DOCUMENT NO. 63SD801
15 OCTOBER 1963

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VOYAGER DESIGN STUDY

VOLUME V: STERILIZATION

Prepared Under Contract NAS W-696

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

OFFICE OF SPACE SCIENCES

WASHINGTON, D.C.

[redacted]

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VOLUME SUMMARY

The Voyager Design Study report is contained in six volumes, an appendix, and subcontractor reports. The volume numbers and their titles are as follows:

Volume No.

I — Voyager Design Summary

II — Mission and System Analyses

1. Mission Analysis
2. Parametric System Performance
3. Voyager Systems
4. Reliability

III — System Design

1. Communications
2. Television
3. Radar
4. Guidance and Control
5. Propulsion
6. Power Supply

Appendix (Classified)

IV — System Design

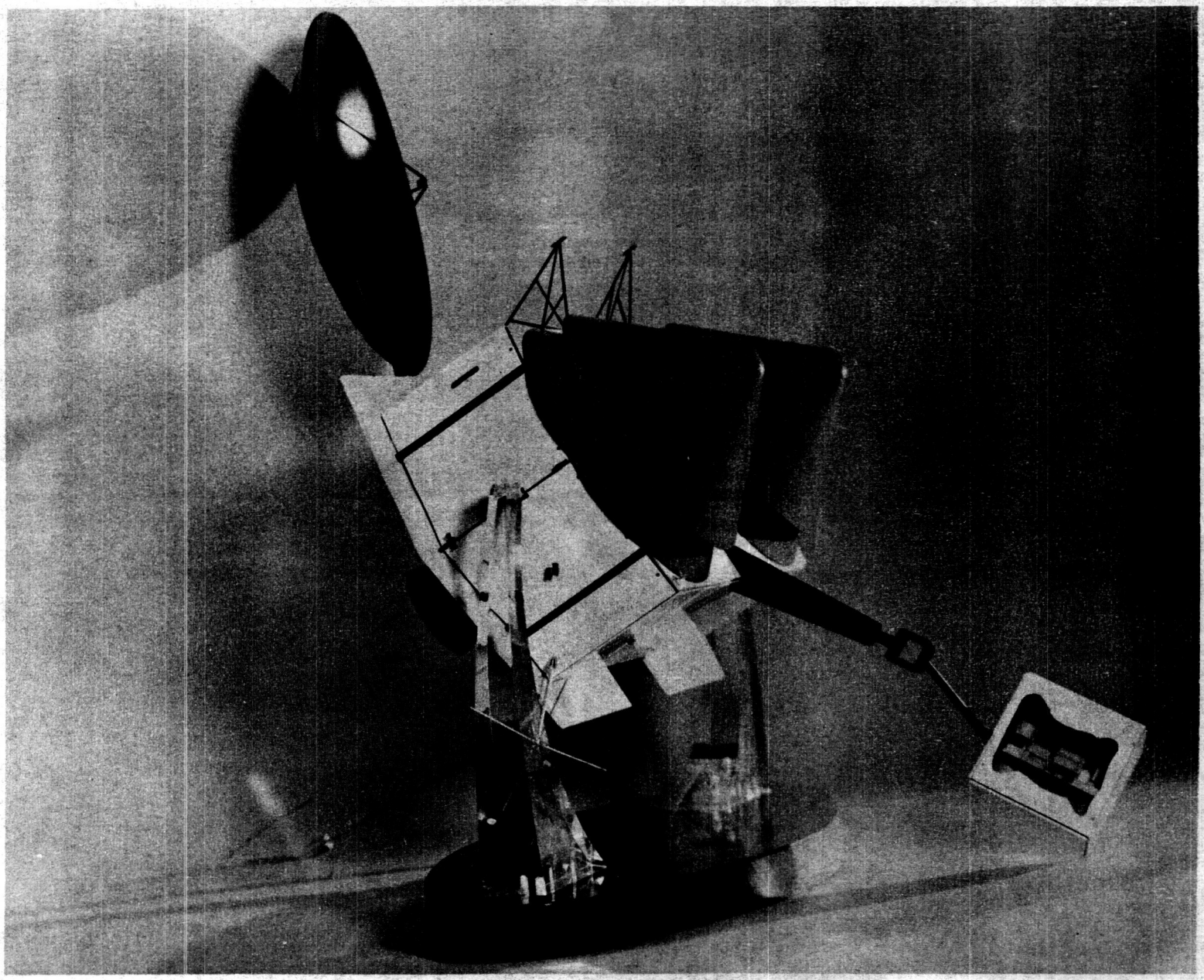
1. Entry/Lander
2. Orbiter

V — Sterilization

VI — Program Development Plans

Separate Reports from the following Companies are also included:

Aerojet-General Corp.
Barnes Engineering
Bell Aerosystems Co.
Conductron Corp.
Electro-Mechanical Research Inc.
General Electric Co.
Light Military Equipment Dept.
General Precision Inc.
Hazeltine
North American Aviation Inc.
Autonetics Division
Rocketdyne Division
Radio Corporation of America
Rocket Research Corp.
Texas Instruments Corp.
Thiokol Chemical Corp.
Elkton Division
Reaction Motors Division



Voyager Spacecraft Model

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

ILLUSTRATIONS

TABLES

SECTION 1. INTRODUCTION

One of the objectives of the Voyager mission is to evaluate the surfaces and environments of Mars and Venus in order to obtain information about the origins of life. Since Mars appears to offer an environment which is conducive to the evolution of life as we know it, this Mars mission has received intense attention of leading scientists. There is no question that the decision to accomplish atmospheric penetration and landing on sister planets is inseparable from the effectiveness with which it can be assured that there will be no contamination by terrestrial organisms.

The objectives and reasons for rigid sterilization requirements have been outlined by many authors (References 1, 2, 3 and 4). Hobby[4] has advocated, as a design requirement, a probability of 1×10^{-4} that must not be exceeded of landing a viable terrestrial organism on the target surface. Agreement that contamination of the target must not be permitted is virtually unanimous among those planning the scientific objective of the mission.

Therefore, a positive requirement for the Voyager system, as set forth by NASA at the beginning of the study, is that the probability of contaminating Mars with terrestrial organisms be less than one chance in ten thousand and for Venus one chance in ten. Viruses have not been considered inasmuch as viruses can reproduce only in specific types of living cells. Accordingly, if earth-type organisms are exluded, then viruses will not reproduce. However, to achieve the 1×10^{-4} probability of contamination, it is not immediately apparent whether an advance in the state of the art is required.

Sterilization must be planned to assure the required reliability and, hence, the success of the total mission. Biological research has shown that the most reliable technique for accomplishing total vehicle sterilization is a suitable thermal treatment, at some practical level attainable by engineering practice. The use of gaseous and liquid sterilants should remain as back-up or as secondary methods. Gases and liquids present an attractive approach for some component problems but sterilization by these methods affords no guarantee of an aseptic vehicle.

Another technique, treatment by radiation, presents engineering and component problems that appear unsolvable at present. Levels of radiation lethal to the majority of microorganisms are approximately equal to those that jeopardize the performance and reliability of vital components. Accordingly, radiation sterilization at present must be limited to selected components. Even this limited use assumes sterile assembly of these parts. Jaffee[1] has discussed current techniques of sterile assembly intended for planetary spacecraft, and indicates that they are not likely to comply with the required 1×10^{-4} probability of contamination. However, radiation may be useful for reducing the "biological load." Koesterer[5] has suggested that a combined treatment at reduced heat levels and lower radiation levels might be a feasible solution to the sterilization problem.

This study has considered primarily the Mars 1969 Lander mission but an analysis of the sterilization problems of the Mars 1973 Orbiter is given in the Appendix. The extreme temperatures forecast for Venusian atmospheres indicate that the sterility standards for Mars and techniques for achieving them will be satisfactory for Venus.

SECTION 2. SUMMARY

2.1 REQUIREMENTS

It is required that the chance of releasing a viable microorganism on the planet target shall be 1×10^{-4}. Only the Lander will be considered since the probability of the Lander striking the target is assumed to be unity. The trajectory of the Orbiter will be such as to present less than 1×10^{-4} probability of planetary impact.

Sterilization will be accomplished by thermal means. The use of ethylene oxide, as well as other gaseous and liquid sterilants, will be restricted to "biological load" reduction or other secondary uses.

Inasmuch as sterile assembly is considered to present more than a 1×10^{-4} probability of organism survival, equipment, parts, components and structures will be heated as a terminal measure for at least 24 hours to 135°C. Sterile assembly will be limited to parts, components, and structures that inherently cannot be heated to 145°C for three cycles of 36 hours. This latter temperature requirement is considered to be a qualification requirement. For qualification, parts, components, and structure must show the required functional reliability (to be established for each mission) after a prescribed dormant period following thermal cycling.

All components, parts, and structures, from the time of preliminary design, will be classified as Class I, Class II or Class III. Class I items can withstand at least three 145°C, 36 hour cycles. They may, but not necessarily will, withstand further temperature soakings. However, these items may present problems related to the "biological load" factors. Class II items will withstand only one thermal treatment: 135°C for 24 hours. An item may be a Class II item due to sensitivity in respect to reliability questions. Class III items will not withstand thermal cycling at prescribed sterilization temperatures. An objective of the design program will be to eliminate all Class III and as many Class II items as possible from the flight hardware.

The three classes may be further subdivided. The basic philosophy of maximum practical sterilization treatment requires, from manufacture on, that each part, structure, and component will be subjected to the maximum sterilization environment without regard to the general sorting and classification of individual parts.

Known high-reliability parts were carefully examined for thermal sensitivity. These parts and materials constitute the basic list for design engineers. The parts, assemblies, and sub-assemblies chosen for flight hardware will be qualified to both reliability and sterility standards. Where functions exist that cannot be performed by a space-qualified component, such functions may be omitted from the flight. Where mission success depends on a non-thermally qualifiable component, the item will be assembled by sterile techniques that will insure less than a 1×10^{-2} probability of contamination. The 24-hour final heat soak will continue to be a requirement for Class II items to assure the 1×10^{-4} standard.

Class III items are not expected to be a part of the final flight hardware. The appearance of a Class III item in the final design will constitute a serious problem to be solved only by detailed examination of that specific part and function.

2.2 PROCEDURE, PROCESSES, AND DESIGN APPROVALS

Clean room requirements for the Voyager program are concluded to be Class 10,000 or less. This manufacturing requirement is regarded as absolute.

During testing of the assembled vehicle, this requirement may be met by conducting the entire testing cycle within a pliable plastic container or biological barrier. It is not anticipated that clean rooms or containers will be sterile, nor will sterility be sought.

During the testing cycles, the sealed portions of parts and components will not be compromised, and thus sterility problems will be limited to outer-surface areas. The final thermal treatment before sealing the protective flight container will sterilize these surfaces.

Class II and Class III spares and components, destined for assembly, require protection of a special kind; soil contamination must be prevented as well as loss of sterility. Containers or biological barriers, designed to protect the items functionally, must include provision for maintenance of sterility and cleanliness.

A Sterility Contamination Control Group should review each design item. Each final machine assembly drawing will be approved and signed by a member of this group. Design items will be checked for sterility interfaces, material compatibility, manufacturing processes and final packaging. During the assembly phase, as well as the manufacturing phase, critical steps and processes will be monitored and approved by a trained sterility inspector.

