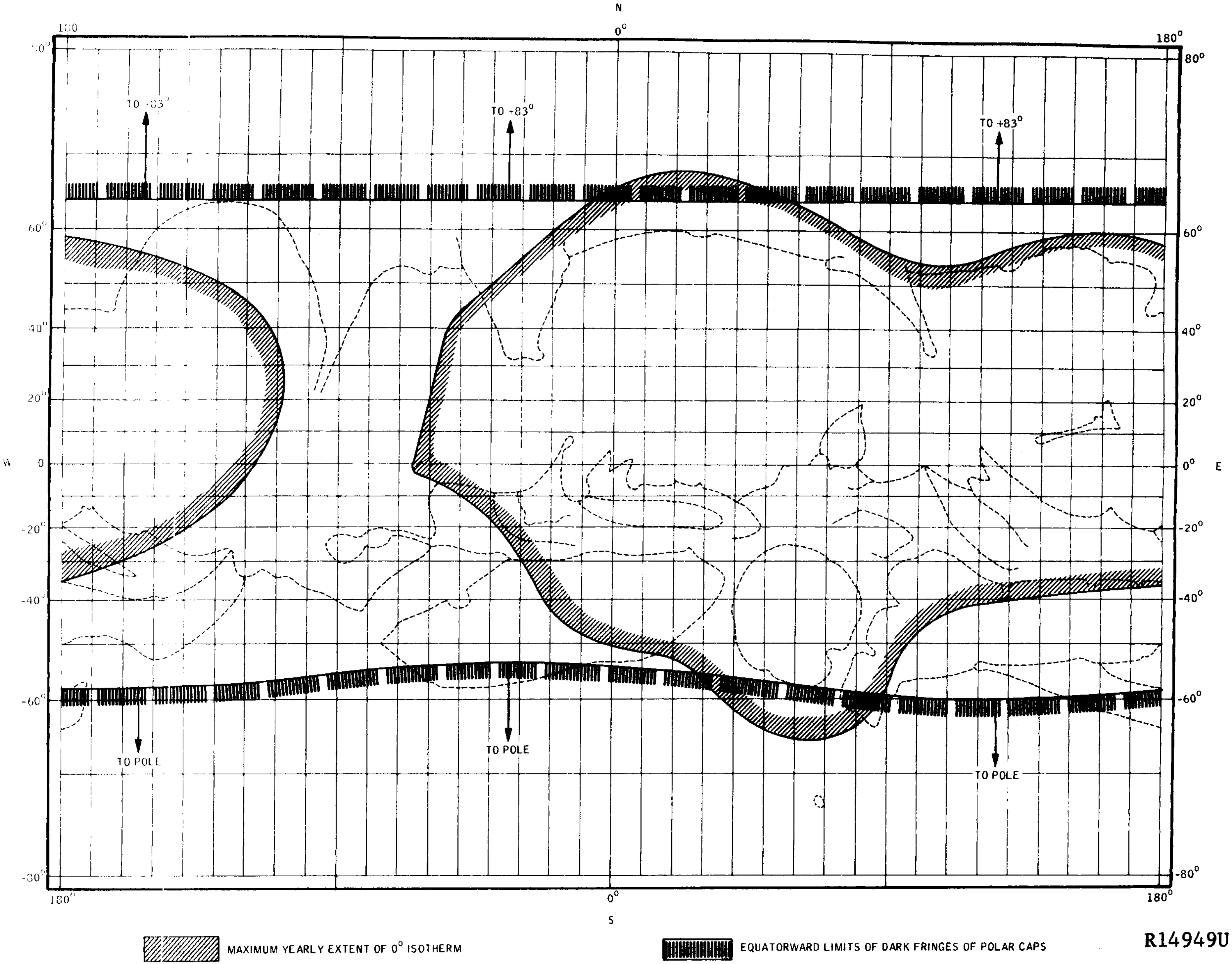

FIGURE 7-11. LIMITS OF OCCURRENCE OF LIQUID WATER ON MARS SURFACE

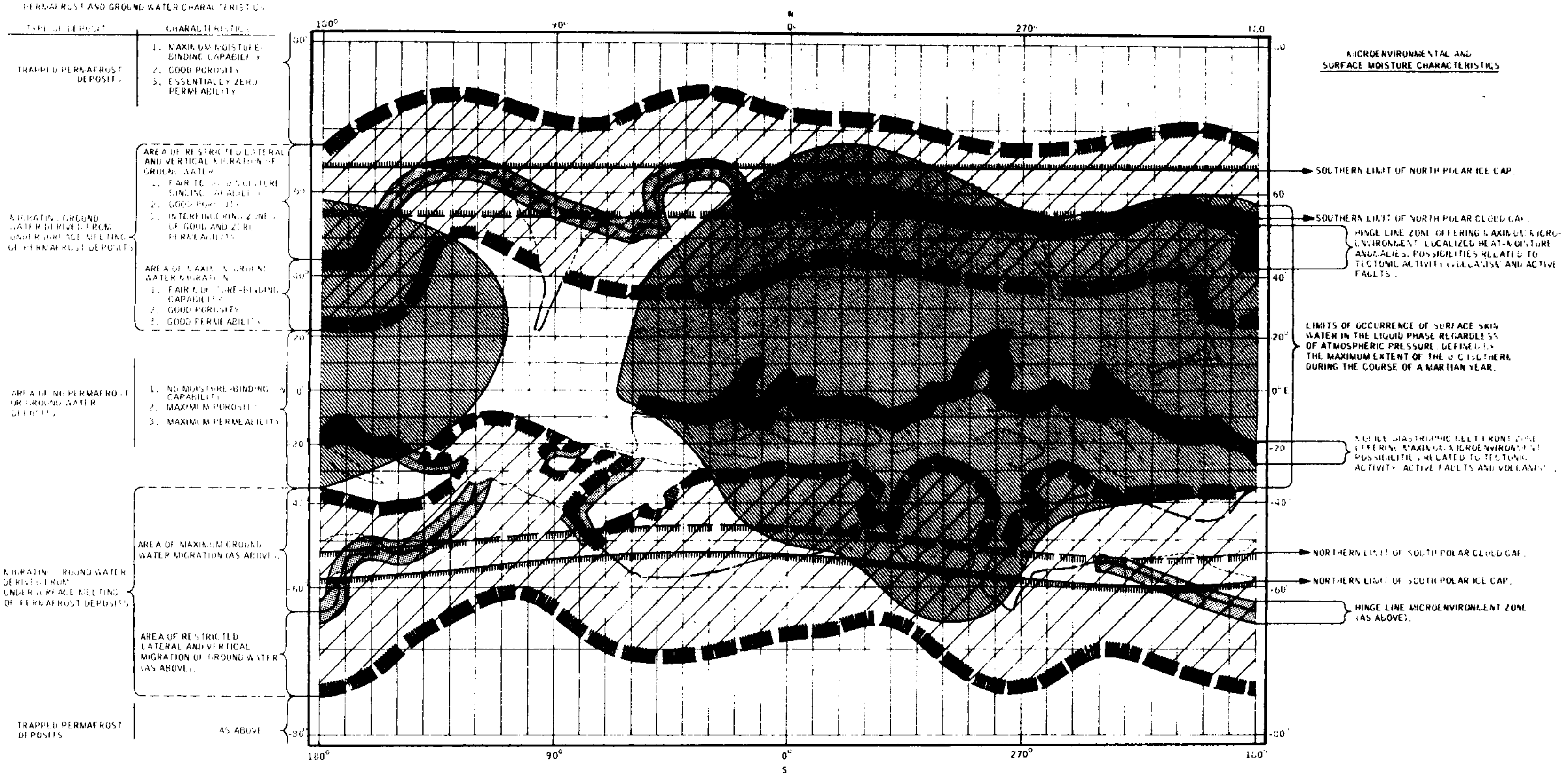

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FIGURE 7-12. SURFACE MOISTURE, GROUND WATER AND PERMAFROST ZONES AND CHARACTERISTICS ratio of mineral grains to ice but still develop and maintain large scale permafrost deposits. Beyond the limits of the polar cloud covers (see Figure 7-3) permafrost will be localized and scattered. Figure 7-12 (left-hand legend) illustrates the location of these zones.

f. Ground Water. As sedimentation proceeds, permafrost deposits will be buried to the plane of the 0^oC subsurface isotherm and subjected to undersurface melting. The depth to which melting occurs may be governed by the depth to the 0^oC isothermal plane or by the presence of soluble salts that serve to depress the freezing point of water. Furthermore, if the surface concentration of salts is high, moisture can be directly absorbed from polar clouds at extremely low atmospheric humidity values.

Ground water obtained from subsurface permafrost melting will be distributed laterally and vertically as a function of the porosity and permeability of the sediments. Within the poleward reaches of the polar dust sinks the porosity will be high but the permeability at a minimum due to the fine grained character of the deposit as a whole. In this area, migration of liquid ground water will be nil. Throughout the lower latitude areas of the polar basins, porosity will be maintained at a high level but lenticular and interfingering zones of high and low permeability will exist depending upon the relative amounts of sand or dust deposited at any particular point in time. In this manner, lateral migration of ground water will occur and any localized vertical rising of water will tend to expand the permafrost zones in the affected areas. By carrying this concept further toward the equator, where sand deposits become more prominent and the surface temperature regime rises, a zone of active vertical migration of liquid water to the surface should develop. Within this zone, the pososity will be high and vertical, and horizontal permeability will tend to be equal. Seasonal freezing of the soil should alternate with active evaporation of capillary water. The geographic position of this zone and the degree to which evaporation takes place will depend on the soluble salt content of the ground water. If the salt content is high, then:

(1) The freezing point of water is depressed and the permafrost limit will be shifted poleward.

(2) Evaporation of more or less saturated soluble salt solutions will cause a salt crust to be deposited and the zone of surface outflow and evaporation will be shifted equatorward.

For this reason, rather wide limits will prevail for the zone within which this phenomenon can occur. Basically, the zone should center on the approximate boundary between pure sand and sand-dust deposits as denoted on Figures 7-5 and 7-12.

g. Depression of the Freezing Point by Salt Solutions. Water can exist in the soil as a solid, as a liquid, or as a vapor. While pressure and temperature alone determine the physical state of pure water, dissolved substances greatly affect the physical state of an aqueous solution. Figure 7-13 shows the phase diagram for a system consisting of sodium chloride and water at various compositions and various temperatures when the system is at one Earth atmospheric pressure (the effect of reducing the pressure to one Martian atmosphere is negligible). As the temperature of a homogeneous solution of sodium chloride in water is reduced, a particular temperature, corresponding to the amount of salt in solution, is reached at which a solid phase begins to form. As the temperature of the solution continues to fall, an increasing amount of solid phase is formed. If the salt content of the initial solution was greater than the eutectic composition, then the solid phase will consist of sodium chloride crystals; if it was less than the eutectic composition, it will consist of ice crystals. In either case, the compositions of the two phases, the solid and the liquid, which coexist in equilibrium at that temperature will be pure ice or pure crystals of sodium chloride for the solid and a saturated liquid solution of the composition given on the curve corresponding to that temperature. As the temperature is reduced further, the composition of the solid phase will not change but that of the liquid will move closer and closer to the eutectic as it is depleted of the substance forming the solid phase. At all temperatures below the eutectic temperature, no liquid phase can be present at equilibrium (however supercooled, metastable, liquid solutions are possible under certain conditions). When the eutectic material freezes, a solid containing both solid phases is formed. A solution of eutectic composition freezes at a single temperature like a pure substance. Characteristically, the eutectic temperature is the lowest temperature at which a liquid phase containing the two substances can exist at equilibrium. The addition of soluble materials to water characteristically "depresses the freezing point" by permitting water to exist in the liquid phase at temperatures below the normal freezing point of pure water. The degree to which a solute can depress the freezing point depends on the nature of the solute. Figure 7-13 shows the eutectic points for several salts in addition to sodium chloride. Note particularly, that the eutectic solutions of either calcium chloride or of ferric chloride are liquid at temperatures as low as -55°C and the vast difference in freezing point depression between potassium carbonate and sodium carbonate. Many salts exist as hydrate crystals when in equilibrium with their saturated liquid solutions.

In the vapor over either the solid crystals or the liquid solutions, there will be a certain amount of water vapor. The partial pressure of this water vapor is equal to the vapor pressure of pure water at that temperature only when the liquid or solid is pure water. For other solids or other liquids, the partial pressure will be less, as is shown in Figure 7-13. Figure 7-14 shows the partial pressure of water vapor over saturated aqueous solutions of several salts.

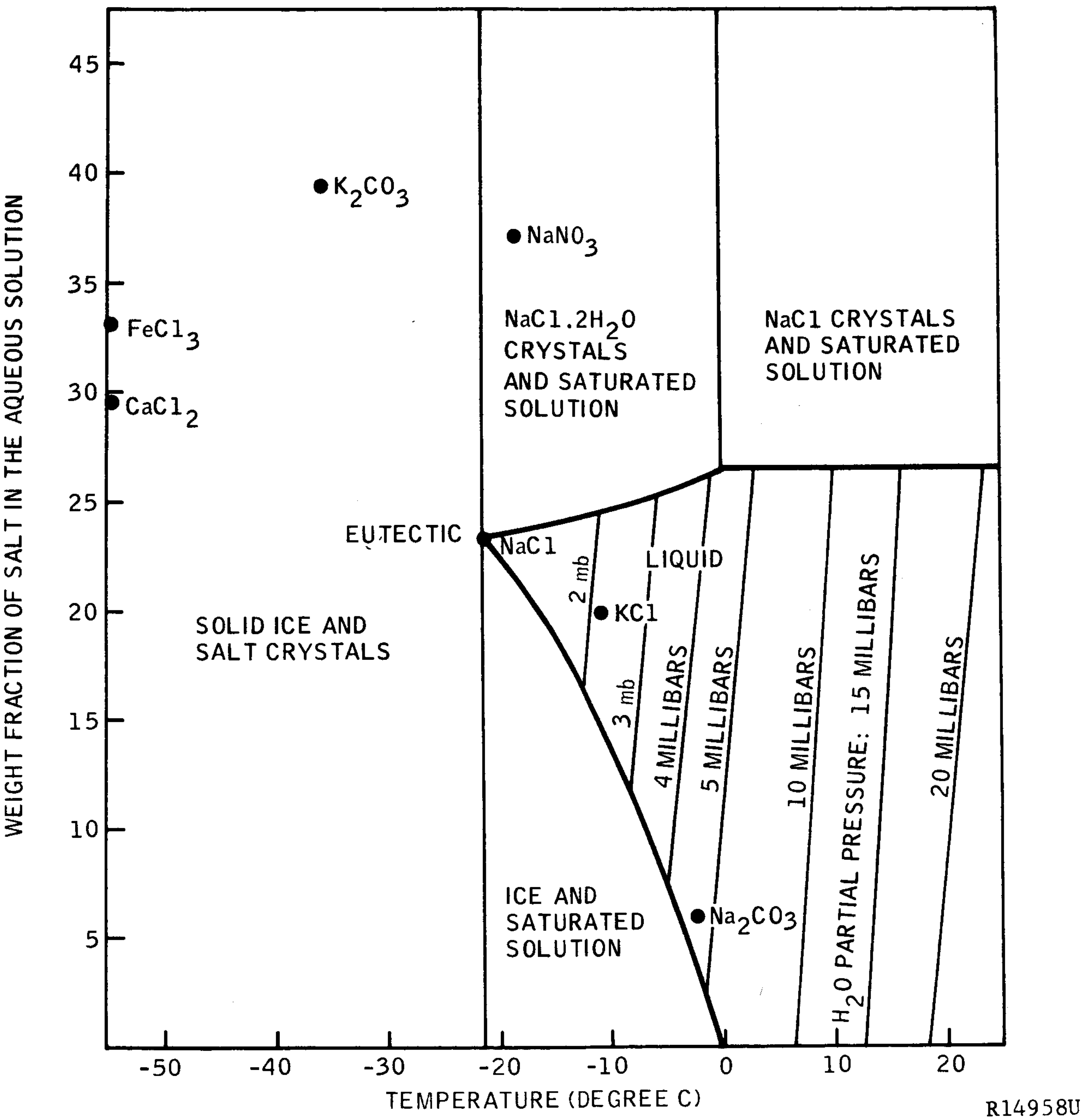

FIGURE 7-13. PHASE DIAGRAM FOR A $NaCl-H_2O$ SYSTEM AND THE EUTECTIC POINTS FOR OTHER SALT-WATER SOLUTIONS

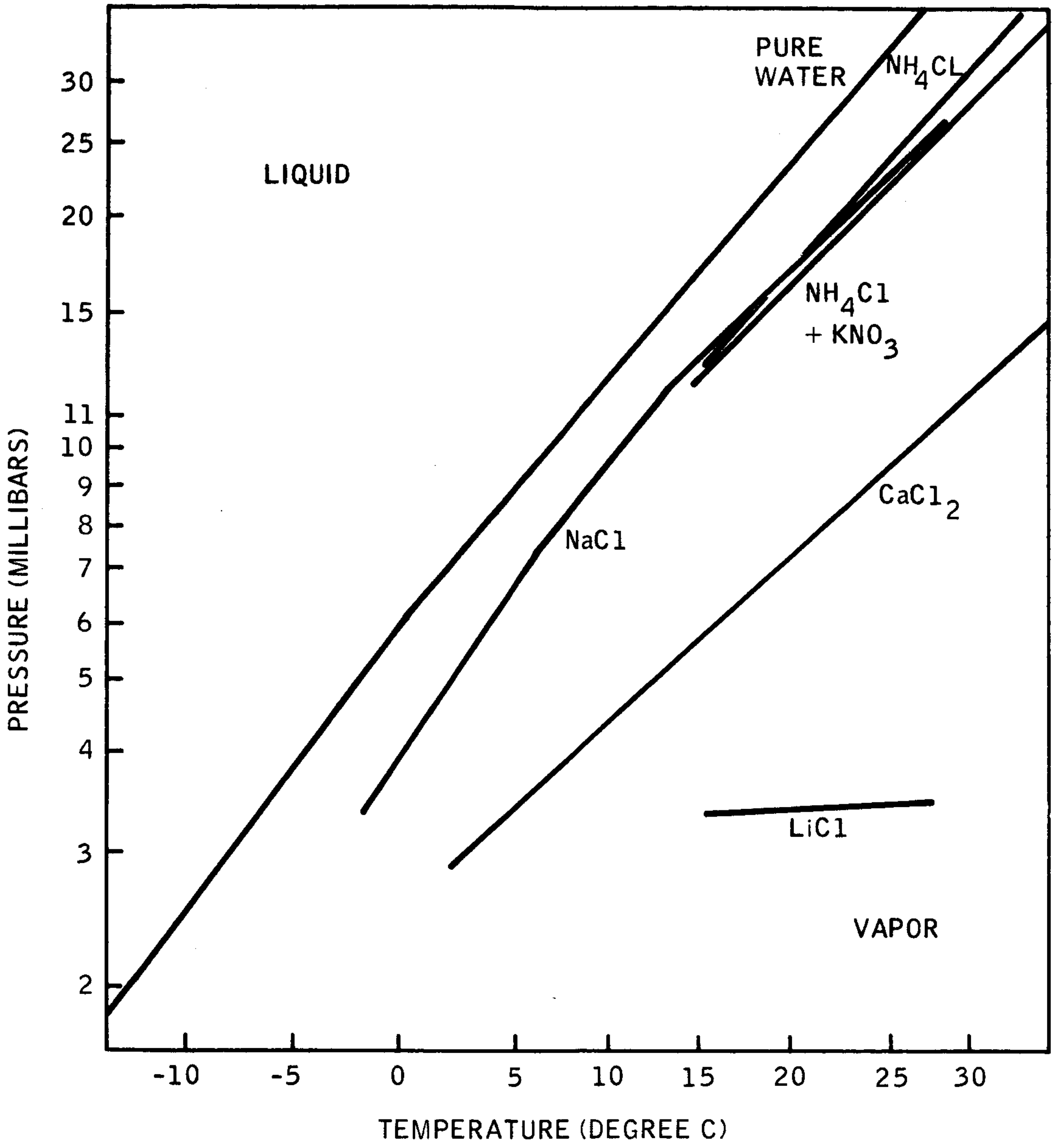

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FIGURE 7-14. PARTIAL PRESSURE OF WATER VAPOR OVER SATURATED AQUECUS SOLUTIONS OF SEVERAL SALTS

Figure 7-15 shows a phase diagram for the ternary system of water, sodium chloride, and disodium phosphate. The vertical wall on the left side of the figure contains the same information as that presented in Figure 7-13. The right wall shows the corresponding information for solutions of disodium phosphate in water. Note, however, that the solid phase which is formed on cooling moderately dilute phosphate solutions is not composed of anhydrous crystals of disodium phosphate but rather of the various hydrates. The particular hydrate which is formed depends on the amount of disodium phosphate in the solution. Figure 7-15 also shows that the addition of a third substance to a eutectic solution of sodium chloride in water further depresses the freezing point; a fourth solute depresses it even more.

The above discussion demonstrates that soil solutions will freeze at various temperatures down to -55°C depending upon the number, the nature, and the amounts of dissolved salts. Organic materials also depress the freezing points of aqueous solutions. Because molecules of organic materials, particularly humus and humic acids, are larger than salt ions there are generally fewer of them per unit volume and therefore, they have a smaller effect on the freezing point. Glinka(15) reports that the freezing point depression in soil solutions is seldom more than 1.5°C. However, many regions of the Earth have soils which are enriched in inorganic salts; the Atacama desert of Chile and the Great Salt Lake desert in the United States are examples. Many dry lake beds in the Western United States contain substantial amounts of soluble materials in the surface horizons. When occupied by a body of water, these playa lakes have depressed freezing points; the maximum on record is -48°C for a pond in Antartica. Underground water reservoirs will also freeze at temperatures dictated by their salt content.

In the soil, water is bound to solid materials in several ways. When large pores are present and the water or solution content of the soil is large, migration is controlled by the forces of gravity. The phase behavior is much like that of the same solution in the absence of soil particles. In soils with smaller pores, the effects of surface tension become important. These effects which depend upon the nature of the soil particles as well as on the properties of the solution may alter the freezing point of the soil solution. When the soil is not saturated, absorption effects control the freezing point. When the soil is rich in soluble salts, the water content may be bound in water of hydration with no liquid phase present.

A salt hydrate will have a vapor pressure (partial pressure of water vapor) equal to that of the saturated aqueous solution from which it would precipitate at a given temperature. The existence of a vapor pressure does not indicate that the crystals contain much water, for crystals of sodium chloride can be devoid of water. Crystals of Glaubers salt or of disodium

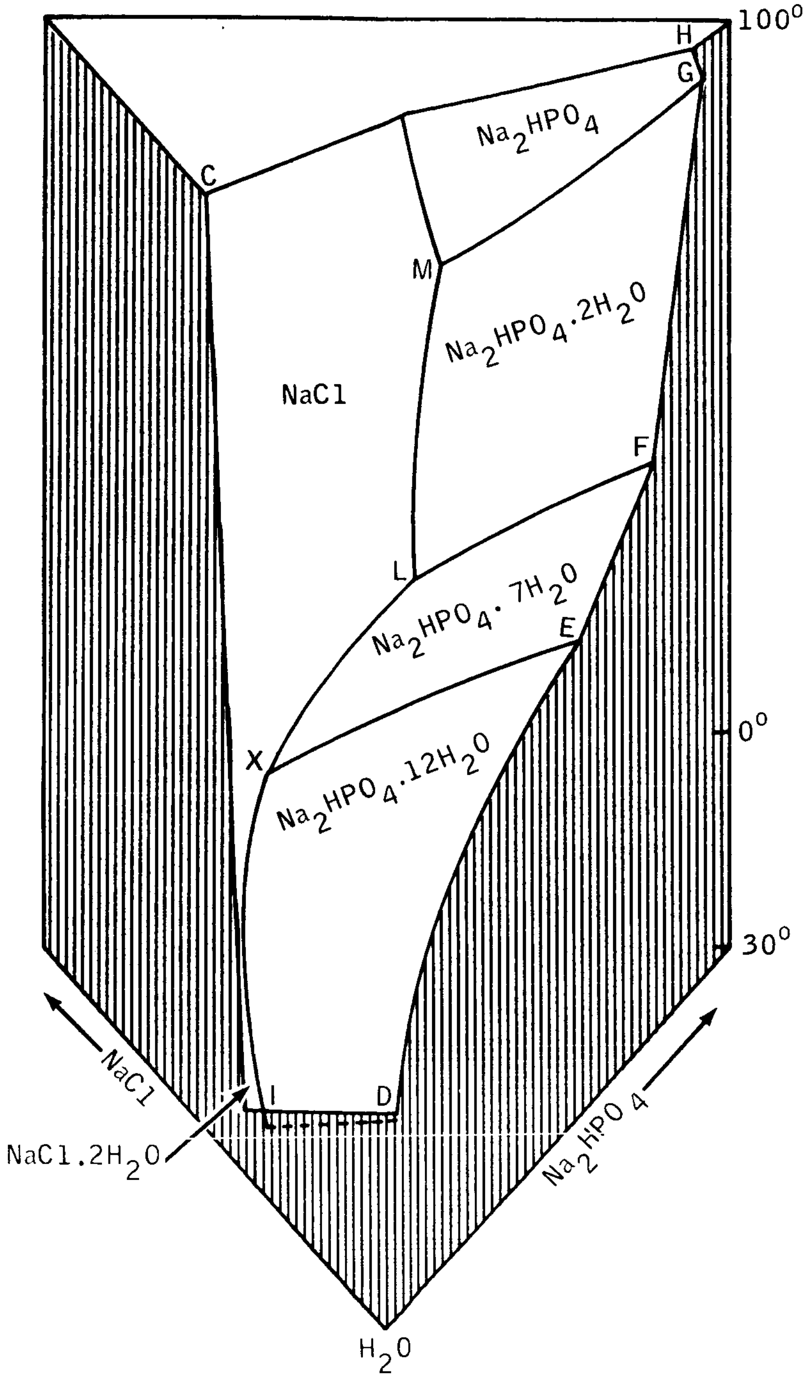

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FIGURE 7-15. PHASE DIAGRAM FOR THE TERNARY SYSTEM OF WATER, SODIUM CHLORIDE AND DISODIUM PHOSPHATE

phosphate can contain much water. The crystals which are in equilibrium with aqueous solutions of disodium phosphate at $0^{o}C$ contain over 60 percent (by weight) of water.

Water in the soil and in underground reservoirs or aquifers occurs in many states, including: Chemically bound as water of hydration, in solid crystalline materials, bound to ions in solution, bound to dissolved molecules, bound to colloidal materials as absorbed water, condensed in pores and in capillary spaces where surface tension forces supress fugacity, and finally, as gravity water. Gravity water has the usual properties which are ascribed to liquid water. At any interface between gravity water in the liquid phase and vapor, the vapor will contain water in the vapor phase in an amount which represents an equality of fugacity on the two sides of the interface. At the temperature conditions expected to prevail on Mars, the phase behavior of pure water will represent the most conservative condition with respect to the availability of water in the liquid phase.

Some materials, such as cobalt chloride crystals, have high water of hydration contents, throughout a range of relative humidities. Other types of crystals have very low equilibrium vapor pressures (of water). The fugacity of the water bound in a crystal depends strongly on the presence of other materials in the crystal.

Many salts can extract water vapor from the atmosphere at low pressure and humidity values. A system consisting of water vapor and a salt will produce a liquid phase containing water whenever the partial pressure of the water vapor in the air exceeds the partial pressure of a saturated solution of the salt at the same temperature. The liquid will contain enough salt to keep the fugacity of the water in the liquid phase equal to that in the vapor phase. If the partial pressure of the water vapor in the gas phase is less than the pressure of the saturated solution, then water will evaporate from the solution. If it is greater than the saturation pressure, water will condense to form a liquid solution. Therefore, the relationship of temperature to the presence of water in a liquid phase will depend upon the concentration of hygroscopic salts in the near surface soil layers. Typically, a salt water lake can extract water from air which has a low relative humidity just as a cold surface can.

In the winter, the surface of the ground is colder than the lower soil horizons. The fugacity of the water vapor in the deeper horizons is greater than that at the surface, therefore, water vapor must migrate toward the surface. If the surface temperature causes condensation and freezing, then the transport of water will be limited to regions well below the surface. In the spring, this moisture may thaw, and the vapor will escape into the atmosphere. To the extent that the pores are open, some vapor will remigrate into the soil to colder horizons. This may occur on a seasonal or daily basis on Mars.