2.3 VERIFICATION

It is not practical within the scope of this study to assay flight equipment. The adoption of a satisfactory method for sterilization, followed by a strict adherence to the systematic method from manufacture through launch, is required to achieve 1×10^{-4} probability of a sterile vehicle.

At the time of equipment selection and qualification, selected components will be "seeded" during the manufacturing cycle. The "seeding" will utilize an organism resistant to thermal and gaseous sterilization. A microbiological assay will be conducted on these components and parts, after trial assembly runs and sterilization tests, to verify the efficacy of the prescribed sterilization procedure.

2.4 PRODUCTION

The sterility program requires a minimum of clean room assembly for all components. Class II and III parts and components require sterile assembly to ensure a less than 1×10^{-2} probability of contamination. Each step of the manufacturing and assembly process will be monitored. Random samples of component parts will be selected, throughout the manufacturing and production phase, and subjected to biological assay techniques. A rigorous personnel training and motivation program will be required.

Each step of the manufacturing process will be analyzed for sterility breaks. Packaging, transporting, and storaging operations represent areas where detailed procedures and minute attention to detail are the best assurance of a sterile end product.

SECTION 3. ANALYSES

3.1 DISCUSSION

The guidelines prepared by the Conference on Spacecraft Sterility[2] held under the auspices of NASA Biosciences Programs, 9 July 1962, has been adopted as the foundation of this study. A functionally reliable, biologically sterile spacecraft is the objective established by the guidelines.

Components and materials have been reviewed and screened for early identification of sterilization problems. The concept of "reducing the organism and dirt load" at all possible steps in the factory-to-launch sequence has been projected into the design manufacturing and handling sequences.

A complete thermal sterilization, at 135°C for twenty-four hours, of the fully assembled and tested spacecraft has been the design goal. It is believed that this goal can only be reached by close control of the entire component and test, design and manufacturing process. Koesterer[5] has reported that microorganisms in ordinary soil are the most difficult to destroy; thus, the control of soil and dust contamination at every point becomes of paramount importance. To achieve a level of no more than two grams of soil[2], on and within the Lander, requires ultra-clean room assembly throughout. (The alternative, cleaning each part and the space vehicle, is not considered a feasible solution either from a technical or an economical point of view.) Clean room assembly of all parts, components, and structure, as well as clean room testing, has been specified. Proposed Federal Standards of clean rooms are Class 100, Class 10,000, and Class 100,000. These standards have not yet been adopted, but it is felt that clean room assembly and test requirements of Class 10,000 will not impose unreasonable requirements if laminar airflow equipment is utilized. The selection of Class 100 is not considered advisable inasmuch as the mere presence of the human assemblers and testers would preclude practical realization of this figure.

3.2 CLASSIFICATION

The interior portions of many structural materials are inherently sterile because of the nature of their manufacturing process (high temperature over substantial periods of time). However, inasmuch as only a small proportion of the parts to be considered fall in the inherently sterile category, it has become necessary to subdivide components into three general classifications: Classes I, II, and III.

Class I consists of items that do not suffer functional damage as result of heat soak. These items can be fully qualified at 145°C for 36 hours, and tolerate ethylene oxide sterilization procedures. They may, if required, be reused in vehicles that suffer loss of sterile integrity and go through recycle procedures. Items in this group further have been demonstrated to withstand the simulated full mission profile including space vacuum and planetary surface conditions following a full sterilization cycle. (6)

Class II consists of items that have a temperature ceiling of 135°C. Items of this group do not tolerate qualification temperature cycles unequivocally but may be further subdivided into two categories: those items that should be exposed to terminal sterilization only once and those items that may be recycled.

Class III consists of parts and assemblies that cannot withstand thermal sterilization. Resolution of the parts selection problem in this class must be achieved prior to finalization of spacecraft and/or Lander design.

3.3 MANUFACTURE AND ASSEMBLY

3.3.1 CLASS I ITEMS

Class I items are to be manufactured in clean rooms. Transportation will be made in dust- and soil-proof containers. Initial thermal sterilization will occur at the earliest possible time. Primary purpose of this sterilization step will be to reduce the organism load. Surface sterilization will occur at each step into a higher assembly. It is expected that gaseous sterilization of component containers will suffice inasmuch as each component would be internally sterile and only surface contamination would occur.

3.3.2 CLASS II ITEMS

Class II items, the minimum grade parts tolerable for the initial Voyager spacecraft, will be assembled in a clean room or sterile chamber as required and containerized in the in the requisite contamination barrier. They will be subjected to surface sterilization by ethylene oxide as they are built into higher assemblies. Modularization will be functional and designed to prevent internal contamination.

3.3.3 CLASS III ITEMS

While Class III parts shall not be planned as a part of the Voyager design, a discussion is included in the event that highly important experiments may have to be handled in this manner. Class III items require sterile assembly. It is possible that Class III items may require sterile raw materials. Each part of the sterile assembly will be sterilized prior to assembly by the most appropriate method (heat, gas, irradiation) and placed into the sterile component container shown in Figure 3.3.3-1. This sterile component container can be rapidly assayed to determine the integrity of the sterile interior by performing pressure check determinations. Assembly of higher components, utilizing items of this class, will be done in ethylene oxide chambers. The resulting assembly will become Class III also. These items will be added to the Lander after thermal sterilization and before the biological protective container or barrier is sealed.

3.3.4 FUNCTIONAL FLOW CONCEPT

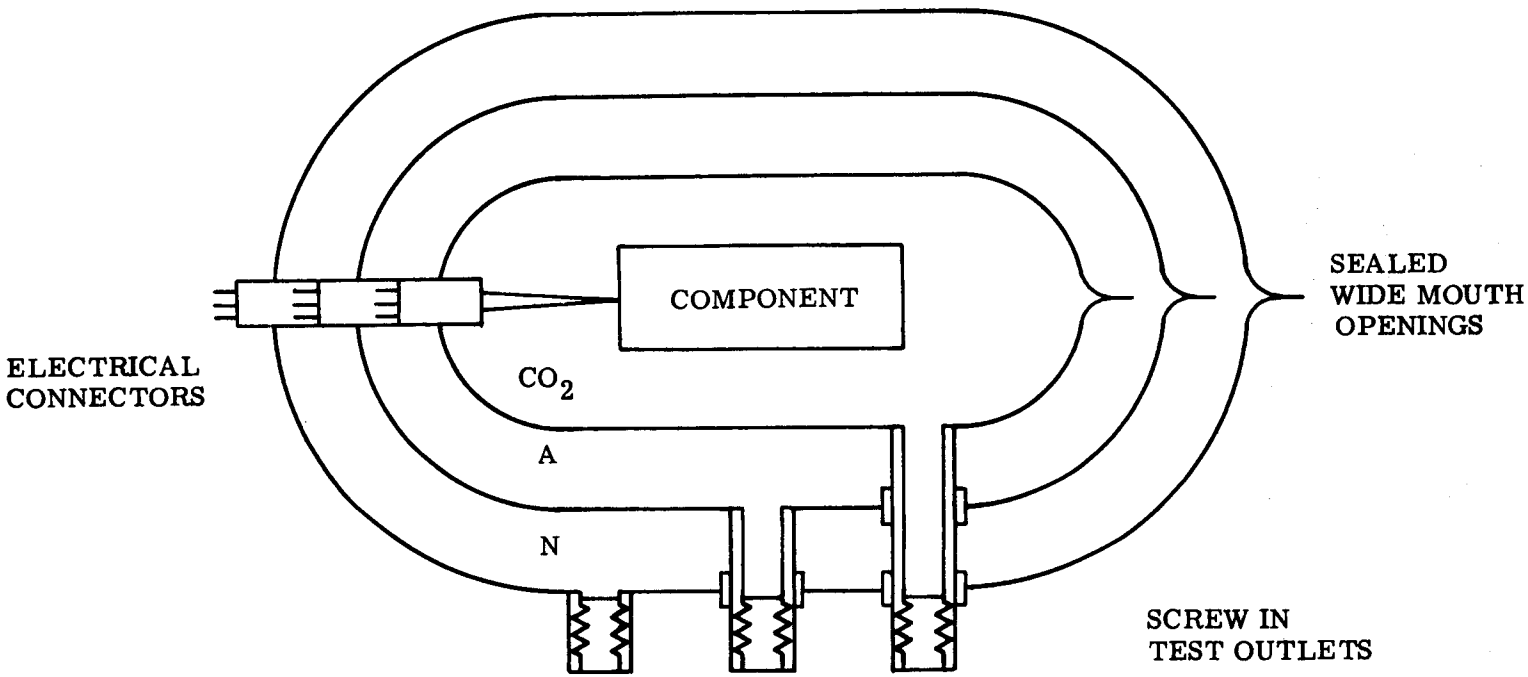
Figure 3.3.4-1, the flow diagram of the sterilization sequence (factory-to-launch), shows the major operational steps of the sterilization plan. Further breakdown of this flow is contained in the manufacturing, handling, and AGE functional flow diagrams.

The use of an independent biological protective container or barrier for the assembled vehicle poses problems. The most desirable barrier, from a weight point of view, would be very thin (1 to 5 mils thick). However, the difficulty in maintaining the integrity of this fragile envelope, after terminal sterilization may make such an approach impractical. The biological barrier problem is discussed in a later portion of this Volume.

Truly identical components of the Class III type must be replaced following the final thermal treatment. Factory testing obviously does not represent the final flight checkout which will be done upon a terminally sterilized ready-to-fly vehicle.

3.3.5 TRANSPORTATION

Transportation functions begin within the clean room. All of the packing containers that are used are sterilized to avoid additional contamination. In this phase, the vehicle is ultraclean rather than sterile. It contains components, however, that are internally sterile. Loaded containers (components, subsystems, etc.) are flushed with ethylene oxide and filled with an inert gas at a positive pressure (0.26 psi). Such pressurized containers can be shipped, or stored, as required. Loss of pressurization would signify compromise of the sterile condition.