Salts in the soil have only a slight inhibiting effect upon the evaporation rate even when their content is considerable, but organic materials can have a substantial effect. Glinka(15) states that free moisture in terrestrial soils will usually freeze at temperatures not lower than -1.5°C. The capillary adsorbed water, on the other hand, will remain unfrozen to temperatures as low as -78°C.

All of the above data forms the theoretical physical and chemical background for the presence of subsurface water derived from the undersurface melting of permafrost and, to a certain extent, directly from the atmosphere by sublimation or vapor shifting.

7.1.4 SEASONAL POLAR DARKENING AND DARK WAVE PROPAGATION PHENOMENA

The principal seasonal effects taking place on Mars are demonstrated by regular surface and atmospheric albedo changes. These phenomena include:

(1) The polar cloud caps(5,10)

(2) The polar ice caps(5,10)

(3) The dark fringe(5)

(4) The wave of darkening(10)

The references cited for each phenomenon are based on the best descriptions of each available. These features, unlike the canals, appear to be real phenomena, that are recorded year after year with remarkably little variation in size, timing and propagation velocity. The polar cloud caps and ice caps are ably described by Focas(10), their equatorward limits are shown on Figure 7-3 and 7-12, and their mode of formation discussed in Paragraph 7.1.3. The following paragraphs will describe only the dark fringe, the wave of darkening, and the probable importance of these phenomena to the biological studies of Mars.

The dark fringe, several hundred kilometers in width, surrounding the polar ice caps, and retreating with their sublimation, is concluded to be a moisture-related phenomenon. This conclusion is based on the timing of the phenomenon. Vaucouleurs(5) has specifically analyzed the appearance, migration and disappearance of the dark fringe as a function of the rate of mass transformation of the polar ice caps. He has determined that the fringe exists only when the curve expressing regression of the polar cap relative to time is at its steepest. If the average survival time of the Martian polar cap is 35 percent of a Martian year, then the dark fringe will be seen during 22 percent of the year when the rate of sublimation of the polar caps is most rapid. Possible explanations for the visibility and occurrence of these phenomena include:

(1) Actual staining of the surface skin by liquid water related to:

(a) Errors in measured values of Martian polar temperatures and atmospheric pressure.

(b) Existence of films of capillary adsorbed water.

(2) Presence of surface skin films of glaze ice related to subsurface or atmospherically derived water vapor:

(a) Concentrated hygroscopic salts in the surface dust layer.

(b) Capillary adsorbed water bound in dust.

(c) Temperature differences between soil horizons and/or saturated near surface atmospheric layers.

(3) Organic growth.

Detailed discussions of most of these explanations are included in Paragraph 7.1.3.

The propagation of the wave of darkening is admirably documented and illustrated by Focas(10). The conclusions of Focas, that the waves of darkening are wholly generated by water vapor, have been challenged by Rea(16), who advances an inorganic theory. The hydrothermal theories of the development and movement of the waves of darkening are associated with hemispheric exchange winds and the darkening wave is produced by the mechanisms described above (for the polar fringe phenomena) or by seasonal organic activity triggered by the humidity wave. The inorganic theories consider two basic agents, volcanic activity and surface roughening, functioning seasonally with hemispheric exchange winds. The volcanic ash film theory seems to be tenable, but it would involve a degree of seasonal coincidence in eruptive cycles. Surface smoothing and roughening of partially cemented (salts or ice) particles and seasonal infilling and deflationary cycles is an effective theory in view of photometric and polarization characteristics and the stratigraphy of the Mars surface discussed in Paragraph 7.1.3 except for the fact that the bright areas of Mars should be effected to a greater degree than the dark areas. This is contrary to fact.

On the basis of this study, it is concluded that the waves of darkening that radiate seasonally from the subliming polar caps to and beyond the Martian equator are probably created by the dual processes of:

(1) Wind transported humidity effects wherein near surface saturation is maintained by the rising elevation of the surface from pole to equator.

(2) The "spring housecleaning" effect of removing dust from dark areas. At high latitudes, the effect of (1) > (2); at low and equatorial latitudes, (1) < (2).

As in the case of the dark polar fringe phenomenon, the precise manner in which these phenomena are implemented remains unclear. Nevertheless, as Focas(10) demonstrates, the greater coincidence of relating cause to effect appears to favor correlation of these Martian darkening waves with the observed cycle of water vapor. For this reason alone, the waves of darkening are very important to biological exploration probes.

7.1.5 MICROENVIRONMENTS(17)

The photodissociation and escape of water from Mars, despite the protection offered by CO_2, is sufficiently rapid to prohibit the past or present existence of large bodies of surface water. The escape rate also demonstrates that a balance must exist between escaping water and that supplied by internal defluidization. Water collected from the atmosphere and deposited as permafrost and that liberated to the atmosphere from the soil is considered as cycled water and cannot be included in the primary water budget. Internal defluidization may range from active volcanism to thermal springs. Thermal springs can also be related to tectonically developed heat in regions where ground water exists.

The sites where internal defluidization is occurring will provide heat-moisture anomalies. These microenvironments should be concentrated in zones paralleling lines of tectonic activity, such as hinge lines and the active margin of a mobile diastrophic belt, such as that shown in Figure 7-12. The equatorward periphery of the permafrost deposits and the zone of surface wetting by ground water are additional areas that can contain moisture anomaly microenvironments. The heat-moisture type microenvironments would afford optimum growth environments for organisms because the latitude dependence on high surface skin temperatures would be essentially eliminated.

7.1.6 TECHNICAL CONCLUSIONS

The general purpose of the analyses described by Paragraph 7.1 was to investigate those parameters most pertinent to organic growth on Mars, define a geological and environmental model of the overall surface of the planet, and from these data define and locate optimum landing sites for biological exploration.

An examination of extreme environmental conditions under which primitive organisms grow or survive suggests that the temperature regime and the presence of water are the two critical parameters. The factors of gravity, atmospheric pressure and composition, pH of the substrate and many others are essentially unimportant to organic adaptation. High tolerances to radiation and ultraviolet fluxes are exhibited; shielding provided by shallow burial can easily expand these limits of tolerance.

The remaining conclusions that can be derived from this study include the following:

(1) The dark fringe surrounding and retreating with the sublimation of the polar ice caps is wholly a water-related phenomenon.

(2) The waves of darkening that radiate from the subliming polar ice caps to and beyond the equator are probably created by the dual process of: (a) "spring housecleaning" as a function of dust removal from dark areas, and (b) wind transported humidity effects. At high latitudes, the effect of (a) < (b); at low latitudes, (a) > (b).

7.1.7 LANDING SITE RECOMMENDATIONS

Based on the preceding geological and environmental analyses, zones can be selected as overall landing sites for biological investigation. Furthermore, these sites can be classified in order of desirability by use of a redundancy of phenomena philosophy applied to any given area. Figure 7-16 shows these zones keyed to the following desirability scale:

(1) Preferred sites based on overall environmental parameters:

    (a) Class A-1

        - Within ecological growth zone
        - Within area of maximum migration of groundwater
        - Contains area of high sensitivity to the wave of darkening

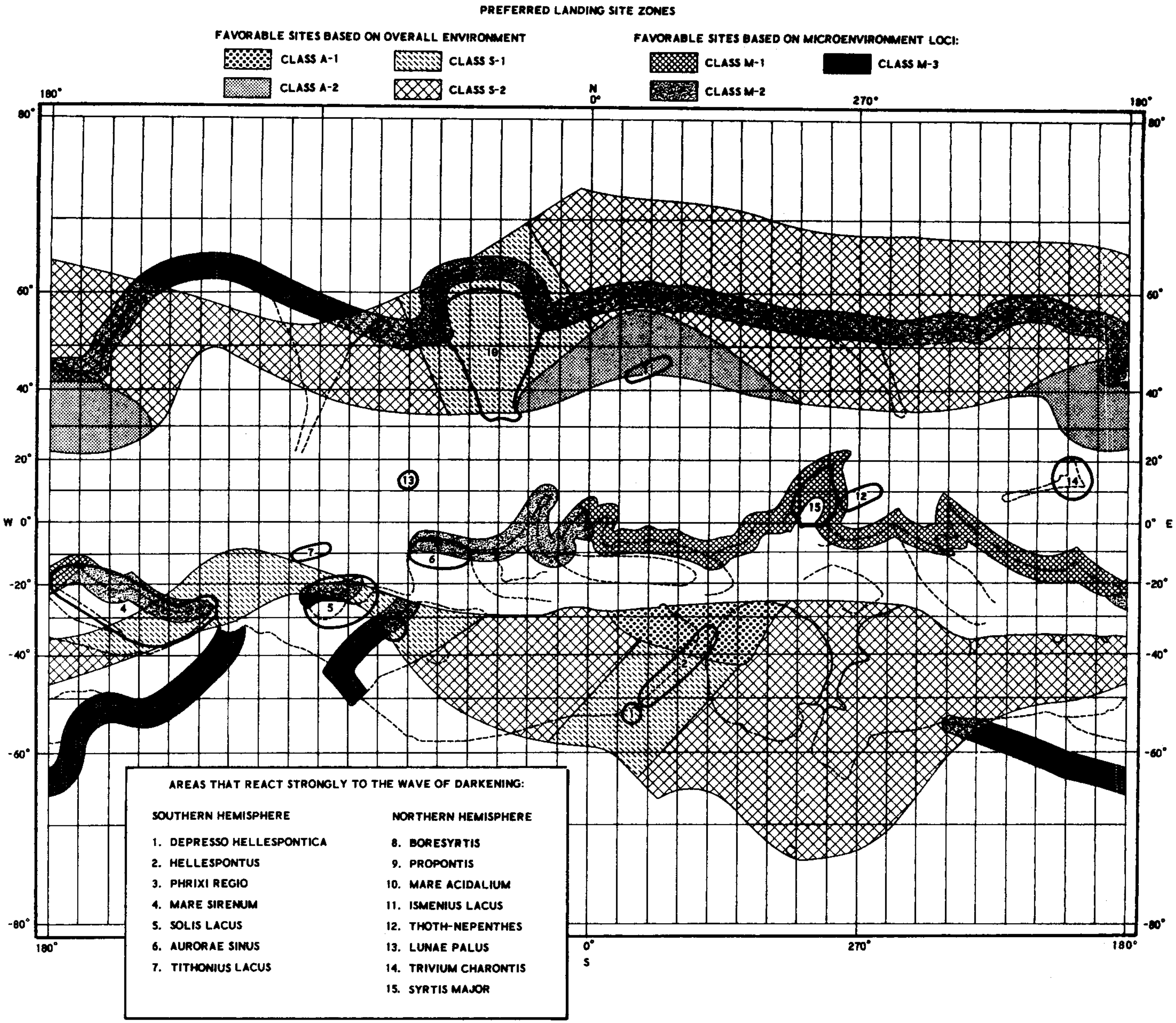

FIGURE 7-16. MARS LANDING SITE DESIRABILITY PLOT

(b) Class A-2

- Within ecological growth zone
- Within area of maximum migration of groundwater

(c) Class S-1

- Within survival zone
- Within area of maximum ground water migration
- Crossed by areas sensitive to the wave of darkening

(d) Class S-2

- Within survival zone
- Within area of maximum ground water migration

(2) Microenvironment loci:

(a) Class M-1

- Contained within the growth zone (low latitude)

(b) Class M-2

- Contained within the Class S-1 area

(c) Class M-3

- Polar basin microenvironments (high latitude)

7.1.8 REFERENCES

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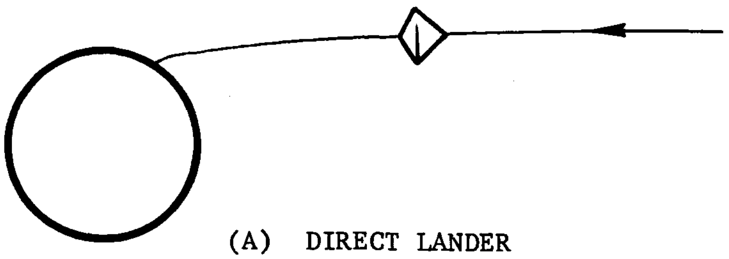
7.2 LANDING SITE ATTAINABILITY

7.2.1 LANDING SITE ATTAINMENT OBJECTIVES AND CONSTRAINTS

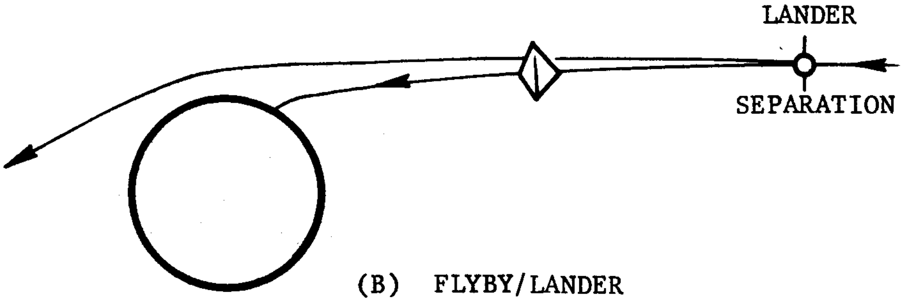
a. Introduction. Scientific objectives of the Automated Biological Laboratory are likely to create the need for landing in preselected areas of the Martian surface. Factors affecting site selection include the communication geometry between the landing site and an orbital relay and/or Earth, the solar position, as it affects lighting at the landing site, and site desirability from the standpoint of experimentation, as discussed previously in Paragraph 7.1. The question ultimately arises as to whether practical means are available for attaining the desired landing sites. If unlimited propulsive capability were available, and if guidance limitations were ignored, any selected landing site would be attainable. As a practical matter, it is necessary to maximize the payload capability, and to avoid overly stringent guidance requirements and unduely complicated approach and landing maneuvers. Further, there will be limitations on the acceleration levels which are acceptable during entry, and the eventual requirement for relatively soft landings will limit the vehicle velocity near the Martian surface to a tolerable value. All these various restrictions, coupled with the characteristics of the Mars arrival trajectory, serve to reduce the portion of the Mars surface that represents a suitable landing area.

b. Mars Lander Concepts. There are a number of possible ways of performing the approach and landing phase of a Mars mission, the simplest of which is a direct lander. Under this concept, the interplanetary spacecraft (bus) and the lander are both guided onto a Mars arrival hyperbola which culminates in entry into the Martian atmosphere. Bus sterilization problems, and the loss of the bus for further experimentation, make this approach relatively unattractive despite its simplicity. A second approach is the flyby/direct lander, in which the bus and lander are placed on a hyperbola with a periapsis somewhat above the Martian surface. While still at a substantial distance from the planet (perhaps 100,000 to 200,000 kilometers), the lander is separated and ejected onto a hyperbola which establishes the desired entry conditions. A third approach is the orbiter/direct lander which resembles the flyby/direct lander, except that the bus is decelerated to an elliptical orbit after the lander is released. The fourth and final approach is the orbiter/lander, in which the bus and lander are decelerated together into an elliptical orbit from which the lander is subsequently ejected onto a descent trajectory to the desired landing site. These four lander concepts are illustrated in Figure 7-17.

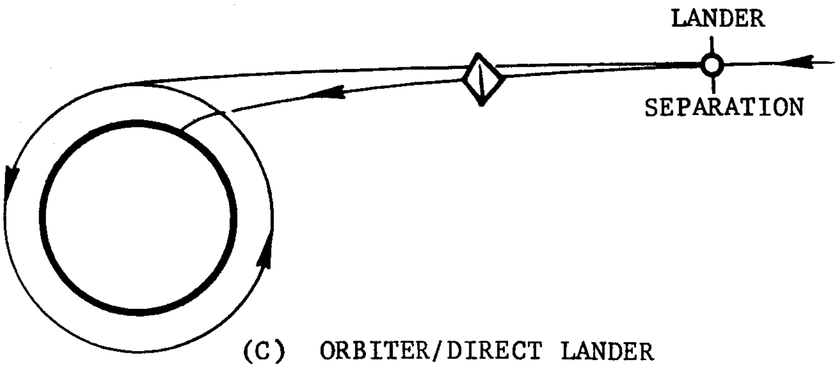
The first three lander concepts have much in common. The lander will approach the planet from a direction dictated by the heliocentric transfer trajectory. Entry velocities will be similar for the three cases and will vary between 5.0 and 7.0 kilometers per second, depending upon the particular trajectory. Landing site attainment will be limited by such factors as the overshoot boundary, undershoot g limitations and terminal



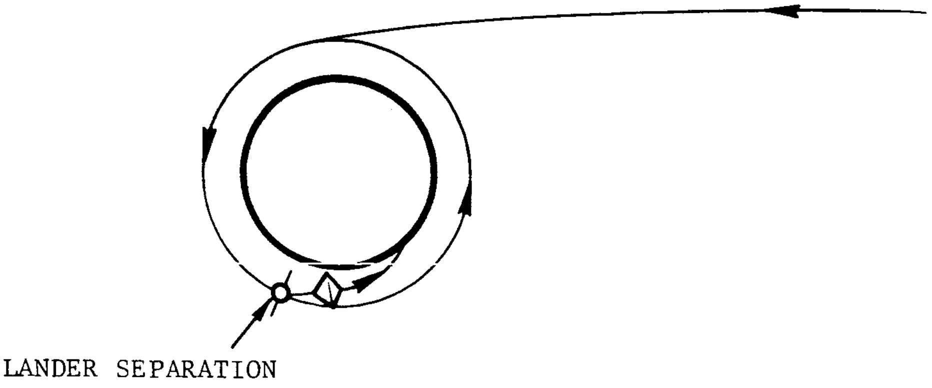
(A) DIRECT LANDER



(B) FLYBY/LANDER



(C) ORBITER/DIRECT LANDER



(D) ORBITER/LANDER

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FIGURE 7-17. MARS LANDER CONCEPTS

velocities. The fourth lander concept, the orbiter/lander, offers substantially lower entry velocities (near 3.5 kilometers per second) and much more flexibility with regard to site attainment, obtained at the price of added propulsive expenditures. Since the direct entry lander concepts are most restrictive with regard to site attainment, these cases have received the principal emphasis in the present analysis.

c. Mars Arrival Geometry. The trajectory of the vehicle as it approaches Mars is dictated by the magnitude and direction of the asymptotic velocity (V_∞) with respect to the planet and to the offset vector $\bar{d}$ which defines the distance separating the arrival asymptote from the planet center. For a given Earth departure date and Mars arrival date, the magnitude and direction of the arrival asymptotic velocity vector will be very nearly constant, irrespective of the particular offset vector which is employed. It is by varying the offset vector and timing the arrival that site attainment flexibility is accomplished.

(1) Effect of Offset Vector Changes. Figure 7-18 shows how variations in the offset vector modify the approach hyperbola and permit the establishment of a variety of entry trajectories. Small "d" values result in large entry flight path angles, and correspondingly high decelerations and possibly higher impact velocities. Larger "d" values result in shallower entry angles but more severe guidance requirements as the overshoot boundary is approached. By imposing quantitative limitations on entry accelerations, guidance accuracies, etc., it is possible to define a zone which represents attainable landing sites. The required variations in the offset vector can be accomplished upon Earth departure and during the mid-course maneuvers.

(2) Effect of Arrival Time Variation. The attainable zone defined above does not account for the fact that Mars is rotating about its polar axis, thereby adding a degree of freedom which may be used for site attainment. By carefully controlling the time of arrival, a desirable landing site, with a suitable latitude, can be permitted to rotate into the attainable zone illustrated in Figure 7-18 . The necessary timing of the arrival can be accomplished at Earth departure and during midcourse and terminal maneuvers. This process is in practice no more difficult than any other guidance functions, since an adjustment in the time of Mars arrival is (in reality) an adjustment of position at Mars arrival.

d. Methods of Analysis.

(1) Interplanetary Trajectories. Interplanetary trajectory data used in the site attainment study was derived in part from References 1 through 3, and also from data generated using Aeronutronic's Patched Conic Interplanetary Mission Program. The latter use was necessitated by the lack of available data concerning Type II trajectories beyond the early 1970's. A summary of asymptotic velocity requirements for the 1970-1980

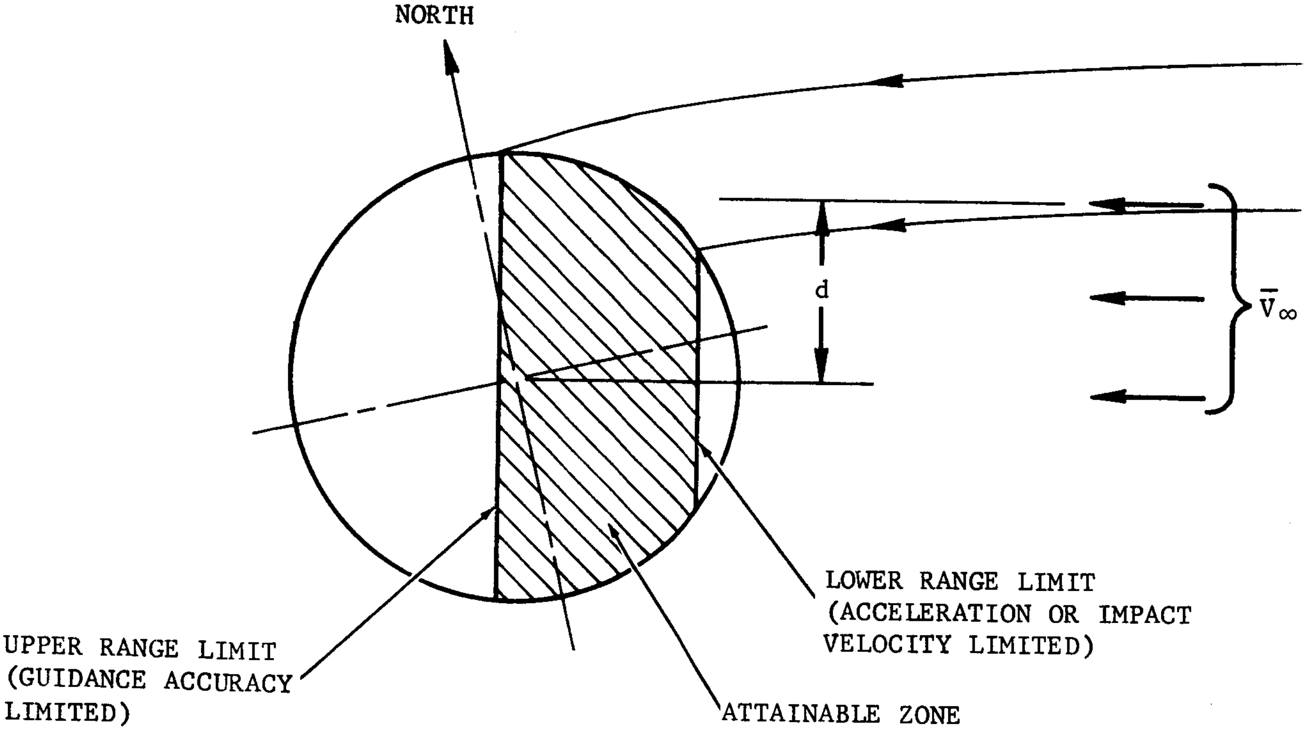

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FIGURE 7-18. ATTAINABLE LANDING ZONE GEOMETRY period is contained in Reference 4. All trajectories were computed as if departure were from the position of the center of Earth on the departure date, and arrival were at the center of Mars on the arrival date. Ephemeris values were taken from Reference 5, and the interplanetary trajectories were assumed to be three-dimensional Keplerian conics.

(2) Mars Approach Geometry. The geometry associated with the approach to Mars made use of a Mars equatorial coordinate system in which the Mars/Earth vector, the Mars/Sun vector, and the arrival asymptotic velocity vector were computed. Orientation elements of the Mars polar axis used to construct this coordinate system are as follows

Right Ascension = $21^{h}\ 11^{m}\ 49^{s}.52$

Declination = $54^{o}\ 44'\ 42''$

1962 American Ephemeris and Nautical Almanac values were used, with adjustment to the year 1975. In constructing the Site Attainment Geometry Plots, the motion of the Sun and Earth in the Mars equatorial coordinate system was neglected during the short period before arrival. The positions used were those on the date that the unperturbed interplanetary trajectory reaches its Mars terminus.

(3) Computation of Lower Range Boundary. The lower range boundary was computed on the basis of entry acceleration and critical velocity limitations, the former to account for structural and payload design problems, the latter to account for the requirements of a velocity reduction system. The computations made use of the linearized entry theory contained in Reference 6. The procedure involved the computation of the entry angle representing the limiting condition, which was used in turn to compute the elements of the arrival hyperbola and the associated impact location.

The acceleration limited entry angle is given by

$$\gamma = \sin^{-1} \left\{ \frac{2\ g_{max}\ g_{\oplus}\ e}{\beta\ V_e^2} \right\}$$

where

g_{max} = Acceleration limit, Earth g's

$g_{\oplus}$ = Earth surface acceleration of gravity

β = Atmosphere inverse scale height

V_e = Entry velocity as computed from vis-viva equation using the arrival asymptotic velocity.

e = 2.71828

γ = Entry angle from local horizontal

The velocity limited entry angle is given by

$$\gamma = \sin^{-1}\left\{\frac{\rho}{\beta\left(\frac{m}{C_D A}\right)\ln\left(\frac{V_c}{V_e}\right)^2}\right\}$$

where

ρ = Atmosphere density at attitude where critical velocity is reached (50,000 ft for this study.)

$\frac{m}{C_D A}$ = Entry vehicle vallistic coefficient

V_c = Critical velocity magnitude (1500 ft/sec for this study)

Having established the relevant entry angle, the elements of the arrival hyperbola are computed as follows:

$$\text{semi latus rectum, } p = \left(\frac{r_e}{r_♂}\right)^2 \left(\frac{V_e}{V_{co}}\right)^2 \cos^2 \gamma$$

$$\text{major semi-axis } a = -\left(\frac{V_{co}}{V_\infty}\right)^2$$

V_{co} = Mars surface circular satellite velocity

$r_♂$ = Mars radius

r_e = Entry radius

V_∞ = Asymptotic velocity

Eccentricity	$e = \sqrt{1 - p/a}$
Periapsis angle	$\Psi = \cos^{-1}\left(\frac{1}{e}\right)$
True anomaly	$v = \cos^{-1}\left(\frac{p-1}{e}\right)$
Impact location angle	$\delta = \Pi - \Psi - v$

The above angles are described in Figure 7-19. The impact location as computed neglects atmospheric effects. For entry angles considered in the study, this is a valid approximation which is slightly more accurate than the usual first-order practice of assuming the trajectory to be a straight line within the atmosphere.

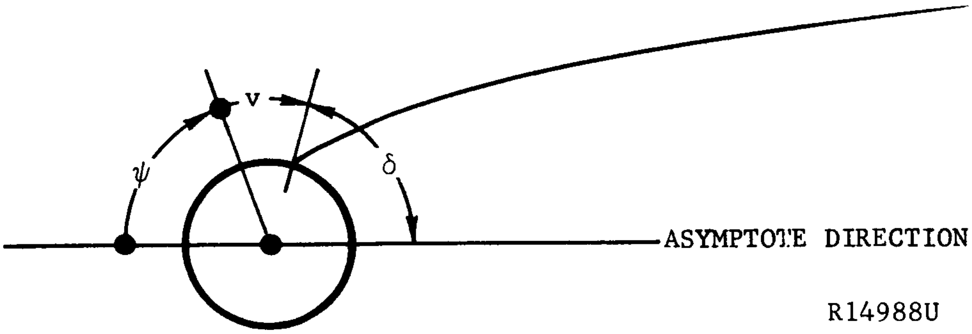


FIGURE 7-19. DESCRIPTION OF ANGLES

(4) Computation of Upper Range Boundary. The first step in establishing the upper range boundary was to compute the entry angle associated with the overshoot boundary. This was accomplished using Chapman's numerical results (Reference 7). Chapman defines the following periapsis parameter which is useful in defining the overshoot boundary.

$$F_p = \frac{\rho_p}{2(m/C_D A)} \sqrt{\frac{R_p}{\beta}}$$

ρ_p = Density at periapsis of unperturbed hyperbola

R_p = Periapsis radius of unperturbed hyperbola

Overshoot will occur for an Fp value which depends upon the entry velocity. Using an empirical fit to Chapman's data, this overshoot value can be expressed as

$$F_{po} = 0.0019\ (11.85)^{V_e/V_{co}}$$

Using this F_p value, it is possible to solve the previous F_p equation for the periapsis radius R_p. Since the equation is transcendental, it is convenient to neglect the variation in F_p produced by the quantity contained in the radical. When this is done, and an exponential atmosphere is used, the periapsis radius may be written as

$$R_p = r_e + \frac{1}{\beta} \ln \left[\frac{\rho_e \sqrt{r_e/\beta}}{2\ F_{po}\ \frac{m}{C_D A}} \right]$$

The overshoot entry angle may then be computed from

$$e = 1 + \left(\frac{R_p}{r_♂}\right) \left(\frac{V_\infty}{V_{co}}\right)^2$$

$$p = \frac{R_p}{r_♂} (1 + e)$$

$$\gamma = - \cos^{-1} \frac{\sqrt{p}}{[r_e/r\ ]\,[V_e/V_{co}]}$$

Because of guidance inaccuracies, it is impractical to attempt entry too near the overshoot limit. Figure 7-20 shows the entry angle error produced by a one milliradian in-plane error in the direction of the hyperbolic asymptote when the vehicle is at various distances from Mars. The uncertainty in this direction is a significant contribution to the entry angle error. When the vehicle is at a distance of 75 planet radii from Mars (a suitable lander separation distance) with an asymptotic velocity of 3 km/sec, the 0.057 degree direction error results in an entry angle error of just under 8 degrees. This same error produces an error in the trajectory periapsis altitude of approximately 200 km. Accuracies of this order require the use of an approach guidance technique. Reference 8 contains a description of an applicable technique. Using televised images of Mars against its star background, it was shown to be possible, with realistic measurement accuracies, to adjust the periapsis altitude to within 150 km of the desired value. The particular case studied had a Mars arrival asymptotic velocity of nearly 4.0 km/sec.