MULTI-PURPOSE STERILIZATION CONTAINER

PURPOSES: (a) HEAT STERILE, (b) TRANSPORT, (c) GASEOUS STERILE, (c) ASSAY, (e) STERILE TEST

ENTIRE BAG & HARDWARE TO BE OF THERMAL RESISTANT MATERIAL

CONTAINER SHOULD BE REUSABLE IF POSSIBLE FOR SPARES & COMPONENT STORAGE

Figure 3.3.3-1. Multipurpose Sterilization Container

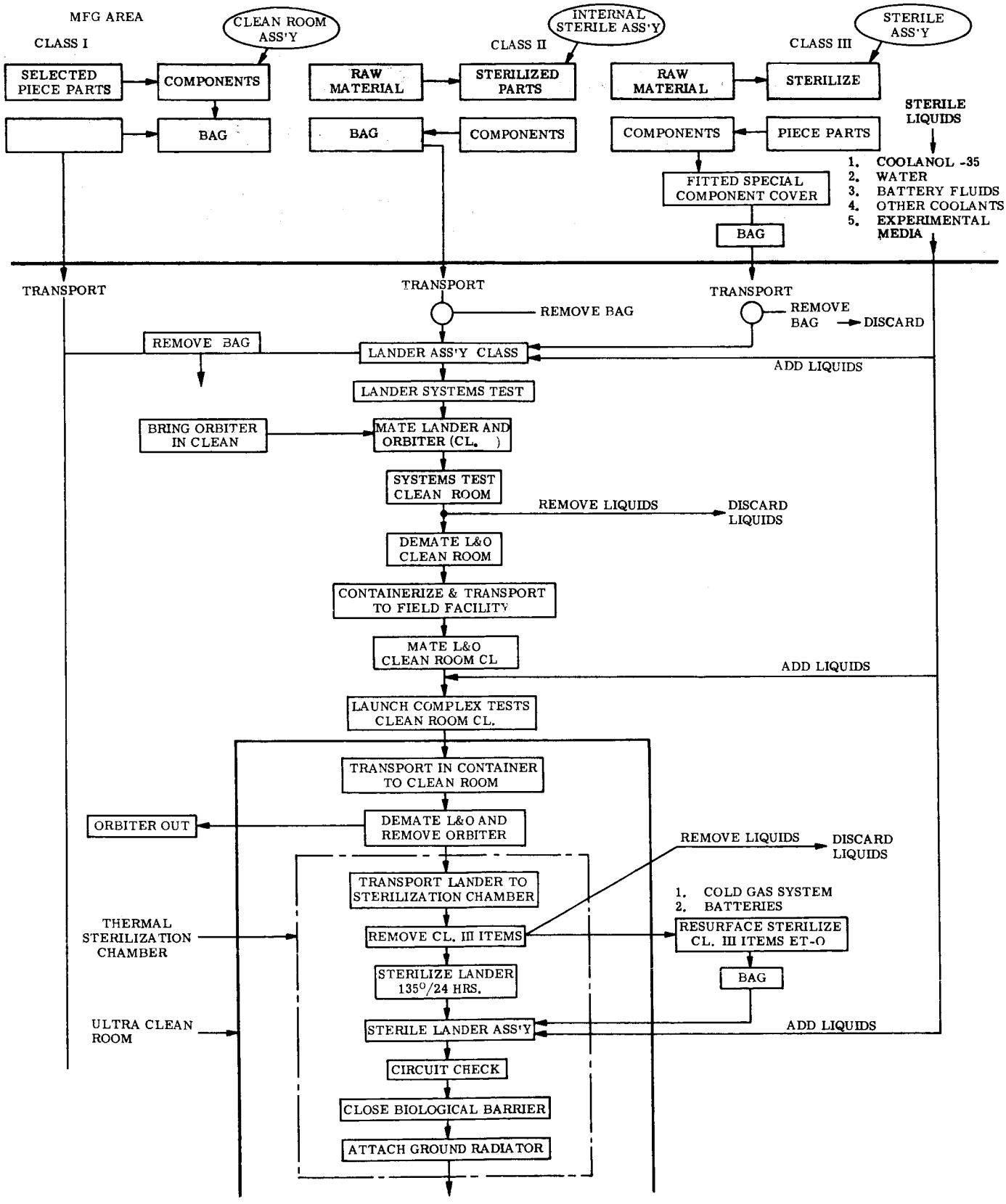


Figure 3.3.4-1. Functional Flow Diagram of Voyager Sterilization Process

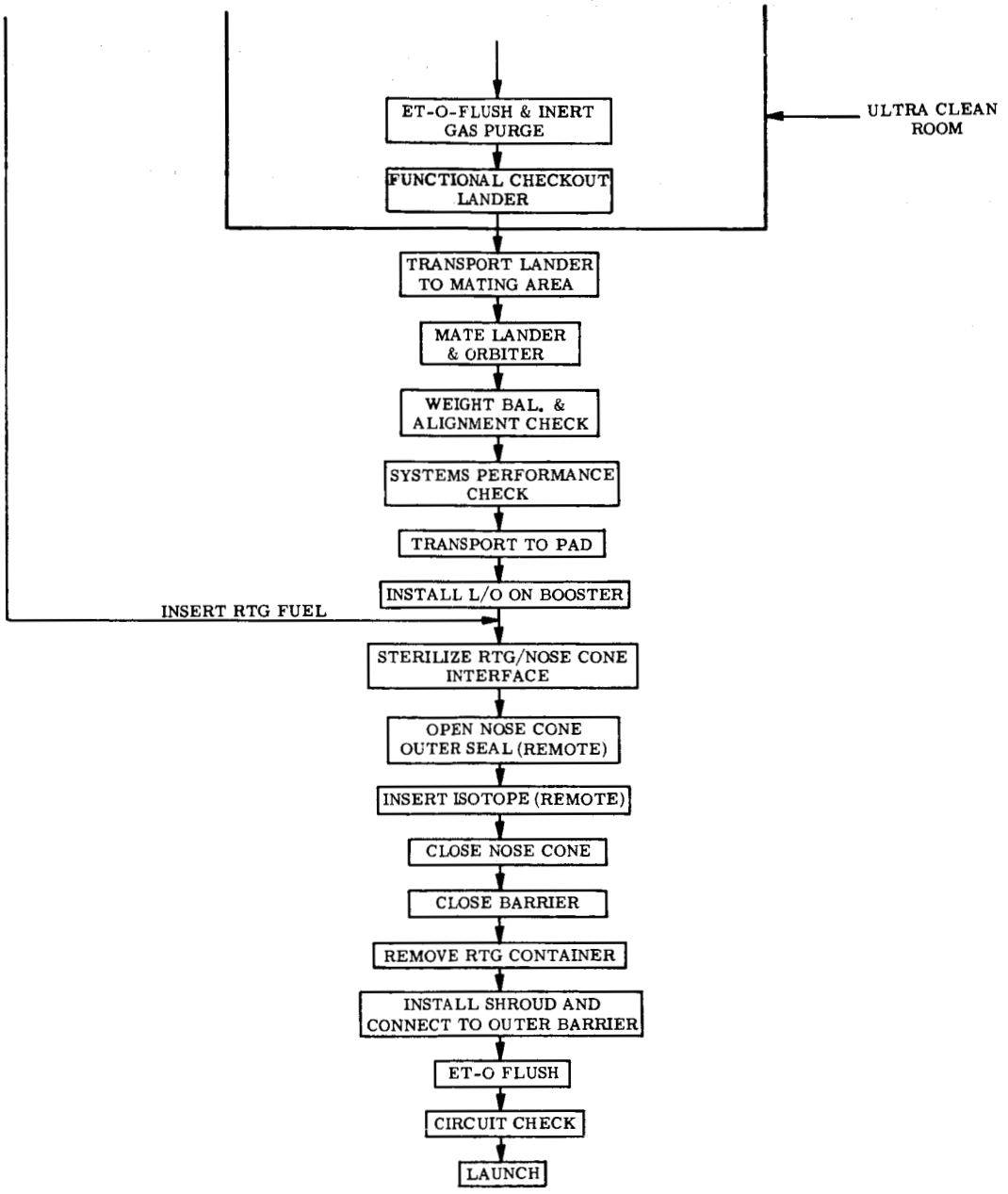


Figure 3.3.4-1. Functional Flow Diagram of Voyager Sterilization Process (Cont'd.)

3.4 LAUNCH AREA OPERATIONS

3.4.1 CONCEPT

The requirement for assembly of the Lander to the Orbiter at the field site, before terminal sterilization, requires that clean rooms be established at the Atlantic Missile Range (AMR) facility. The entire train of events, including all testing, leading to the sterilization chamber is conducted within a clean room.

The terminal sterilization will be thermal. Based upon the assumption that the final vehicle will include only a minimum of Class II items, the Lander will be sealed within its biological container and given the specified thermal soak. Liquids, such as coolants and battery fluids, will be separately sterilized. This step is required in order that the liquids not be within their flight containers during the sterilization process because of the weight penalty that would otherwise be paid to strengthen the container walls enough to withstand expansion occurring during the 135°C soak. Final design trade-offs have not been completed, but it is presently estimated that the vehicle plumbing system required for the insertion of liquids will not outweigh the additional materials that would be required to resist the expansion pressures if liquids were thermally sterilized in their functional-use containers.

3.4.2 CLASS III ASSEMBLY

The flow diagram, Figure 3.3.4-1, illustrates a complete system including Class III materials. Such materials must be considered until such time as system concepts permit their replacement.

A basic problem area related to Class III materials, the use of air locks and the transfer of ethylene oxide sterilized parts into a thermally-sterilized unit, is not improved by remote apparatus. A cheaper and more attractive solution appears to be the use of flexible plastic tunnels in which a technician could advance and work using rubber gloves similar to those used in glove boxes. The exterior surface of the tunnel will be sterile at all times.

The flexible plastic tunnel would be sterilized when the thermal sterilization takes place. Figure 3.4.2-1 illustrates this concept. The location of the Voyager spacecraft scientific experiments dictates that relatively complex assembly operations must take place if the experimental equipment is of a Class II or Class III nature.

Sterility violation would be monitored by adding helium to the tunnel air and monitoring the sterile inside of the chamber for leaks.

After completion of the assembly process, the biological protective barrier would be sealed, enclosing the sterile Lander. All operations, including electrical checkout, would be done without violation of the barrier. Transport of the barrier protected Lander would be done using a dust-proof container capable of being flushed with ethylene oxide and inert gases.

3.4.3 BIOLOGICAL BARRIER AND INTERFACE

Due to the handling difficulties with a fragile envelope and therefore a potential loss of biological integrity, a wholly sealed Lander with a rigid barrier of polyimide is considered to be the most practical solution. Prior to the thermal sterilization, the Lander-Orbiter interface section will be attached to the base of the Lander. The interface, Figure 3.4.3-1, is conceived to resemble a form-fitting gasket. The interior (Lander site) would always remain sterile. The outer-surface of the interface, which would become contaminated immediately upon leaving the sterilization chamber, is attached to the Orbiter by means of bolts built into the interface. Exploding nuts will separate the interface from the

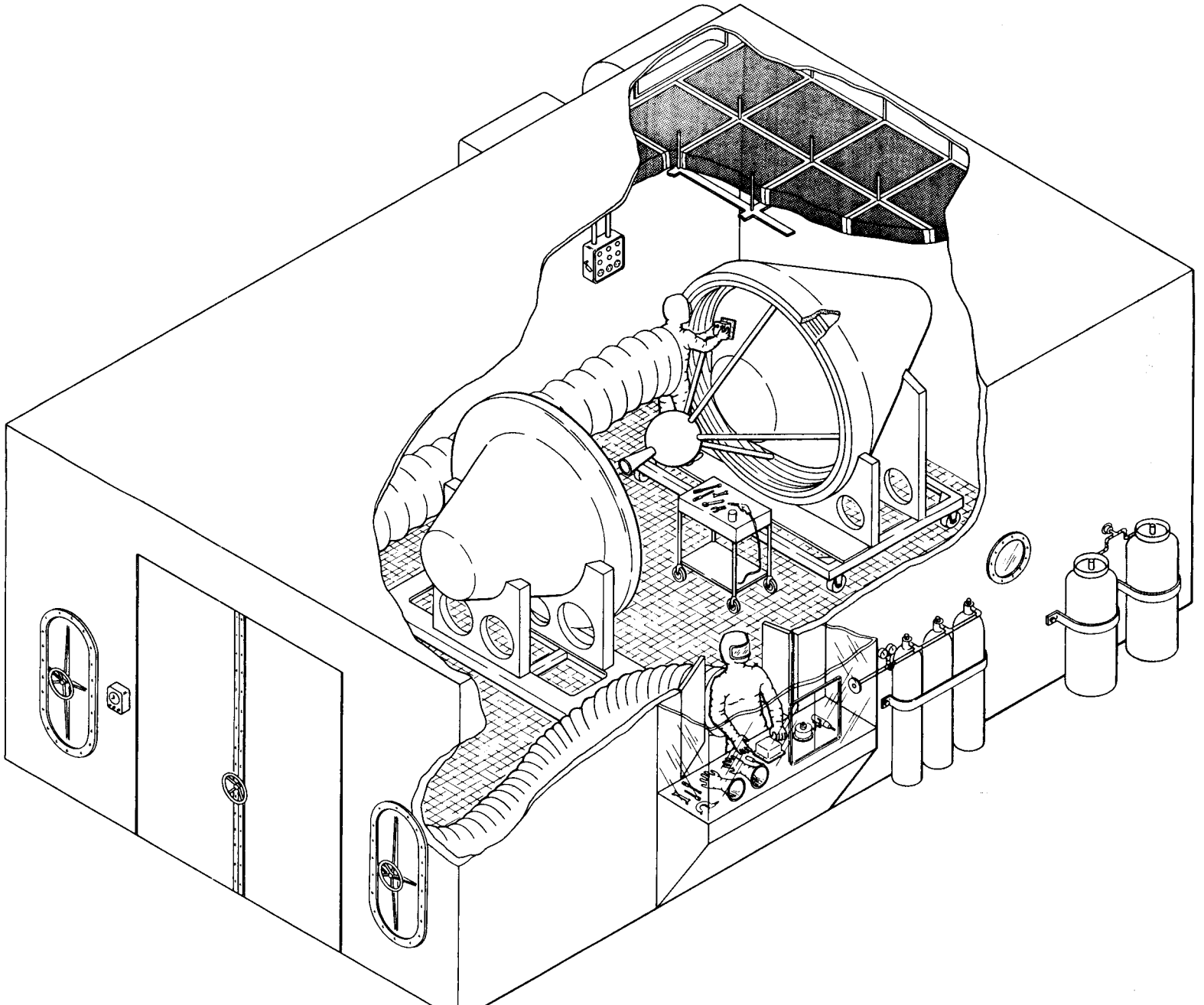
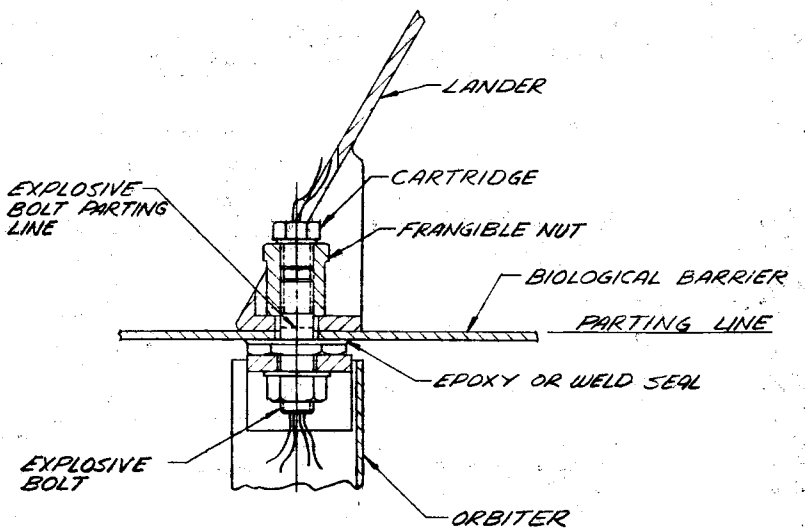


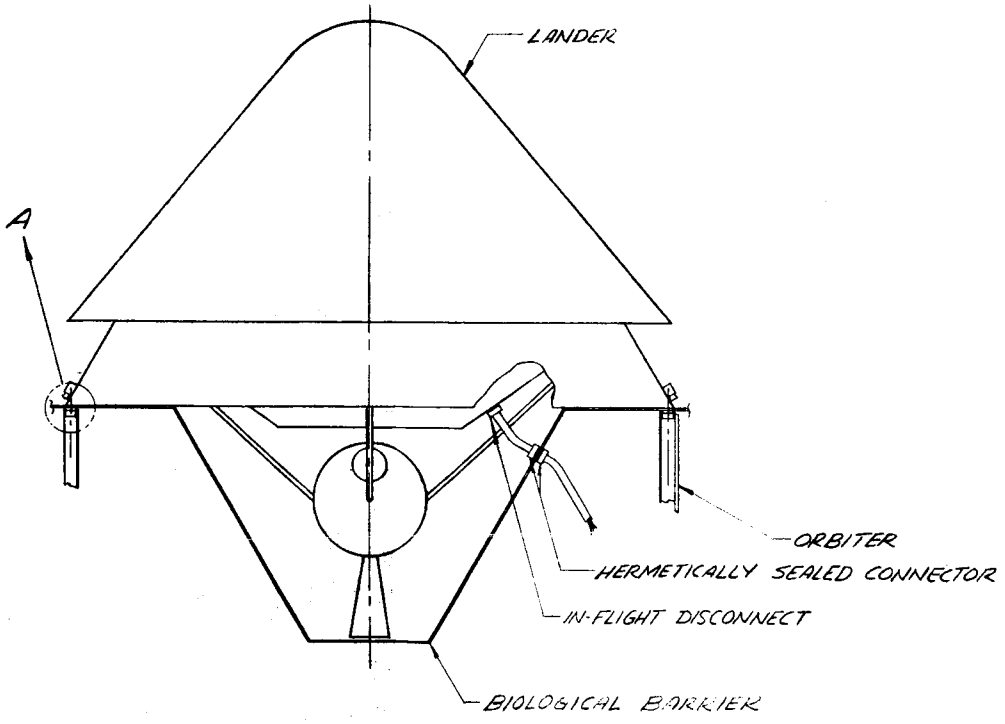
Figure 3.4.2-1. Visual Concept of Sterilization Chamber



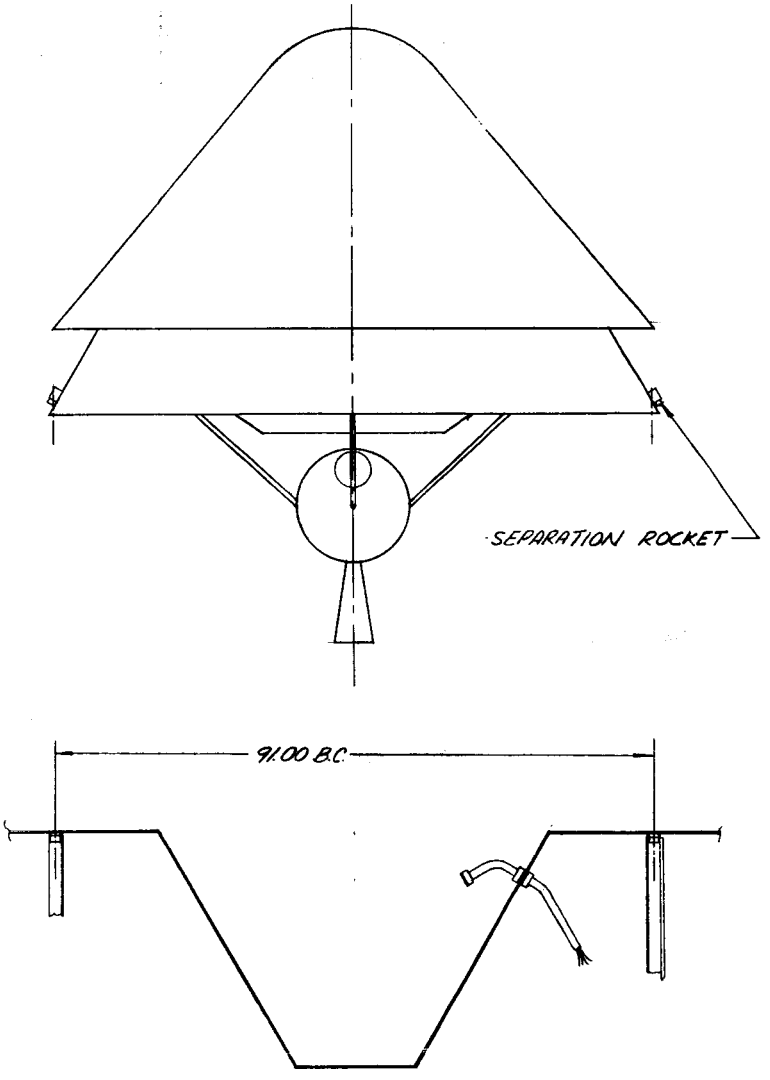
SEPARATION INTERFACE

DETAIL-A

SCALE 1/1



LAUNCH & TRANSIT CONFIGURATION



LANDER SEPARATION

Figure 3.4.3-1. Lander/Orbiter Interface

Lander at the proper time. This operation is described in detail in another section of this study report. The interface will remain with the Orbiter after separation.

The nose of the Lander is sealed with a thermally resistant section of thin plastic (similar to DuPont Polyimide) before thermal treatment.

3.4.4 FINAL ELECTRICAL CHECKOUT

Required testing of the Lander can be done directly upon the flight hardware, although it is obvious that the Lander, once sealed, cannot be opened. Electrical testing is not considered to be a problem involving sterilization, inasmuch as sterile connectors would be built through the Lander-Orbiter interface.

3.4.5 RTG FUELING

Upon completion of ground testing and checkout, the Lander-Orbiter is lifted onto the launch gantry. The RTG fueling device is fitted to the nose cone and electrically heated at the interlock and nose cone interface for a length of time sufficient to insure stabilization of the mass at a sterilization temperature. Flushing with hot ethylene oxide is also practical at this point since the nose shield and the device interlock are ethylene oxide tolerant as well as heat resistant. Insertion of the RTG fuel is done through this sterile interface. The RTG fuel is sterile by its nature even to the extent that heat dissipation is a problem. A nose cone plug is a part of the RTG fuel insertion device. It is fitted when the fuel is added and the barrier is then resealed. The insertion device is removed from the Lander barrier and the launch shroud emplaced. The interior of the shroud is then filled with a positive pressure of ethylene oxide.

3.4.6 POST LAUNCH

A pressure outlet built into the shroud will lower the ethylene oxide pressure as the vehicle rises after launch. It has been suggested[2] that a helium purge be used after ethylene oxide treatment, and that the vehicle be launched carrying positive pressure helium. This would save considerable weight and is recommended as a solution.

The removal of the shroud will release the last of the entrapped gas. It is a remote possibility that some spores or organisms might drop onto the Lander surface at this time. The question of contamination from a shroud leak has been discussed at some length by the members of the NASA Ad Hoc Sterilization Committee. The conclusions of that Committee and the General Electric engineering staff are in agreement that a shroud can be designed that will accomplish the purpose to the reliability required.

3.4.7 HANDLING PROCEDURES

The following step-by-step procedure is recommended to attain the goal of delivering a sterile Lander to the Martian atmosphere. The steps described here; involved in assembly, test, and servicing of the Lander; permit utilization of reasonable checkout procedures while maintaining the vehicle in a sterile condition.

A. The Lander is assembled in a clean room as shown in Figure 3.4.7-1. Procedures and facilities employed are designed to maintain a high degree of cleanliness throughout the assembly operation.