In order to reflect comparable guidance accuracies in the present study, it was assumed that no trajectory would utilize an entry angle nearer than 8 degrees to the overshoot boundary. The entry angle for the upper range boundary was taken to be

$$\gamma = \gamma_o + 8 \text{ degrees}$$

and the impact locations were computed as described in Paragraph 3.

7.2.2 STUDY RESULTS

The study described in this paragraph was undertaken in 1964 as one of the first tasks in the present ABL study.(4) Uncertainties in the Martian atmosphere have always presented a major obstacle to the design of a Martian lander and this condition was true for the present analysis. Atmospheric models selected at the time of the initiation of the study even predated publication of Reference 9 (November 1964) and so were selected from previous Mars mission studies performed by Aeronutronic and from the work of Kaplan, Spinrad, and Munch.(10) They are described in Appendix 17, Volume VI. The lower limit model used had a surface pressure of 15 mb which correlates well with early interpretations of the Mariner IV occultation data (10 to 20 mb). However, the scale height employed with this atmosphere was significantly greater than that currently being indicated by the occultation data, such that ballistic coefficients appreciably higher than now are being considered, appeared to be feasible. As indicated in a typical plot resulting from these analyses, as shown in Figure 7-21, ballistic coefficients of 20 $\text{lb}/_m/\text{ft}^2$ gave feasible undershoot boundaries. In contrast, however, note the values of 7.5 to 10 $\text{lb}/_m/\text{ft}^2$ employed with the less dense model used in the later analyses of Paragraph 6.6. While these data now appear (in consequence of the

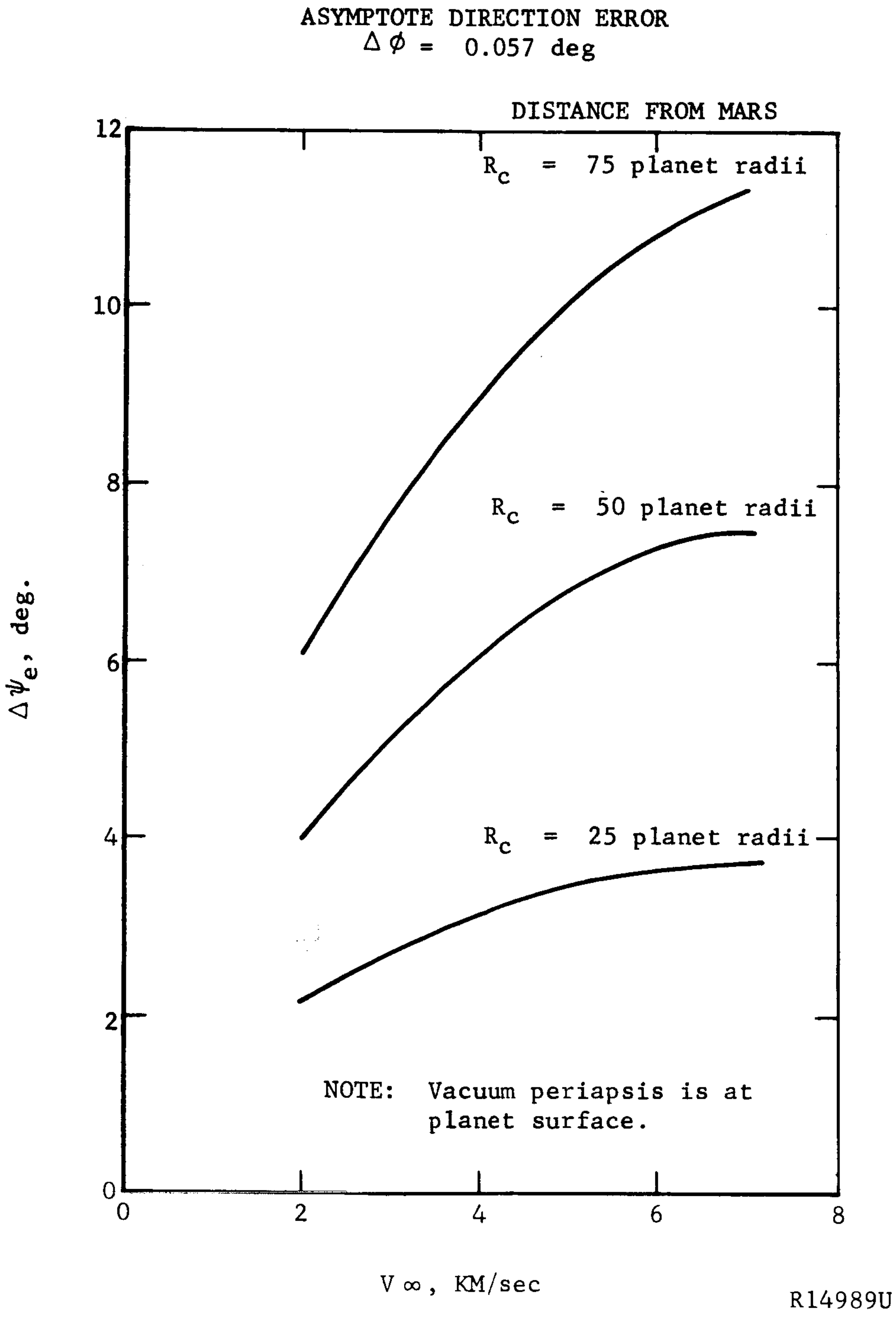
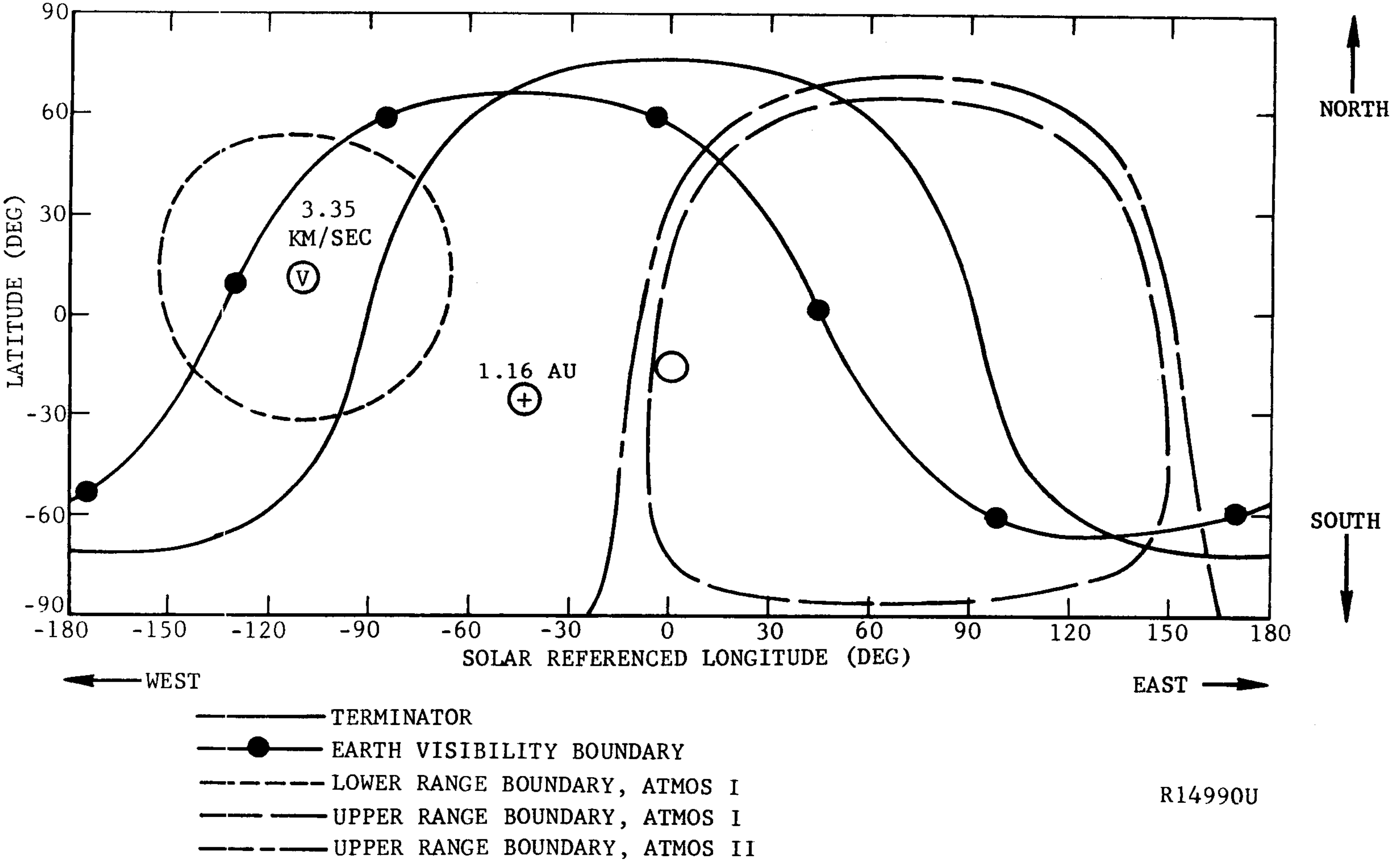


FIGURE 7-20. EFFECT OF ASYMPTOTE DIRECTION ERROR ON ENTRY FLIGHT PATH ANGLE



LAUNCH DATE - 24 APRIL 1971, LAUNCH 15 DAYS BEFORE MIN LAUNCH ENERGY
ARRIVAL DATE - 28 DEC 1971
ENTRY VELOCITY - 5.92 KM/SEC
M/C_oA = LB_M/FT^2

FIGURE 7-21. SITE ATTAINMENT GEOMETRY 1971 TYPE II postulated lower density) to have limited usefulness for actual selection of landing sites, it was felt that presentation of the data was warranted because of the useful trends which the data indicate. Furthermore, while the atmosphere is now generally acknowledged to be less dense then the models used in this analysis, the final results of the Mariner IV occultation data reduction have not been published as of the writing of this report, and it was felt that sufficiently firm data were not available at this time to justify the recomputations required by these analyses. The analytical procedures and computational programs exist at Aeronutronic for this analysis, as described in the preceding paragraphs, and when firm atmospheric data become available to warrant such an investigation, this information can be readily generated. The detailed assumptions employed in this analysis and the bulk of the data obtained may be found in Appendix 17.

The overshoot and undershoot boundary limits to the selection of landing sites were not, however, the only data generated by the program developed in this study. Information on Earth communication geometry, radar aspect angle, location and magnitude of the approach velocity vector, and the Earth-Mars distance at arrival are also displayed on these plots and, of course, are not affected by the assumptions for the atmospheric model. The variations of the Earth's position in the Martian coordinate system were utilized directly in defining antenna pointing requirements in Paragraph 6.2 of this volume (see Figures 6.2-5 and 6.2-24). The plots of the terminator line were useful in developing the time-line event diagrams in Paragraph 4.2 by indicating available day-light hours available after landings at various longitudes for the phasing of light-dependent experiments.

Also developed as a result of these same analyses was the plot shown in Figure 7-22, giving the relationship between Martian season at arrival and the various mission opportunities in the 1970-1980 time period. The convenient form of this plot can aid in the evaluation of different flight opportunities with respect to expected seasonal phenomena, the effects of launch window length, and other-than minimum-energy trajectories (earlier or later arrival dates) on experimental mission planning.

7.2.3 CONCLUSIONS

The difficulty of defining specific ABL landing sites from arrival hyperbolas at Mars can vary considerably, depending upon the density of the Martian atmosphere. For the lower density atmosphere models, site attainment becomes more difficult. To keep terminal velocities low, it is necessary to employ low ballistic coefficient structures, shallower entry angles, and probably to make considerable use of retropropulsion. This results in rather restricted entry ranges, limited on the upper side by guidance accuracy and on the lower side by the extent of the measures required to slow the vehicle for landing. Site attainment capability

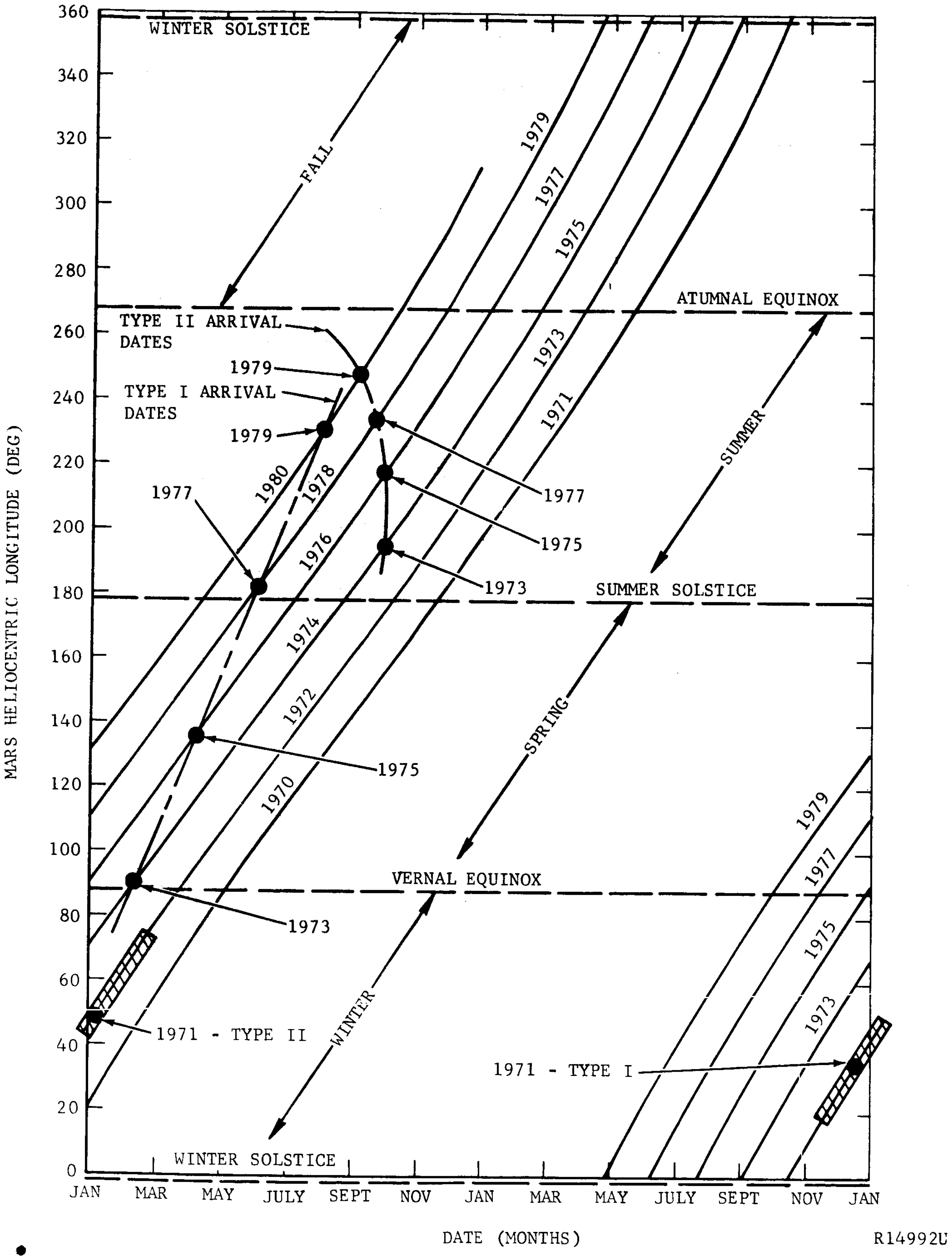


FIGURE 7-22. ARRIVAL DATA - MARS SEASONS RELATIONSHIPS (NORTHERN HEMISPHERE, 1970-1980)

would still be fairly good, if further constraints were not required. For example, a direct lander-to-Earth communications link may be desirable during and shortly after landing. The use of optical sensors during and after landing may dictate that the landing be in a sunlit zone. These constraints, coupled with the vehicle design constraints, make the attainment of certain landing sites rather difficult. If near equatorial landing sites, e.g., Syrtis Major, are desired for a Type I mission, and if the Earth visibility and illumination constraints are imposed, it will often be necessary to use entry angles that are large. This can be accomplished only by a considerable payload sacrificed for a larger velocity reduction system. Type II missions ease the site attainment problem, but add the difficulties associated with longer trip durations and greater communication distances.

7.2.4 REFERENCES

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SECTION 8

ANALYSIS OF EXISTING PLANETARY PROGRAMS

8.1 GENERAL

As a part of the ABL study Aeronutronic was directed to undertake a task (1) to determine whether currently planned NASA programs would provide data in support of an ABL program, (2) to recommend where useful data could be obtained with modification of or addition to planned programs, and (3) to recommend pre-ABL exploration. With a 1975 ABL Launch as a reference point, no currently planned program will provide information about Mars in time to significantly influence system design. Figure 8-1 shows a preliminary ABL development schedule along with Mariner 4 data input and estimated Voyager 69 data input. The Voyager 69 data would influence ABL design if the schedule were slipped approximately two years. The design of an ABL would be influenced very significantly by discovery of macroscopic life forms on Mars; however, engineering data (i.e., Mars surface environment data) would not change the design approach developed during this study. Engineering data would certainly aid in optimizing system design, particularly design of support systems, but the basic technology for ABL design exists now.

This task also included investigation of booster systems that have application to ABL. Seven such systems, including Saturn 1B, Titan IIIC, Atlas, and Centaur are discussed in this paragraph.

8.2 EXISTING PLANETARY SCIENTIFIC PROGRAMS SURVEY

This portion of the ABL study was directed toward summarizing the requirements for pre-ABL exploration and comparing it with currently planned planetary missions. In this way, it is possible to define those areas in which useful data will be available, and to highlight those areas in which additional planetary programs could prove advantageous.

8.2.1 EXPERIMENTAL REQUIREMENTS

In the ABL work statement, two possible categories of pre-ABL experimentation were defined, (1) required, and (2) desirable. The term "required" infers experimental data without which the success of the ABL mission would be compromised. "Desirable" data infer information that is useful, but not critical to mission success. It is felt that it is possible, through particular attention to careful system and design detail, to synthesize an ABL vehicle based only upon the information known at this time. Within this framework, there are no data that could be classified as "required" or "mandatory." The data, instead, fall into a broad range of desirability. The availability of specific information would, however, permit the design of an ABL vehicle with a higher payload ratio, since the design contingency would be reduced in that particular area. For example, if the diurnal and seasonal temperature variation with longitude could be defined with some certainty, the thermal control system design could be far more definitive than if it must be based upon the current hypotheses. The data requirements discussed in the following paragraphs are those which are desirable, in order to permit the design of an ABL-lander system that can devote an optimum amount of its total weight to its basic scientific mission.

a. Biological Program Support Data. The parameters listed below are necessary for an evaluation of the Martian environment, in support of the exobiology program.

- Daily and seasonal variations in the temperature of the lower atmosphere, soil surface, and immediate soil subsurface.
- Spectral distribution and intensity of radiation at the planetary surface.
- Water content of the atmosphere, surface soil, and subsurface soil.
- Chemical composition of the lower atmosphere.
- Ionizing radiation levels and energies.

These experiments have been included in the ABL and therefore are not required in advance of the ABL for support of the biological program.

An important piece of data in support of the biological program, but not itemized above, would be confirmation of the presence of macroscopic life. If the presence of macroscopic forms could be confirmed, the nature of the ABL biological experiments would be drastically modified. Particularly affected would be the sample search, collection, and processing systems in ABL.

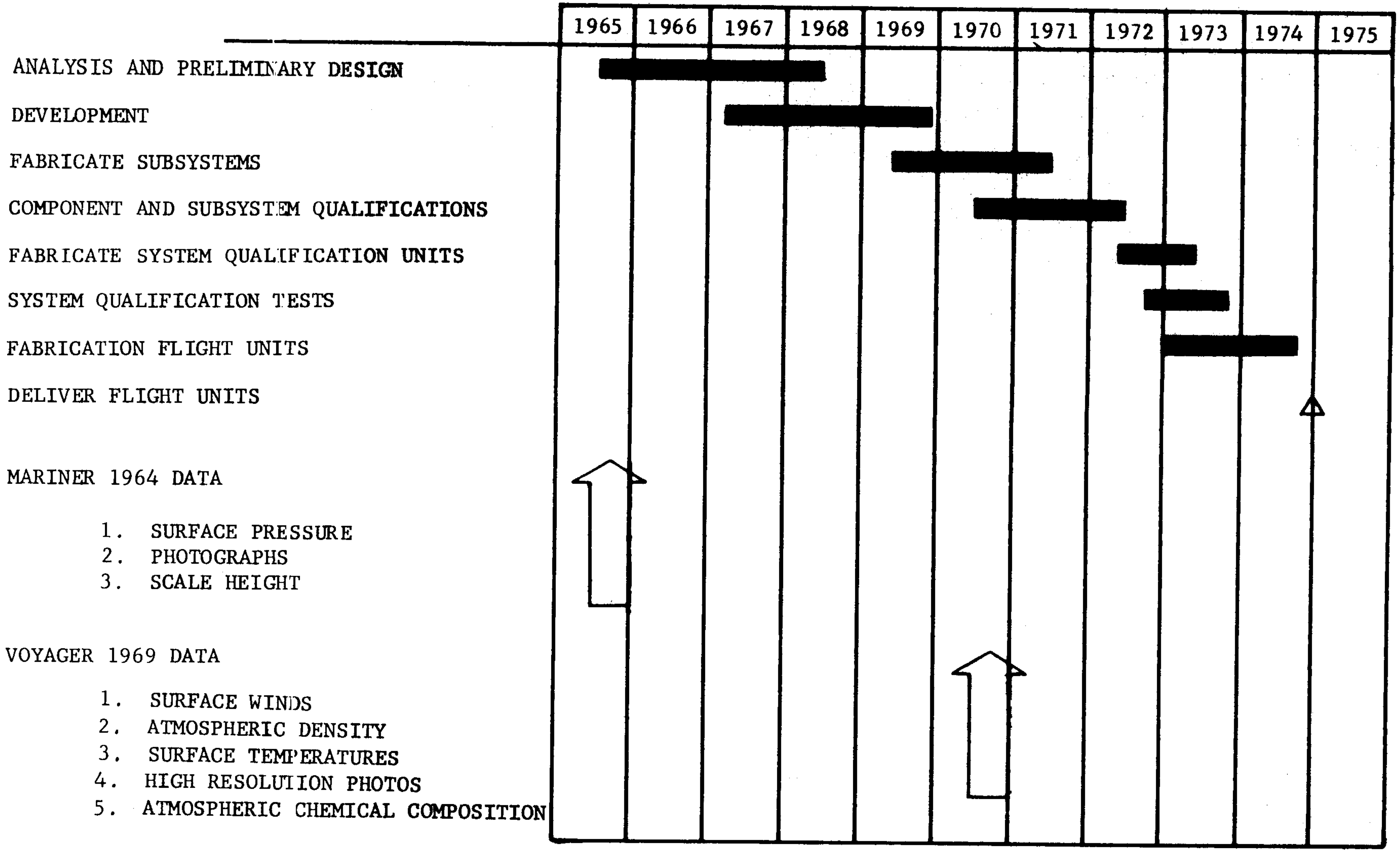

FIGURE 8-1. ABL DEVELOPMENT SCHEDULE BASED ON A 1975 LAUNCH DATE

b. ABL Design Support Data. The parameters listed below are desirable to assist in optimizing the ABL and lander vehicle systems. It should be noted that representative ranges for much of these data are available in the responsible literature. However, if the ranges of uncertainty can be narrowed by pre-ABL missions, the effectivity of the ABL can be increased immeasurably. The parameters have been listed in the order of their importance to the ABL design program, along with the disciplines most vitally affected.

(1) Surface Wind Phenomena. The literature indicates the presence of large weather fronts moving across the visible face of Mars. Dust storms are postulated on the surface and at high altitudes. Combined with the relatively wide diurnal temperature variation, and using Earth meteorology as a model, violent atmospheric disturbances can be expected. The effect of severe local (small scale) atmospheric disturbances on the ABL and its mission could range from troublesome to catastrophic. While current data can be used to postulate such phenomena, no direct measurements are available. Additional information on the horizontal and vertical wind velocities and patterns is very desirable.

In combination with the atmospheric surface density, the wind phenomena will define the dynamic pressure of the lower airstream, and hence its capability to transport surface particles and to affect erected structures (e.g., antennas). The effects of wind-transported particles can range from possible degradation of critical vehicle surface (e.g., optical surfaces) to burying of critical vehicle components.

(2) Atmospheric Density at the Surface. Atmospheric density at the surface is necessary to define airstream dynamic pressure as discussed above. Atmospheric density also influences rate of heat transfer between the Martian atmosphere and the ABL as summarized below.

(3) Daily and Seasonal Temperature Variation of the Atmosphere and Soil Surface. Heat is radiated to the vehicle as a function of T^4. Thermal radiation constitutes a major part of the external thermal heat exchange with the ABL. Radiator size and insulation thickness and type are directly affected by surface temperature. The opportunity to employ passive rather than active thermal control may depend on the accuracy with which the surface temperature extremes are known.

(4) Medium and High Resolution Photography. Quality image data will assist in establishing gross topological features, thus helping to define landing sites with a maximum biological interest and entailing a minimum of landing risk. If the presence of a macroscopic life could be detected, the entire emphasis of the biological program would be influenced.

(5) Chemical Composition of the Lower Atmosphere. Many of the parameters entering into the heat transfer rate are dependent upon the chemical makeup of the working fluid. This includes viscosity, thermal conductivity, and specific heat. Antenna breakdown power is also affected by the constituents of the atmosphere. Tests have shown that in an argon atmosphere, breakdown power is about 50 percent lower than in air. The possibility of utilizing the Martian atmosphere for certain ABL processing functions (e.g., as carrier gases) is critically dependent on a precise knowledge of the chemical composition.

8.2.2 PLANETARY MISSION PLANNING

Literature surveys and personal contacts with members of the engineering and scientific community were utilized to survey the extent of currently planned and anticipated Mars missions. The experimental emphasis of these missions and studies has been investigated in detail in order to define those experiments which have particular application to the ABL program. Each program and its scientific emphasis is discussed in the sections which follow.

a. Mariner Program. The Mariner 4 mission has provided new data that tend to verify the low pressure models of Mars' atmosphere. A much lower scale height that previously postulated is also evident. Analysis of the photos has not been completed at the writing of this report. The remainder of the measurements are directed toward gathering data on interplanetary and near-Mars phenomena (see Table 8-I).

The 1966 Mariner flyby mission was to provide a considerable amount of detailed data concerning the atmospheric and surface properties of the Martian environment. It has been cancelled. A summary of the previously planned experimental equipment is presented in Table 8-I.