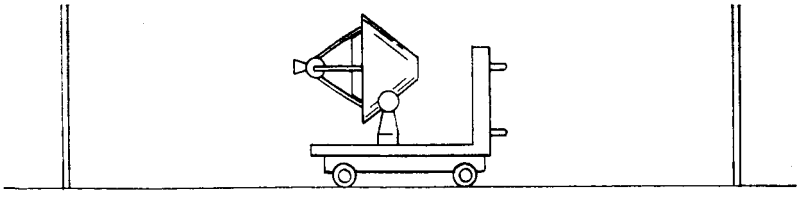


Figure 3.4.7-1. Assembly of Lander in Clean Room

B. Lander acceptance tests (performance testing, alignment, dynamic balance and c.g. determination, and vibration testing) are performed in a clean room environment. When it is necessary to transport the vehicle outside a clean area, a sealed plastic shroud is employed. These operations are shown in Figure 3.4.7-2.

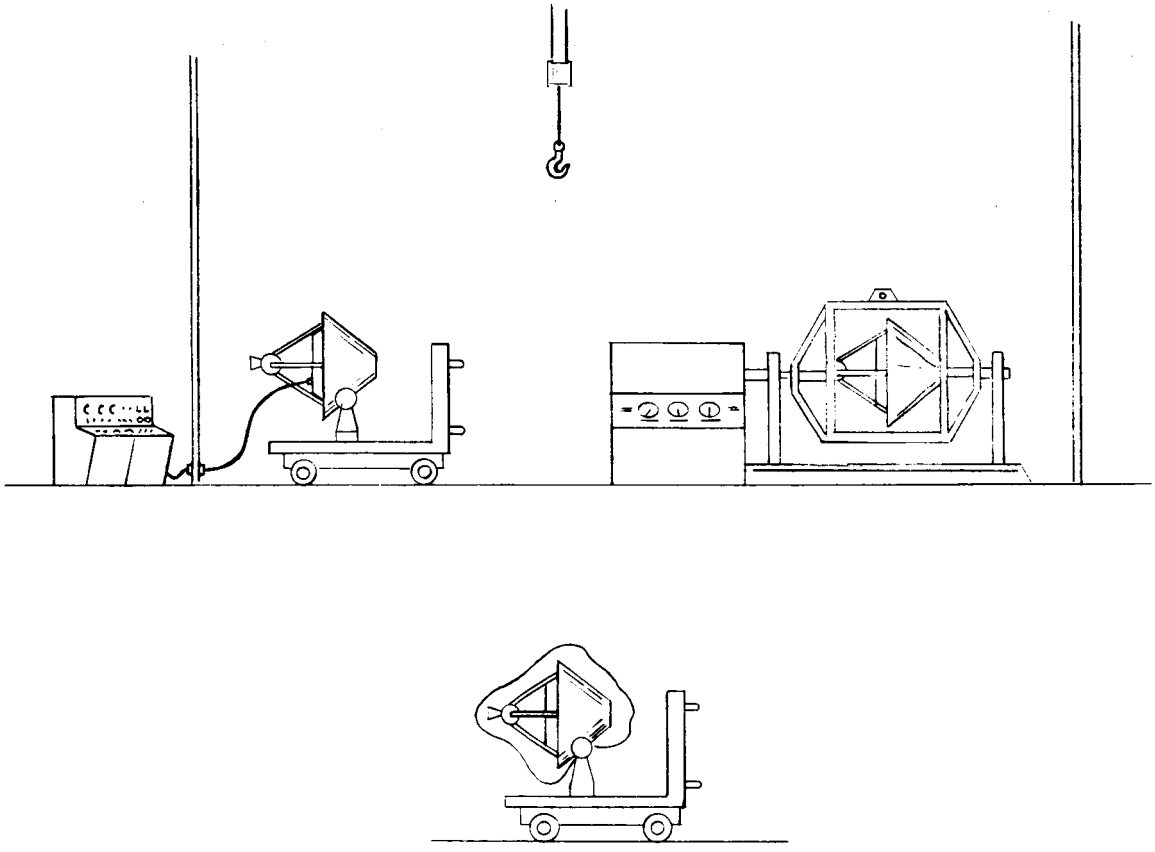


Figure 3.4.7-2. Lander Acceptance Tests

C. Systems tests of the Voyager Spacecraft are conducted with each Lander enclosed in a plastic shroud as shown in Figure 3.4.7-3. The shrouds may be opened if necessary, provided that adequate precautions are taken to preserve the cleanliness of the Landers.

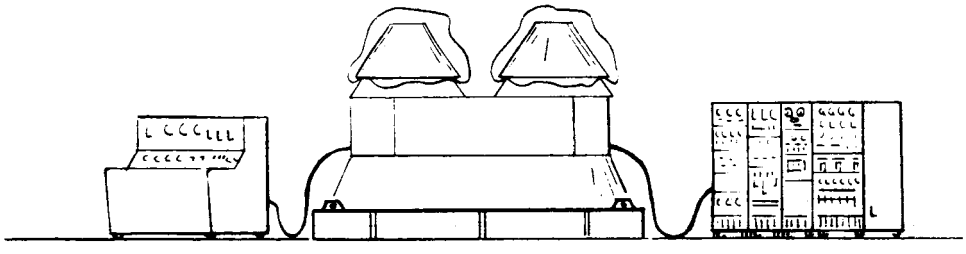


Figure 3.4.7-3. Systems Tests of Spacecraft

D. Thermal-vacuum testing of the Voyager Spacecraft is carried out with the plastic shrouds removed from the Landers since the thermal vacuum chamber will meet clean room environmental requirements. The technique is shown in Figure 3.4.7-4.

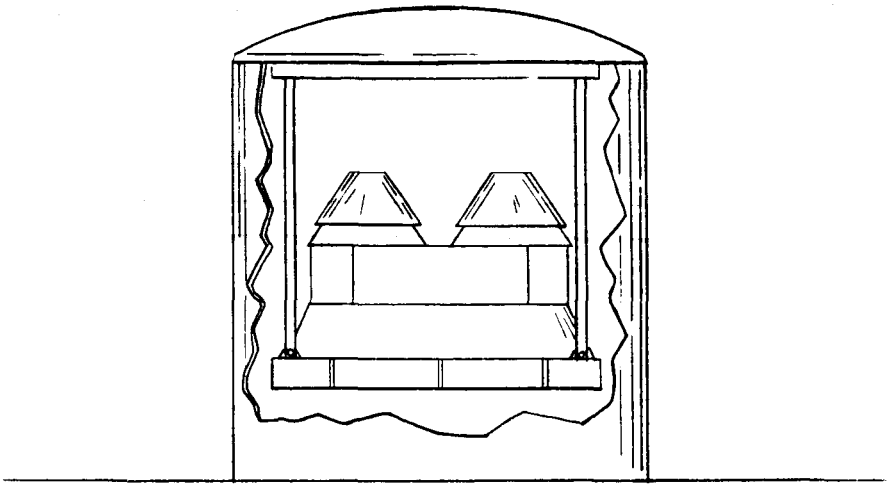


Figure 3.4.7-4. Thermal-Vacuum Test

E. Final in-house Voyager Spacecraft systems tests are performed with the Landers again enclosed in their plastic shrouds as sketched in Figure 3.4.7-5.

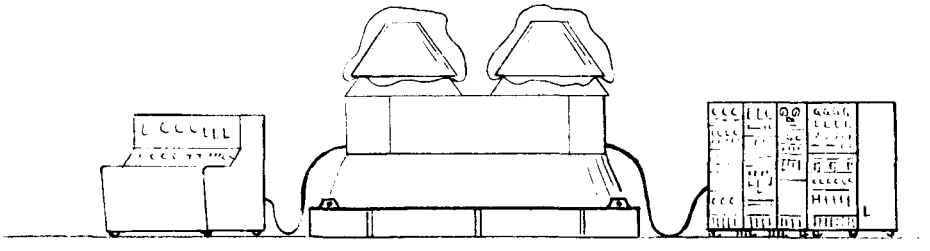


Figure 3.4.7-5. Final In-House Systems Tests

F. The Landers are removed from the Orbiter and final in-house Lander check-out tests and alignment checks are conducted in a clean room. Each Lander is then again placed in a sealed plastic shroud and prepared for shipment to AMR, which follows. Preparation for shipment is shown in Figure 3.4.7-6.

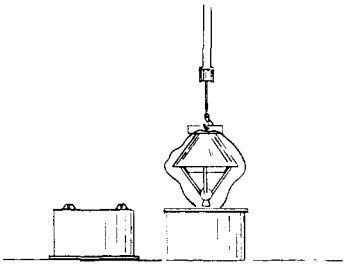


Figure 3.4.7-6. Preparation for Shipment

G. Upon arrival at AMR, each Lander is transferred to a sterilization chamber that is a clean room environment. The plastic shroud is removed and discarded as sketched in Figure 3.4.7-7.

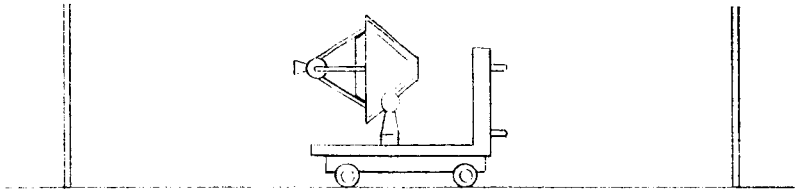


Figure 3.4.7-7. Lander Ready for AMR Sterilization Chamber

H. The Lander is placed in fixtures provided and partially disassembled as shown in the sketch, Figure 3.4.7-8. Any vehicle components which are not heat tolerant are removed from the Lander and placed in the gas sterilization bay. The sterilization chamber is closed, sealed, and pressurized, and the temperature is raised and stabilized at 135°C for 24 hours. In the gas sterilization bay, the surfaces of the components there are sterilized by exposure to ethylene oxide.

Besides the vehicle itself, the sterilization chamber also contains all tools and fixtures required for reassembly of the Lander, a complete set of spare parts, a shielded radioisotope fuel cartridge loading mechanism, and the container that will later encapsulate the Lander to maintain it in a sterile condition.

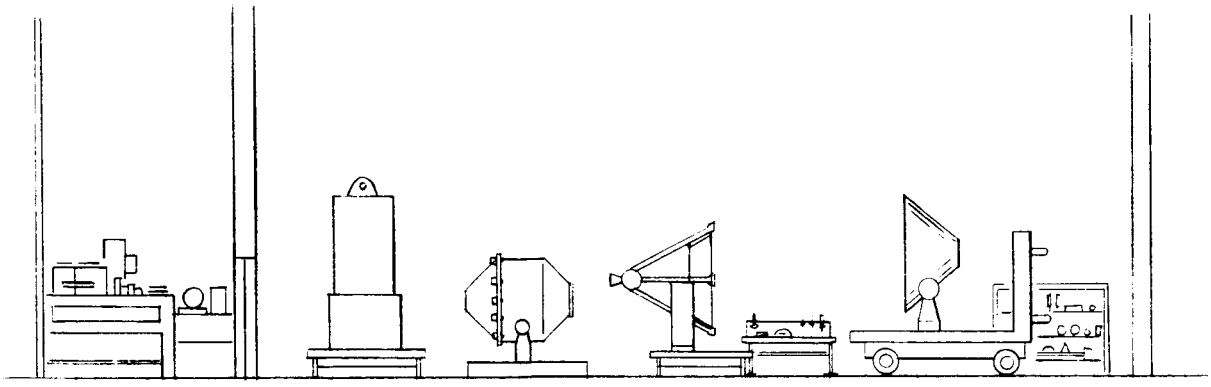


Figure 3.4.7-8. AMR Sterilization Chamber

I. Following the heat and ethylene oxide sterilization cycles, the Lander is reassembled as shown in Figure 3.4.7-9. Sterility is maintained through use of "tunnel" type suits, as described earlier in Figure 3.4.2-1.