TABLE 8-I

MARINER EXPERIMENTAL EQUIPMENT SUMMARY

1964 Flyby	1966 Flyby
1. Cosmic ray telescope	1. Infrared scanner
2. Cosmic dust detector	2. Infrared interferometer
3. Trapped radiation detector	3. Ultraviolet spectrometer
4. Ionization chamber	4. S-band occultation
5. Plazma probe	5. Magnetometer
6. Magnetometer	6. Trapped radiation detector
7. Television	7. Micrometeoroid detector

b. Voyager Program. The studies of Reference 4 and 5 were conducted to investigate the operational requirements for the Voyager spacecraft. In both studies, the operational sequence featured both an orbiter and surface landing vehicle.

The second study report included the instrumentation requirements for both 69 and 71 Voyagers. The equipment list for the 69 Voyager was used during this study, since it was felt that it was more representative of missions likely to influence ABL design. The equipment from this 69 Voyager study is presented in Table 8-II.

The study of Reference 4 employed the philosophy that the broad categories of experimental interest, e.g., biology, geology/geophysics, and data for manned landings, precluded the delineation of a fixed experimental equipment payload. Payload values were assigned each instrument based upon the mission value, and the rated ability of the instrument in question to provide the desired data. The selection of a payload package then consisted of selecting the experiments with the highest payload values and accumulating them until previously determined weight, volume, power, or bit capacity were exceeded. It became evident, however, that many experiments were common to all missions, and that the variation from mission to mission was in only a few specialized experiments. Thus, the attempt to apportion the payload instrumentation along mission lines was abandoned in favor of selecting a payload to provide optimum scientific information within a given framework of vehicle weight and communications capability. A 24-hour mission time was selected, and a payload assembled by selecting instruments according to their payload values until the system limitations were met. In this manner, a 60-pound "minimum payload" and a 95-pound "optional minimum payload" were selected for the Mars landing vehicle. A supplemental payload was added to the "optional minimum payload" to increase the payload weight to 200 pounds. These experiments, along with those included on the orbiter-bus are presented in Table 8-II.

c. The Orbiting Observatories. Three large observatory type satellites are currently being used and/or prepared for use to augment the small satellites in collecting specific scientific data. These are the solar observatory (OSO), geophysical observatory (OGO), and astronomical observatory (OAO). In addition, an advanced version of the solar observatory (AOSO) is currently planned for operation late in the 1960's. The experiments or equipment planned for use on these vehicles is summarized in Table 8-III.

d. Manned Orbiting Laboratories. The Air Force Manned Orbital Laboratory (MOL) program and the NASA Manned Orbital Research Laboratory (MORL) program are in their early conceptual stages. The current planning for MOL indicates a first-launch date in the 1969-1970 time period. The stated purpose of the MOL is to support a series of space experiments to determine man's long-term usefulness in space. In view of this mission, no effort appears to be directed in support of interplanetary exploration.

TABLE 8-II

SUMMARY OF 1969 VOYAGER INSTRUMENTATION RECOMMENDATIONS

Voyager Study (Ref 1)

A. Entry and Descent Phase

   1. Resistance thermometer
   2. Elastic membrane
   3. Densitometer
   4. Mass spectrometer
   5. Gas chromatograph
   6. Radar altimeter
   7. Langmuir probe

B. Surface Phase - Two Landers

   1. Resistance thermometer
   2. Elastic membrane
   3. Densitometer
   4. Mass spectrometer
   5. Gas chromatograph
   6. Anemometer
   7. Television
   8. Precipitation cone
   9. Microphone
   10. Light level indicator
   11. Penetrometer
   12. Oven/collector
   13. 1-axis seismometer
   14. Gravitometer
   15. Radioisotope growth detector
   16. Turbidity/pH growth detector
   17. Multiple chamber growth detector
   18. Photoautotroph detector
   19. Microscope
   20. Drill
   21. Pulverizer
   22. Sample handling equipment

C. Orbiter

   1. IR Multichannel radiometer
   2. IR Spectrometer
   3. Magnetometer
   4. Television (multicolor, stereo)
   5. Cosmic dust detector
   6. Bistatic radar
   7. Geiger tubes/ionization chamber
   8. Solar multichannel radiometer
   9. Polarimeter
   10. Sferics detector

Voyager Study (Ref 2)

A. Surface Phase

   1. Minimum payload

      a. Gas chromatograph
      b. Inorganic X-ray diffractometer
      c. Television
      d. Sample collector
      e. Mass spectrometer
      f. Anemometer
      g. Thermometer
      h. Pressure detector
      i. Multiple chamber growth detector

   2. Optional Minimum Payload

      a. Television
      b. Pressure detector
      c. Densitometer
      d. Thermometer
      e. Sonic velocity detector
      f. H_2O detector
      g. Anemometer
      h. Microphone
      i. Bio pack

         (1) IR spectrometer
         (2) UV/Visible spectrometer

      j. Sample collector

   3. Payload Supplement

      a. 3-axis seismograph
      b. Turbidity/pH growth detector
      c. X-ray diffractometer
      d. X-ray spectrometer
      e. Core drill and mill
      f. Petro microscope
      g. Mass spectrometer

B. Orbiter

   1. Particle flux detector
   2. Ion chamber
   3. Cosmic dust detector
   4. Bistatic radar
   5. Magnetometer
   6. IR spectrometer
   7. Micrometeoroid detector

TABLE 8-III

EXPERIMENT SUMMARY FOR THE ORBITING OBSERVATORIES

I- Orbiting Geophysical Observatory
Launch Dates: 1964, 65(3), 66, 67, 68, 69(2), 70, 71

OGO's A and C

1. Solar cosmic rays, 10-90 Mev
2. Positron and gamma ray detection
3. Trapped radiation studies, or trapped electrons with directional energy flux 10 Kev E 100 Kev, and protons with directional intensity, 120 Kev E 4.5 Mev.
4. Galactic cosmic rays and isotope abundance
5. Low energy galactic cosmic ray flux
6. Trapped radiation, using Geiger tubes to measure omnidirectional intensities of outer belt electrons exceeding 40 Kev, 120 Kev, and 1.5 Mev.
7. Trapped radiation, using spectrometer to measure electron energy up to 4.0 Mev.
8. Fluctuations in vector magnetic field in frequency range 0.01 to 1000 cps.
9. Magnitude and direction of magnetic fields over the range 1-100 gammas.
10. Measurement of proton concentrations as a function of proton energy.
11. Proton flux and energy spectrum and their variations, in the energy range 10 ev-10 Kev.
12. Concentration and energy distribution of charged particles in energy range 0-1.0 Kev.
13. Densities and energy distributions of charged particles of both polarities in the low energy or thermal range.
14. VLF noise and propagation at frequencies of 200 to 100,000 cps.
15. Dynamic radio spectra in solar bursts.
16. Electron number beneath satellite.
17. Positive ion composition in the range 1-50 AMU.
18. Micrometeoroids, vector velocity distribution, cumulative mass distribution, effect of geocentric distance.
19. Lyman alpha scattering in the geocorona and interplanetary medium
20. Geogenschein photometry in UV, green and IR.

B. OGO's B and D

1. Galactic emission at 2.5 and 3.0 Mc/s.
2. VLF measurements of terrestrial and other emissions in the frequency range, 0.2 to 100 Kc.
3. VLF terrestrial and other emissions at 0.5 to 10 Kc.
4. Magnetic field fluctuations in the low audio-frequency range.
5. World magnetic survey.
6. Comparison of ionization over polar regions with that measured by space probes.
7. Determination of nucleons, 0.3 to 30 Mev.
8. Energy spectrum and charged particle composition of galactic and solar cosmic rays.
9. Net downflux of corpuscular radiation in the auroral zones and over polar caps.
10. Low energy trapped radiation and auroral particles (electrons, 10-100 Kev; protons, 100 Kev to 4.5 Mev).
11. Photometer airglow at 6300A, 5577A, 3914A, and in near UV.
12. Airglow studies in the Lyman alpha, far UV, and 1230A-1350A region.
13. Airglow measurements between 1100A and 3400A.
14. Neutral particle and ion composition in the mass ranges 0-6 AMU and 0-40 AMU.
15. Bennett RF ion mass spectrometer for mass ranges 1-6 AMU and 7-45 AMU.
16. Density of neutral particles.
17. Micrometeorites, spatial density, mass distribution, velocity and charge.
18. Ionosphere charged particles and solar UV radiation.
19. Time variations in solar X-ray emissions in the 0.5-3A, 2-8A, 8-16A, and 44-60A bands.
20. Solar emission in the 200-1600A region.

TABLE 8-III (Continued)

II - Orbiting Solar Observatories
Launch Dates: 1964, 65, 66, 67, 68(2), 69

A. OSO-A - Launched 7 March, 1962

1. Returned useful solar data during eleven weeks of continuous operation and several weeks of intermittent operation.

B. OSO-B

1. UV spectrometry in ranges, 75-600A, and 500-1500A.
2. Solar X-ray bursts in the 8-20A and 44-66A regions.
3. White light coronagraph
4. Solar scan in the Lyman-alpha region
5. Intensity and direction of polarized light from interplanetary space
6. Arrival direction and energies of primary cosmic rays, 50-1000 Mev.
7. Gamma ray energy spectrum, 0.1 to 5 Mev
8. UV stellar and nebular spectrophotometry in the region 900-3800A
9. Emissivity stability of surfaces in vacuum environment.

C. OSO-C

1. Monochromator measurements of solar extreme UV.
2. Studies of solar spectrum from 1-400A.
3. Emissivity stability of low temperature coatings.
4. Earth albedo from 1000A to 4 microns
5. X-ray and gamma ray astronomy.
6. Gamma ray astronomy
7. Solar X rays
8. Solar gamma rays
9. Proton-electron measurements
10. Solar flare X ray spectroscopy

} alternates

D. OSO-D

1. Solar flare X-ray spectroscopy
2. Normal incidence scanning spectrometer, 300-1300A
3. Solar X-radiation
4. Cosmic Gr or solar X-rays
5. Total solar X-ray emission over wide bands (1.2-3,6A 3-9A, 6-18A, 44-54A, 44-70A)
6. Proton/electron detector
7. Solor He II resonance emission (303.8A)
8. Monitoring of solar radiation (8-16A, 2-8A, 0.5-3A, 0.1-1.6A)
9. Lyman-alpha night sky glow
10. X-ray spectroheliograph (back-up)

E. OSO-E

1. X-ray spectroheliograph
2. White light coronograph and extreme UV sprectroheliograph
3. The solar spectrum from 1-400A.
4. Self-reversal of the solar Lyman-alpha line
5. Solar radiation monitoring
6. Low energy gamma ray observations of sun.

TABLE 8-III (Continued)

III - Orbiting Astronomical Observatory
Launch Dates: 1965, 66, 67, 68, 69

A. OAO-A

1. Mapping in three UV regions
2. Stellar broad band photometry in UV

B. OAO-B

1. Absolute spectrophotometry measurements

C. OAO-C

1. Interstellar absorption measurements
2. X-ray telescope

IV - Advanced Orbiting Solar Observatory
Launch Dates: 1969(2), 1970(2), 1971(2) Plus 16 Others

1. Program definition is currently underway. AOSO is expected to increase by at least an order of magnitude the resolution now possible in solar observation. In general, AOSO will continue OSO solar studies with increased pointing accuracy.

The MORL is aimed at the 1970-1975 time period. Funding difficulties and program slippages appear to place useful data from the MORL well beyond ABL design deadlines.

e. Balloon-borne Experiments. Ideally, equipment transported through a portion of the Earth's atmosphere could produce valuable information about the Martian environment. Several factors tend to compromise the value of this type of investigation:

(1) The Earth atmospheric column above the instrument as well as the entire Mars column influences the validity of the readings. This is particularly true in the UV, where the water vapor content of the Earth atmosphere acts as a filter except at discreet wavelengths.

(2) The short mission times of balloon-borne experiments restrict the amount of data recorded in a single flight.

(3) Single launches have been estimated to cost in the neighborhood of one million dollars. Some members of the scientific community feel that, in view of the two limitations outlined above, the funding could be more beneficial if directed toward the construction of fixed based installations.

The balloon flight experiments that were planned for 1964 are summarized in Table 8-IV.

TABLE 8-IV

SUMMARY OF BALLOON-BORNE INVESTIGATIONS

1. Continuation of Stratoscope II flights (Absorption spectroscopy of Mars).
2. Collection of meteoroids at time of Perseid showers.
3. Charge spectrum of primary cosmic radiation.
4. Anisotropies of cosmic radiation.
5. X-ray and gamma ray astronomy.
6. Neutron detector.
7. Cerenkov-scintillation technique.
8. Auroral light, particle flux, and UV and gamma ray flux.
9. Cosmic ray investigation (two flights).

f. **Fixed Base Programs**. The largest quantity of data at an early date can be expected from fixed base programs. During the past year (1965 opposition), H. Spinrad (McDonald and Lick Observatories), G. P. Kuiper (McDonald Observatory, possibly utilizing the same equipment as Spinrad), Guido Munch (Mount Wilson Observatory), and V. I. Moroz (Alpine Astronomical Observatory of the Kazakh Academy of Sciences) exposed some 50 absorption spectra plates of Mars. It was planned that all these plates would have comparison spectra of the moon exposed at the same time. The primary goal of these observations is the examination of specific bands that will, hopefully, result in a clarification of the contradictions currently prevalent in both the composition and structure of the atmosphere. A review of Kuiper's data is underway at JPL at the present time, but the results are not yet available for inclusion in this analysis. Questions of interpretation of the ground based data remain a severe problem in its utilization in engineering planning. The planning for future oppositions is difficult to predict. Many of those contacted felt that the interest of planetary astronomers cannot be estimated with regard to later oppositions. Certainly other techniques, such as photometry, colorimetry, polarimetry, etc., may yield useful data in the future. Definite planning for radiometry and radar astronomy is in evidence, but is not firm enough to be integrated into any ABL planning.