J. Upon completion of reassembly, the Lander remains in the sterilization chamber and undergoes final systems checkout and alignment. Again "tunnel" type suits are employed along with specially devised instrumentation. The last operation performed is installation of squibs and igniters. The operation is shown in Figure 3.4.7-10.

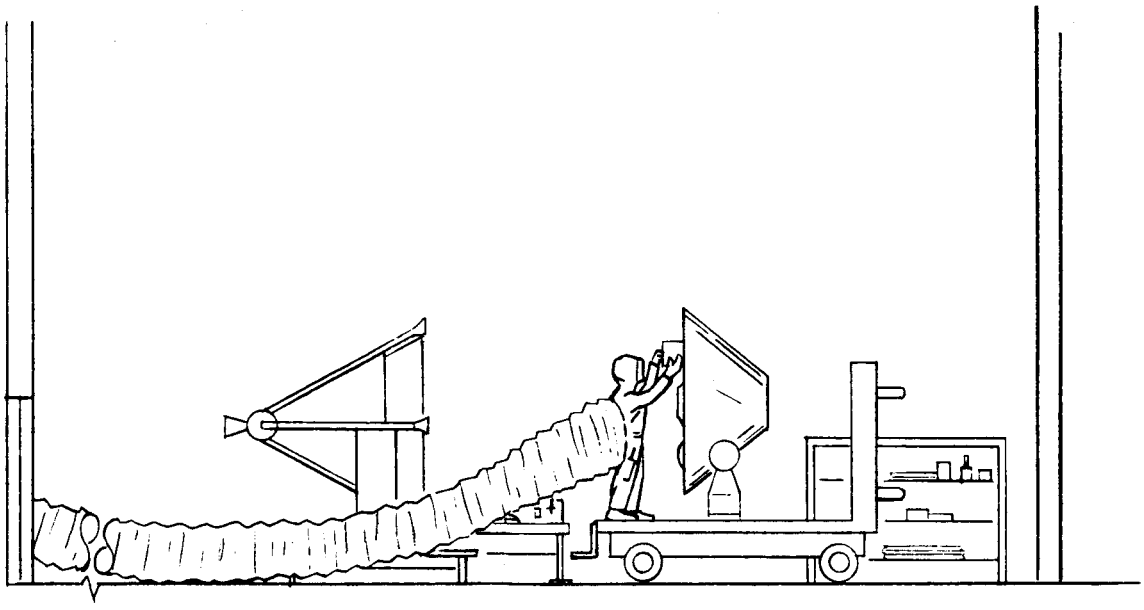


Figure 3.4.7-9. Reassembly of Landers in Chamber

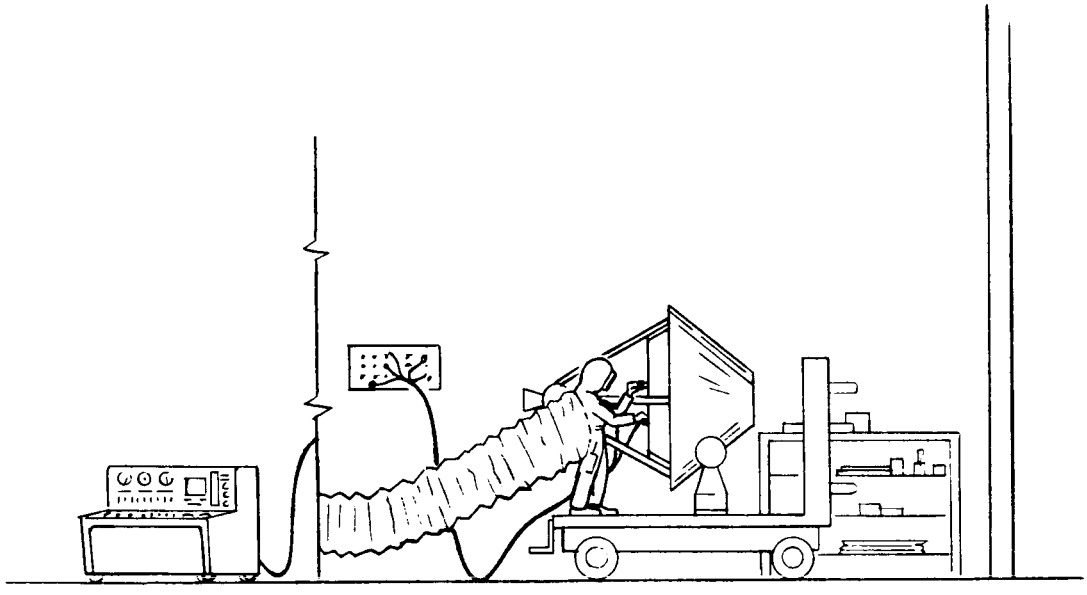


Figure 3.4.7-10. Final Systems Checkout in Chamber

K. The Lander is now encapsulated in a rigid two-piece container which is sealed and pressurized as shown in Figure 3.4.7-11. The container assembly with the Lander enclosed is then removed from the sterilization chamber.

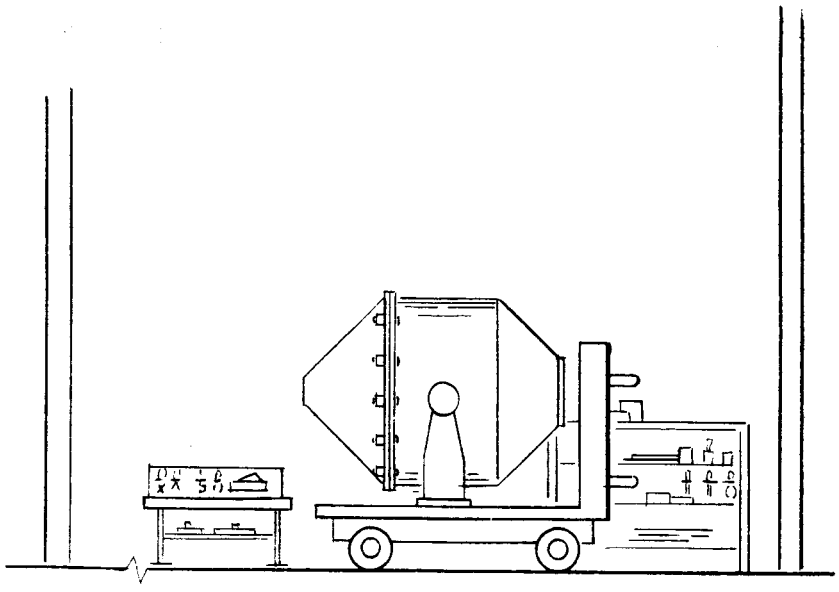


Figure 3.4.7-11. Encapsulation in Two-Piece Container

L. The Lander in its container is transported to the assembly area as shown in Figure 3.4.7-12.

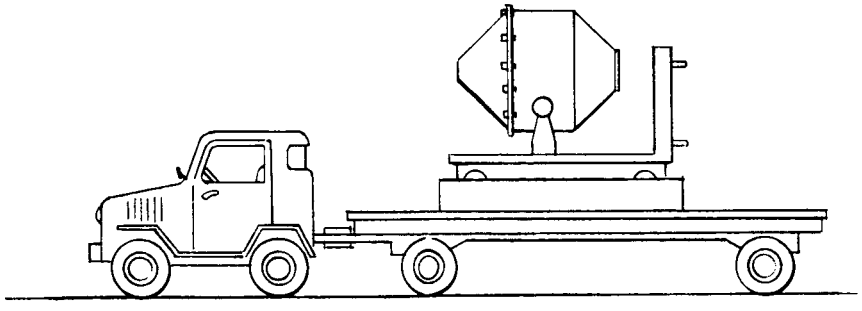


Figure 3.4.7-12. Transportation of Lander

M. The Landers, in containers, are installed aboard the Orbiter. The Lander Orbiter interface checks are performed as shown in Figure 3.4.7-13.

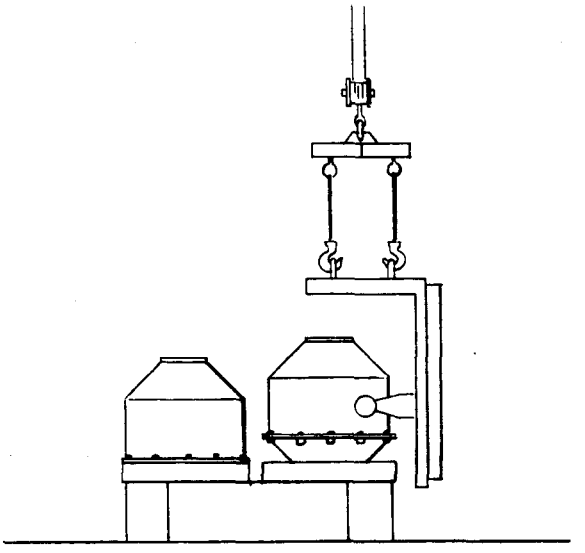


Figure 3.4.7-13. Installation of Landers Aboard Orbiter and Lander Orbiter

N. The Voyager Spacecraft is installed aboard the booster as shown in Figure 3.4.7-14.

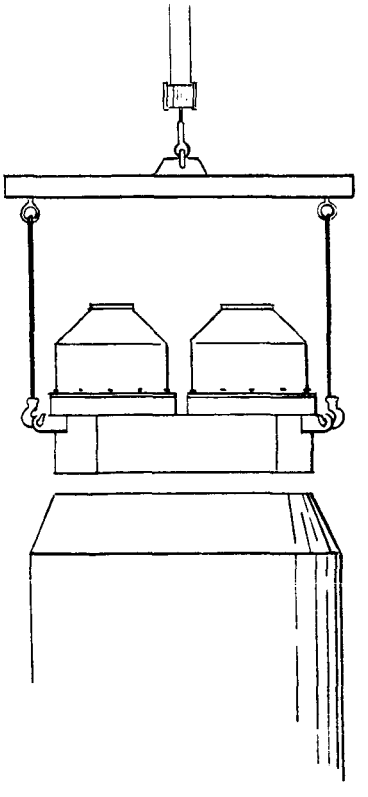


Figure 3.4.7-14. Installation of Voyager Spacecraft Aboard Booster

O. The radioisotope fuel cartridge loading mechanism is mated to the Lander container as shown in Figure 3.4.7-15. (The loading mechanism was sterilized in the sterilization chamber along with the Lander.) The "lock" on the loading mechanism is then sterilized.

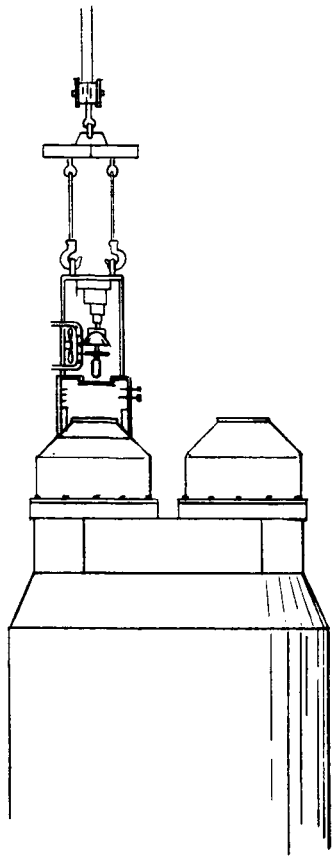


Figure 3.4.7-15. Mating of RTG Fuel Loading Mechanism

P. Within the sterilization lock, the protective covers are removed from the loading mechanism and from the Lander container. The radioisotope fuel cartridge along with the RTG cover plate and a plug of ablative heat shield material is installed in the Lander. The protective cover is replaced on the Lander container, still within the sterilization lock as sketched in Figure 3.4.7-16. (For an explanation of the operation of the radioisotope fuel cartridge loading mechanism, see Section 3.4.8.)

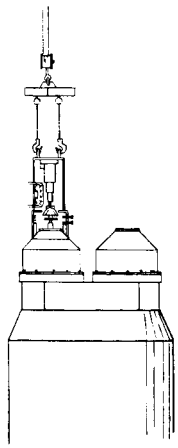


Figure 3.4.7-16. Installation of RTG Fuel Cartridge

Q. The radioisotope fuel cartridge loading mechanism and associated equipment are removed from the Spacecraft as sketched in Figure 3.4.7-17.

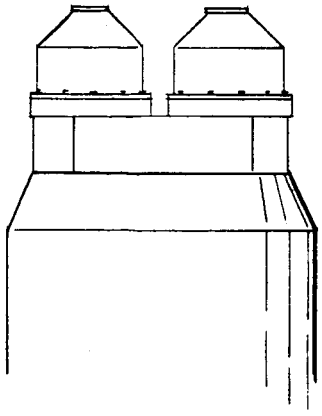


Figure 3.4.7-17. RTG Fuel Load Mechanism Removed

R. The flight shroud is installed as shown in Figure 3.4.7-18. If desired, the volume within the shroud can be purged with ethylene oxide followed by helium.

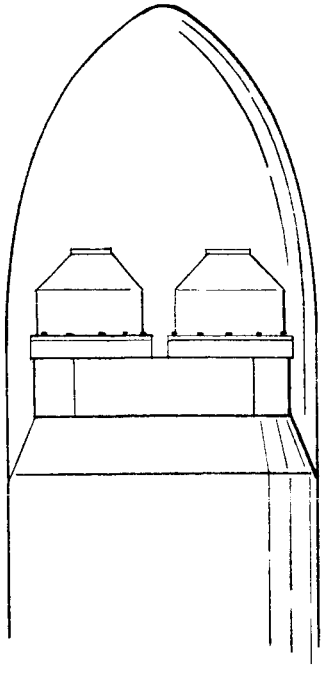


Figure 3.4.7-18. Installation of Flight Shroud

S. The Landers remain in their sealed and pressurized containers during launch and while the flight shroud is separated from the Voyager Spacecraft (presumably during second stage burn). The step is shown in Figure 3.4.7-19.

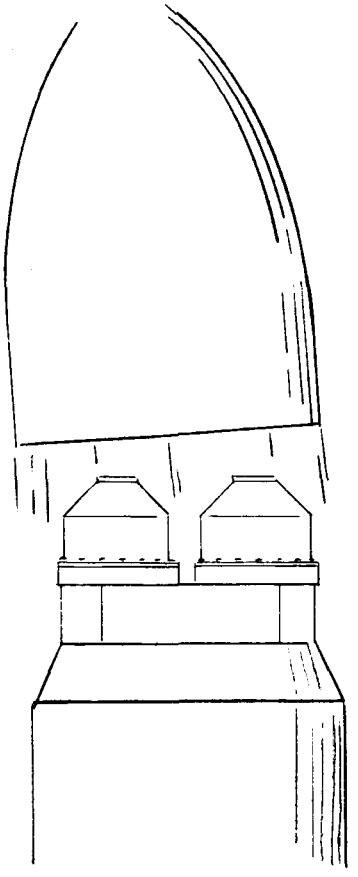


Figure 3.4.7-19. Flight Shroud Separation

T. Immediately subsequent to flight shroud separation, the upper portions of the Lander containers are separated as shown in Figure 3.4.7-20. The lower section of each container remains with the Orbiter when the Landers are separated for their entry into the Martian Atmosphere.

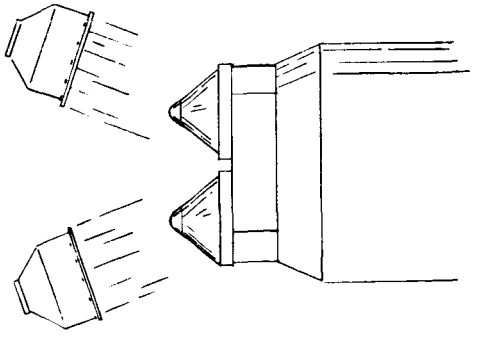


Figure 3.4.7-20. Lander Separation

The advantages of the preceding procedure are:

1. The Lander is assembled and tested in a clean environment to assure a low original organism count.

2. The Lander is sterilized in the sterilization chamber by use of heat or by use of ethylene oxide when components with low heat tolerance are involved. The chamber is sealed and pressurized to produce controlled leakage in the direction desired (out of the chamber).

3. Lander performance and reliability is assured because each vehicle is checked out after sterilization. Should any malfunction occur, spare parts are on hand in the chamber.

4. Procedures are relatively safe since squibs and igniters are installed following checkout of the circuits involved.

5. The rigid pressurized container lends itself to efficient handling and servicing operations prior to launch. It has relatively little likelihood of sustaining damage. It will permit storage of the vehicle for an extended period should this be necessary.

6. Use of a pressurized container permits leakage to flow only in the direction away from the sterilized Lander, thereby, assuring maintenance of sterilization.

Problems associated with this procedure are:

1. The protective container is "opened" to install the radioisotope fuel cartridge. (This is performed under closely controlled conditions; see Section 3.4.8.)

2. A rigid container will add considerable weight to the flight package. (The greater part of this weight is separated during boost, however, so that it has relatively little effect on mission performance.)

Other methods of maintaining sterility have been investigated. Most of them involve a thin plastic bag to act as the biological barrier. The idea of using such a bag has been rejected because of the following problems:

1. Difficulty would be encountered in sealing the plastic bag (and resealing it following radioisotope cartridge insertion). Sterility cannot be assured unless a good seal is obtained.

2. The chance of damage to a plastic bag during handling, servicing, and test operations, subsequent to sterilization, is very high. This could result in contamination of the Lander.

3. The biological barrier itself, with all its mechanical and electrical interfaces with the Lander, presents problems. The Orbiter and support equipment would become a rather complex piece of equipment of appreciable weight. Furthermore, the plastic bag does not lend itself well to the development of a compact and reliable article.

4. Separation is difficult to accomplish with a plastic bag. The possibility of entanglement with the Lander or the Orbiter exits. The result could be contamination of the Lander at this time.

3.4.8 OPERATION OF THE RADIOISOTOPE FUEL LOADER

Figure 3.4.8-1 furnishes a mechanical schematic of a device for loading the RTG fuel capsule into the Lander. The schematic does not furnish all of the design details but does illustrate the salient features of the loading and sterilizing mechanism.

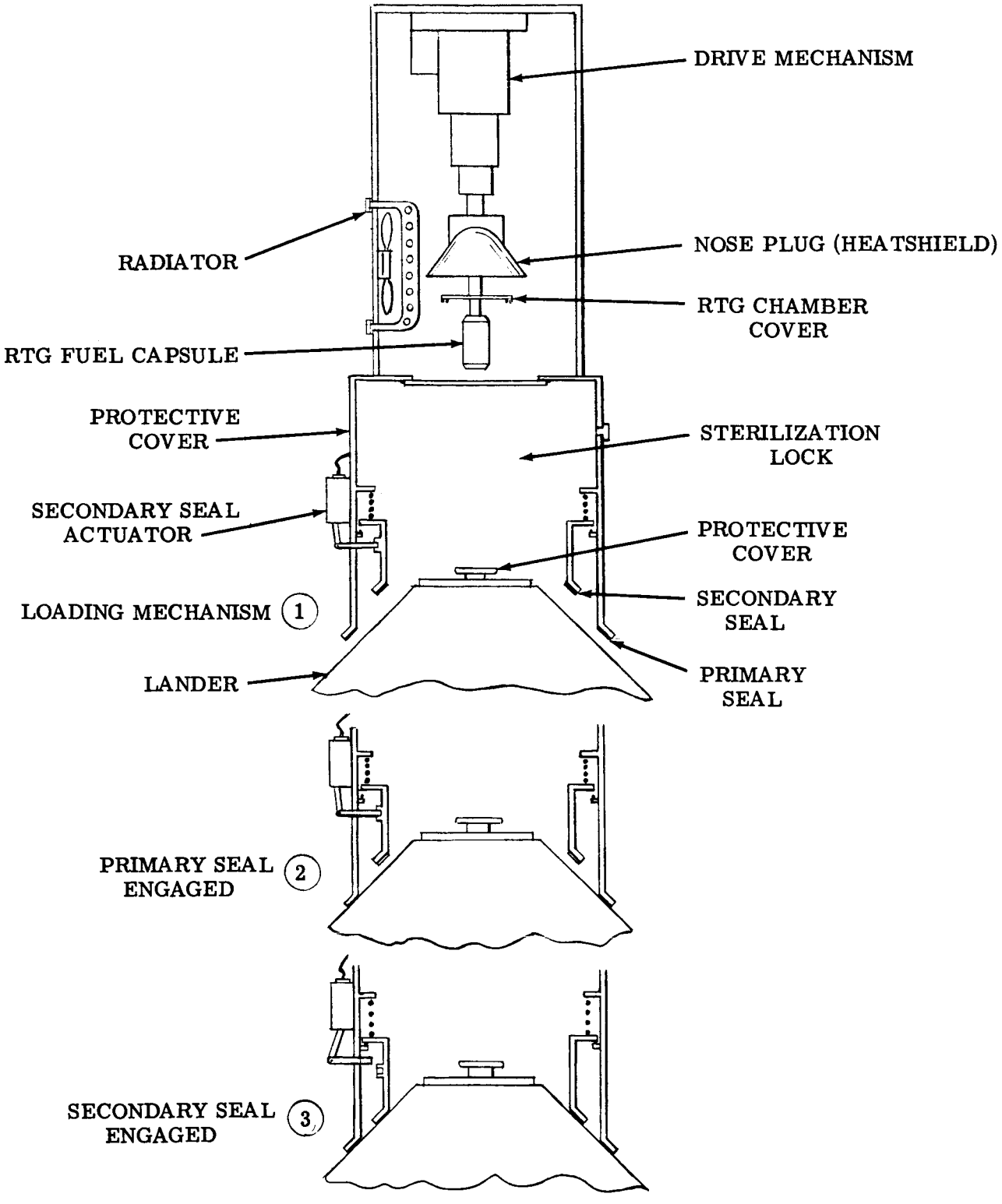


Figure 3.4.8-1. Mechanical Schematic, RTG Loading Device

A typical operation of the unit will be as follows:

A. With the Lander installed aboard the Orbiter and the entire spacecraft atop the booster, the loading mechanism is brought into position, sealed, and locked to the Lander, as shown in Figure 3.4.8-2.