8.2.3 CONCLUSIONS AND RECOMMENDATIONS

The experimental data considered to have the broadest influence on the ABL system synthesis has been defined in Paragraph 8.2.1. The various techniques that are capable of gathering these data, and that are currently in definite planning stages, are delineated in Paragraph 8.2.2. Bringing these two sets of information together allows an evaluation of the current interplanetary planning, insofar as ABL is concerned, and also points out several areas where tentative programs need to be reinforced and programs possibly redirected or expanded. These data are summated in Table 8-V, which indicates that, with the exception of the 69 Voyager mission, no data gathering technique provides all, or even the two most desirable pieces of information. As mentioned before, the capability of fixed based operations to provide useful data for engineering planning is open to some question. An overall consideration of the ABL program requirements, in the light of the planned data collection techniques, would seem to highlight the following conclusions and recommendations:

(1) The ability of the 69 Voyager (as defined in References 1 and 2) to provide all of the desired data for ABL design effort indicates its overall importance to the ABL program. As such, it is very desirable that the 69 Voyager program be fully supported and every effort made to avoid schedule slippage. This conclusion and recommendation were concurred with and supported by

TABLE 8-V

AVAILABILITY MATRIX
ABL DATA REQUIREMENTS

	64 Mariner	66 Mariner	69 Voyager	OGO	OSO	OAO	OASO	Balloon	Fixed Base
Wind Velocity at the Surface		Canceled	X						X
Atmospheric Density at the Surface	X		X						
Daily and Seasonal Temperature Variation of Surface Atmosphere and Soil			X						
High Resolution Photography	X		X						
Atmospheric Chemical Composition			X					X	X

the ad hoc Bioscience Working Group (see report of this Committee, Appendix 8.1 and 8.2) with the added recommendation that the mission include an orbiter rather than a flyby.

(2) The planned exploration of Mars by unmanned vehicles in the 1970's and possibly manned explorations in the 1980's will require the expenditure of large sums of money. It would seem that the dedication of a small portion of the orbiting observatory program to the support of these missions would be technically and financially expedient.

8.3 BOOSTER PROGRAMS

A survey was made to identify launch systems applicable to the ABL mission and to determine their performance. Only those systems that could reasonably be expected to be fully qualified by 1969 were investigated. Seven booster configurations are identified and their payload capability defined. The seven systems selected are:

(1) Atlas/Centaur

(2) Floxed Atlas/Centaur

(3) Titan IIIC

(4) Titan IIIC (Stages 0 and 1)/Centaur

(5) Titan IIIC/Centaur

(6) Saturn IB/Centaur

(7) Saturn IB/Shrouded Centaur

In 1975, payloads ranging from 100 to 10,500 pounds can be injected into an Earth-Mars orbit with these systems. Other systems such as Titan II/Centaur are comparable to some of the seven presented; however, the objective has been to show a range of payload capability rather than to show every possible system. One potential system not considered is Saturn V. Its payload capability appears to be greatly in excess of that required for early ABL missions.

8.3.1 PERFORMANCE

Figures 8-2 and 8-3 present weight injected into an Earth-Mars transit orbit as a function of launch data for each of the seven launch configurations. Figure 8-2 is for a Type I* orbit and Figure 8-3 is for a Type II** orbit.

The performance shown does not include restrictions on launch azimuth. That is, the optimum launch direction from Cape Kennedy was used for each case. A 30-day launch window was used as representative.

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* A Type I orbit has a shorter transit time than a Hohmann minimum energy orbit.

** A Type II orbit has a longer transit time than a Hohmann minimum energy orbit.

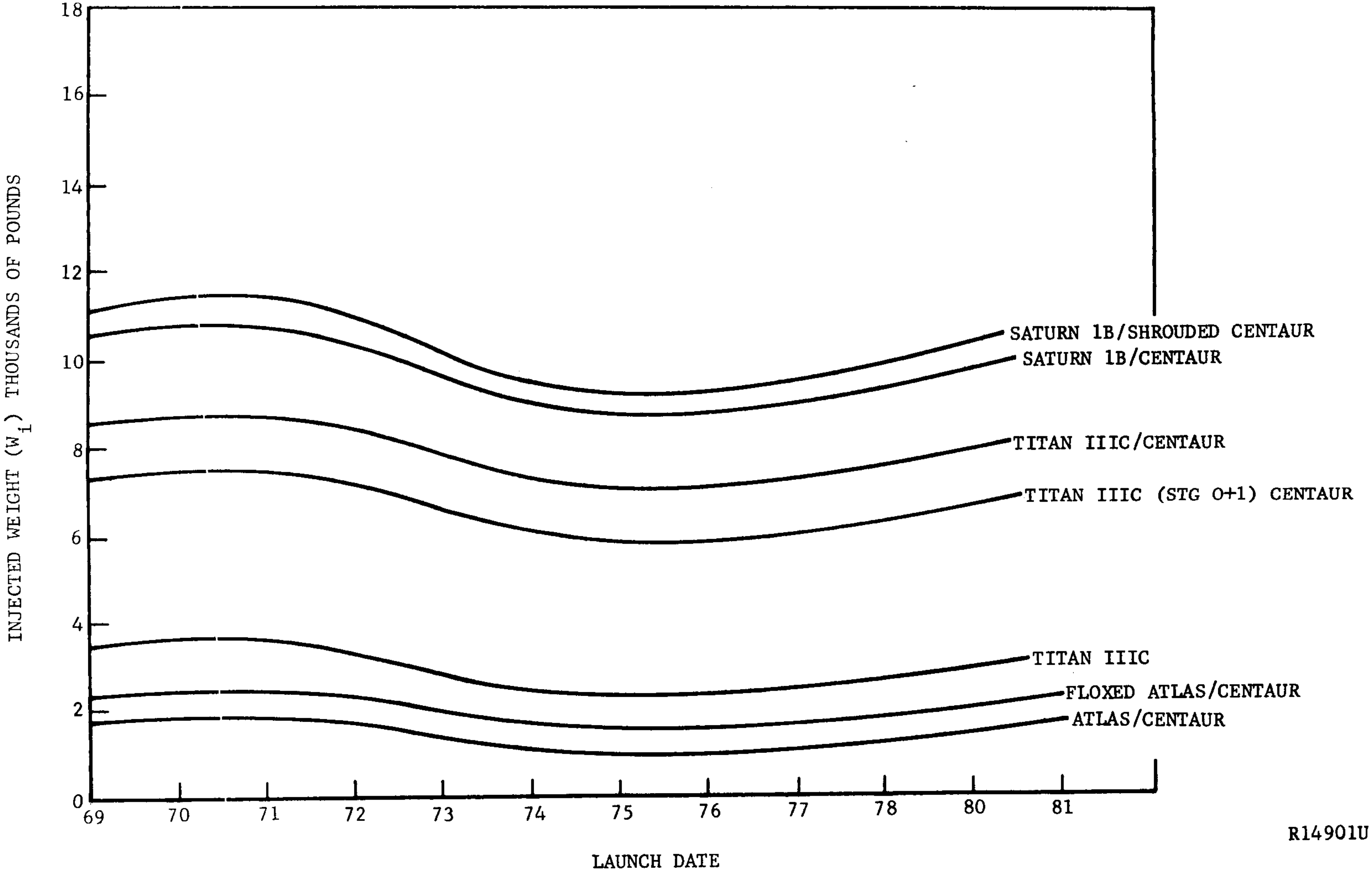

FIGURE 8-2. BOOSTER PERFORMANCE SUMMARY MAXIMUM INJECTED PAYLOAD WEIGHT AS A FUNCTION OF LAUNCH DATE

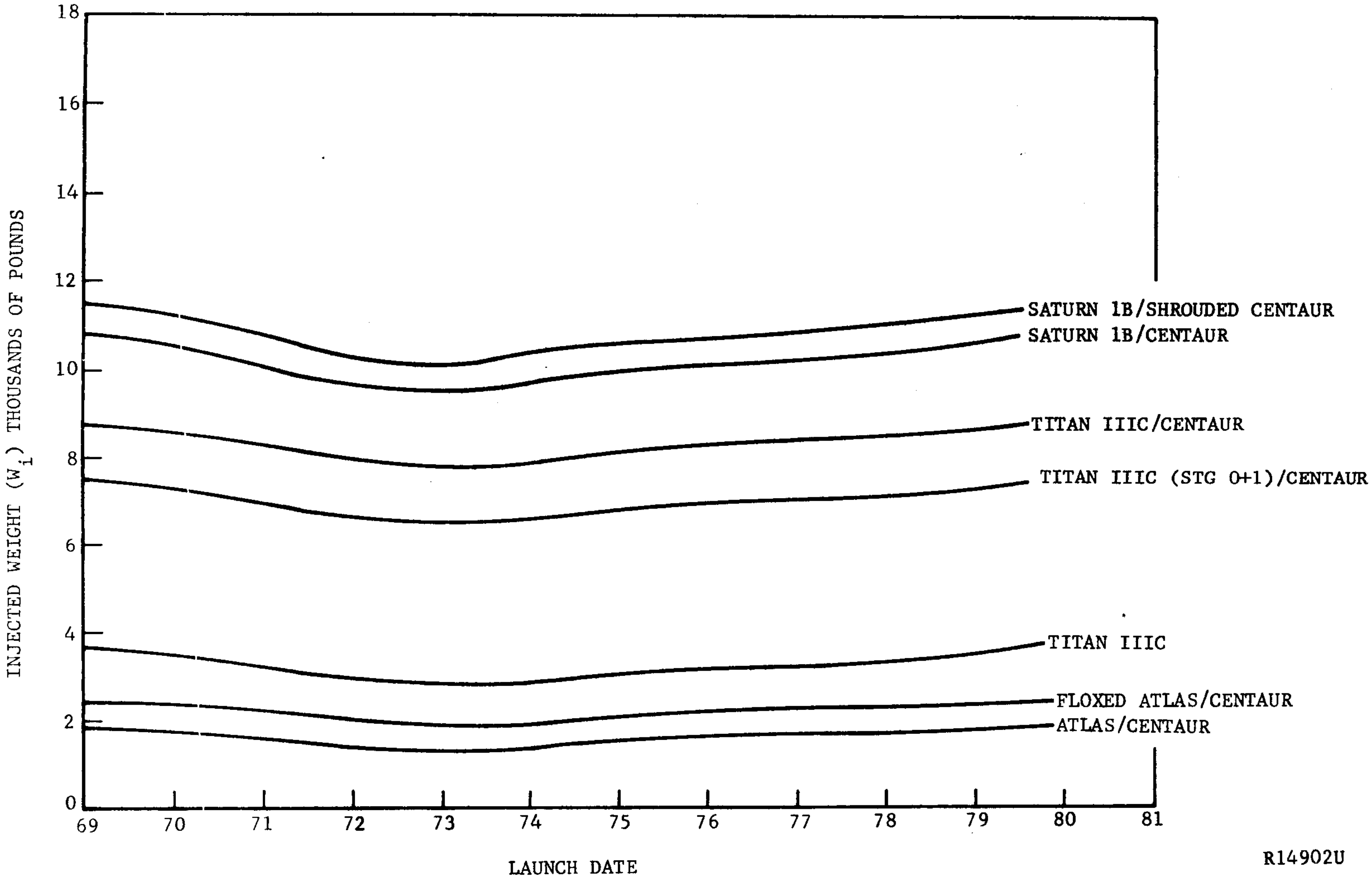

FIGURE 8-3. BOOSTER PERFORMANCE SUMMARY MAXIMUM INJECTED PAYLOAD WEIGHT AS A FUNCTION OF LAUNCH DATE

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    Dr. Roland Carpenter
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    Dr. Alden Loomis
    Dr. Ray McFe
    Dr. Ronald Schorn
    Dr. Gerald Soffen
    Duane Spencer

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SECTION 9

SUMMARY CONCLUSIONS AND RECOMMENDATIONS

The principal study results can be summarized as follows:

(1) A representative ABL configuration has been shown to be a feasible concept for a Voyager-class landed payload in the 1975 time period. Such a payload can be mechanized well within booster performance capability for that time period and all technologies are currently available or are reasonable nominal extrapolations of today's art.

(2) Significant advantages have been shown to accrue to a biological payload organized as an integrated ABL. These advantages include the following:

a. Far more meaningful scientific results are possible from a given instrument capability organized as an integrated ABL than from the same equipment mechanized as individual experiments.

b. Weight advantages for equal instrument capability are roughly a factor of 2 over individual experiments using common sampling and a factor of 3.5 over individual experiments using reasonable, but considerably less comprehensive, individual sampling capability.

c. The weight advantages in the instrument complement reflect as weight and size advantages in the total entry system. Weight advantages for a typical entry vehicle mechanization are a factor of 1.6 and 1.75, respectively, for the two cases previously cited.

collection coverage, earlier and later mission time periods, more complex equipment and procedures, e.g., video and electron microscopy, and the effects of, and proper methods to be used for, the eventual employment of terrestrial biological material in Martian experiments.

(8) A unique feature of the ABL is the interplay between the experimenter on Earth and the laboratory operating on Mars. This function implies Earth-based facilities different from those required for current generation space missions. The scientist must be provided with information on the status of the laboratory and the progress of experiments and must be provided the facilities for evaluating results returned, for making decisions, and for determining the consequences of commands to be transmitted to the laboratory. The analysis of these requirements deserves further study.

(9) While certain specific material sterilization incompatability problems were examined in this study, no results justify a conclusion at this date that any specific payload can or cannot meet NASA sterilization objectives. It is clear only that much additional specific analysis and test data are required. It also appears that considerable further study is warranted of alternative methods of achieving sterilization without compromising the NASA sterilization objectives.

Corresponding size advantages in this particular example reflect the difference between a feasible and a marginal solution if Saturn Ib shroud limits are considered to control the entry body size.

d. Reliability advantages have been shown to accrue to the ABL concept both because of the flexibility of the laboratory for performing a given experiment using alternative sensors, and because alternative experiments can be performed to achieve essentially similar knowledge about the sample.

(3) It has been shown that a science payload organized as an integrated automated laboratory is relatively independent of the specific experiments which are to be performed, when the laboratory is sufficiently comprehensive. This important result means that engineering development of instruments and laboratory hardware need not be delayed until the final selection of experimenters and experiments.

(4) Both performance and functional advantages have been shown for the ABL organized as a separable landed payload, and this approach is recommended.

(5) The RTG (Radioisotope Thermoelectric Generator) form of electrical power supply has been shown to provide such a perfect match to both the electrical load and environmental control requirements of the laboratory that its availability in the correct capacity and configurations for the ABL mission should be considered essential. Additional development should be continued on these units in the areas of general performance upgrading, fuel availability and packaging, the latter particularly with the objective of improving the shock and vibration resistance of the units.

(6) The heart of ABL is the chemical processing capability. It has been shown that a form of mechanical batch processing is probably optimum for the ABL application and early development work should be initiated on this piece of processing equipment, regardless of the final complement of experiments selected, because of its very general use in the ABL payload.

(7) The design point case analyzed in this study has provided a definition in some detail of a single feasible concept. It is also necessary to evaluate the cost in terms of weight, power, complexity, reliability, etc., of variations in the system capability around this design point case. These evaluations should consider improved sample