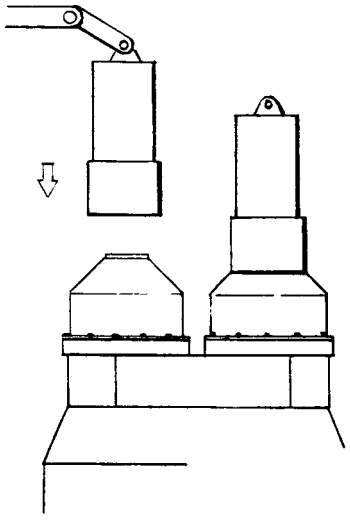


Figure 3.4.8-2. Mating of Loading Mechanism to Lander

B. The sterilization lock is sterilized by heat or by ethylene oxide or by a combination of these, thereby, providing an environment far more rigorous than that to which the Lander itself was originally exposed in the sterilization facility. The operation is shown in Figure 3.4.8-3.

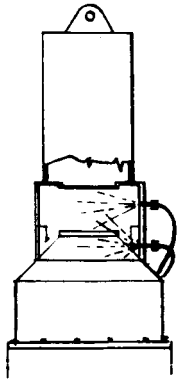


Figure 3.4.8-3. Operation of Sterilization Lock

C. Upon completion of the sterilization of the lock, secondary seals are engaged. These seals are designed to produce controlled leakage of ethylene oxide so that no organism could possibly enter the sterilized lock. The step is shown in Figure 3.4.8-4.

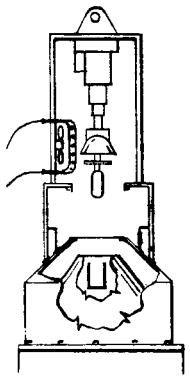


Figure 3.4.8-4. Engagement of Secondary Seals

D. The protective covers at either end of the lock are removed, remotely, and the RTG fuel capsule is inserted and locked along with its cover plate and the necessary block of ablative shield material that forms the outer covering of the vehicle. The operation is shown in Figure 3.4.8-5.

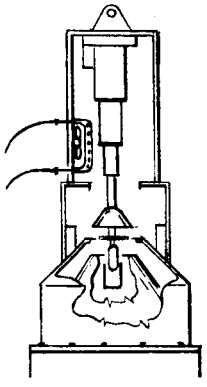


Figure 3.4.8-5. Insertion of RTG Fuel Capsule

E. The protective cover is replaced over the vehicle and the seals between the sterilization lock and the Lander are broken. The loading mechanisn is removed. Prevention of contamination in the joint on the ablation shield can be accomplished by means of a controlled leakage seal utilizing ethylene oxide. The operation is shown in Figure 3.4.8-6.

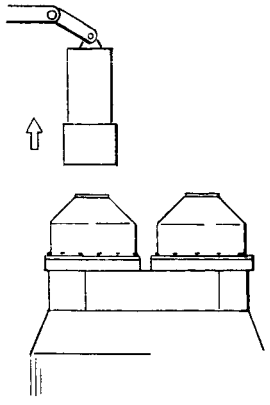


Figure 3.4.8-6. Removal of Loading Mechanism

3.5 BIOLOGICAL BARRIER

3.5.1 CONCEPT

Design requirements for the biological barrier for the Lander vehicle have been carefully examined. A brief concept of the protective container (or barrier) is as follows:

The sterile protective container (or barrier) surrounds the Lander portion of the Voyager system from the time of thermal sterilization until approximately 500,000 ft into space. In addition, the Lander is sealed, thus providing the primary shield against contamination. This inner barrier is never entered, once it is sealed and pressurized, thereby, guaranteeing the integrity of the sterilization performed.

3.5.2 DESIGN CONSIDERATIONS

Preliminary design requirements of the container were as follows:

1. It will have electrical connections for check-out and test. This will involve an estimated 5 connections.
2. It will have "hose" fittings for liquids and gases. It is estimated that two fittings for liquid and one fitting for gas will be required.
3. It will be sealable by "hot iron" heat or some other simple equivalent method.
4. It will be big enough to contain Lander, RTG and protective container, and remote handling gear.
5. It will have straps, handles, or fasteners for attachment to the shroud.
6. It will leave an opening large enough to accept items without tearing.
7. It will be as lightweight as possible since the barrier accompanies the spacecraft into space.
8. It will not be affected by hot (up to 100°C) or cold ethylene oxide.
9. It will not be affected by heat up to 300°F (150°C).
10. It will have a method for cutting off a section when the shroud is ejected during flight.
11. It will require a built-in electrical junction box between Lander and Orbiter.
12. A rigid or form-fitting end for the Orbiter fit is required. Rigidity on remainder of bag is not desired (except when loading).
13. The purpose of barrier is to keep out bacteria spores and other microorganisms.
14. The preliminary size estimate is that it will be a tube 10 ft long and 10 ft in diameter. This length must be indefinite until remote isotope handling gear is designed.
15. To avoid carrying the junction box into space, it will be possible to detach this before flight.
16. A support frame will be designed to hold the container open when inserting the Lander, etc.

3.5.3 DISCUSSION

Such a container/barrier is technologically feasible. Du Pont Polyimide plastics meet many of these above specifications. Yet, even without this barrier, the Lander can still be sealed tightly. The shroud can still be easily designed to hold a final gaseous purge. The nose cone material is still capable of withstanding ethylene oxide. Therefore, by means such as these, a sterile capsule interior can still be maintained.

The problems of handling the capsule within a separate plastic primary barrier are discussed at length within the GSE portion of the study report.

The interface between the Lander and Orbiter will not change as a result of incorporating the plastic barrier in the design. (The operational sequence for sterile separation in the vicinity of the target is described elsewhere in the report.) The interface material can be of any thermally-resistant material and, though assembled to the Lander first, it is essentially a part of the Orbiter after separation. The interface material is internally sterile, since it is treated with ethylene oxide before flight. Only the exterior side toward the Orbiter may be assumed to be contaminated.

Figure 3.5.3-1 illustrates the assembly and separation of the Lander/Orbiter with their interface.

3.5.4 RECOMMENDATION

The recommendation, based on the studies discussed in the preceding paragraphs, is to utilize the exterior of the Lander as the primary sterility barrier. The additional plastic barrier would be used as additional protection.

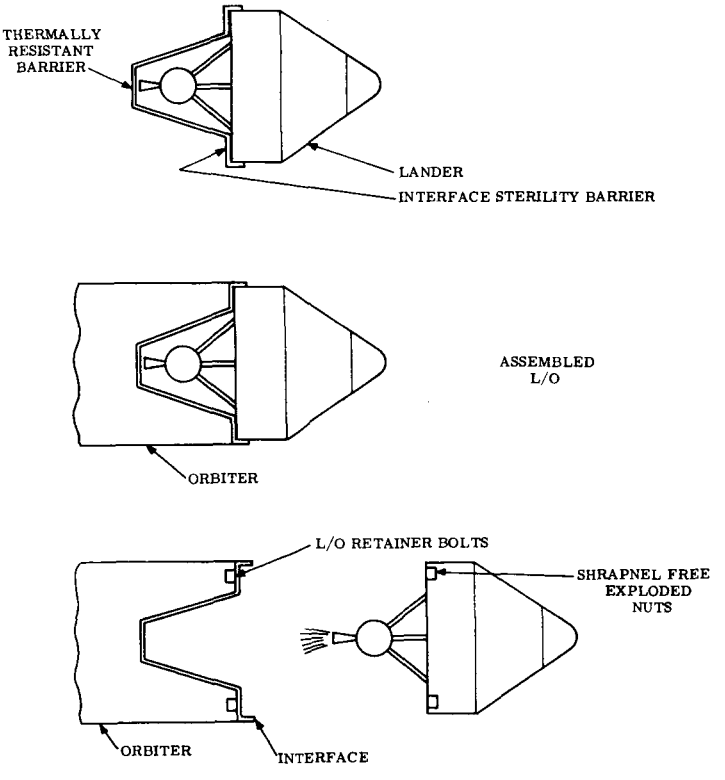


Figure 3.5.3-1. Conceptional Drawing of Lander/Orbiter Interface

3.6 RADIATION STERILIZATION OF COMPONENTS AND PARTS

Irradiation by nuclear particles has been studied as a means of terminal sterilization of the spacecraft. This technique is not considered feasible for the reasons discussed below. The Radiation Effects Information Center at Battelle Institute has been consulted for effects on electronic components.

Exposure energies in ergs can be directly related to specific heats and to weights of particular materials. Thus, a temperature-equivalent can be derived. The integrated neutron flux (nvt) can be roughly translated into energy as follows: 10^8 neutron/cm^2 = (0.1 Mev) 25 ergs/gm. This relationship is the carbon relationship, but the results obtained should be sufficiently close to give an understanding of the problem. For example: an electronic device, that will withstand 10^{15} neutrons (steady state), can be expected to withstand

$$2.5 \times 10^6 \text{ rads } 10^{15} \text{ nvt} \times \frac{25}{10^8} = 25 \times 10^7 \text{ ergs/gram.}$$

Approximatly 100 ergs = one rad.

Then:

$$2.5 \times 10^8 \text{ ergs} = 2.5 \times 10^6 \text{ rads.}$$

A conservative figure for sterilization purposes would be a requirement of 10^7 rads to insure a lethal dose to microorganisms. In the case in question, then, sterilization by means of radiation would be inadequate. Each case must be individually treated. Trade-offs, however, involving combinations of techniques are possible. An additional consideration is that the components will be subjected to additional radiation during the voyage. This must be estimated and added to the total sterilization dosage when calculating component reliability for the entire trip.

Possible trade-offs include such considerations as the radiation resistance of germanium devices as compared to silicon devices, the effect of shielding on voyage dose, etc. In view of the difficulties of dry heat or chemical sterilization, each potential problem component should be examined to determine radiation tolerance level. It would seem possible that relatively large sections may be efficiently sterilized by radiation.

The effects of combined radiation and temperature are generally unknown. Active investigation is proceeding within this area. As this information becomes available it should be examined for applicability.

It is most probable that the use of irradiation on the Voyager program should be limited to sterilization of items that cannot take thermal or ethylene oxide treatment. The attached table, Table 3.6-1, indicates the state-of-the-art and potential development.

TABLE 3.6-1. STATUS OF MATERIALS IN RELATION TO NUCLEAR ENVIRONMENT

Section A: Exposure, ergs gm^{-1} (C)

	Material(1)	Material(2)
Elastomers	5×10^9	5×10^{10}
Plastics	7×10^9	2×10^{12}
Fuels	10^9	5×10^{12}
Lubricants and Hydraulic Fluids	5×10^{10}	5×10^{11}

TABLE 3.6-1. (Cont'd)

Section B: Integrated Flux, N/cm^2

	Material(1)	Material(2)
Structural Metals	10^{20}	10^{20}
Ceramics	10^{19}	10^{20}
Electronic Components	10^{15}	10^{18}
Semi-Conductors	10^{13}	10^{15}

(1) Current materials are satisfactory to this dosage.
(2) Materials under development may give satisfactory service to this dosage.

3.7 STERILIZATION WITH ETHYLENE OXIDE

Thermal sterilization treatments are to be used wherever possible to provide internal as well as surface sterilization for Voyager systems. Where the nature of the component module, part, etc., is such as to preclude thermal treatment, chemical sterilization, utilizing a 12 percent ethylene oxide, 88 percent Freon 12 gaseous mixture, provides a good backup technique. In addition, terminal sterilization can be preserved by maintaining a slight positive pressure of this gas mixture in an air-tight shroud.

3.7.1 MATERIALS COMPATIBILITY

Information on the effects of ethylene oxide and ethylene oxide-freon mixtures on the properties of materials is limited. While there are some indications that these effects are, in most instances, not critical (References 7 and 8): it is, nevertheless, necessary to test candidate materials for compatibility. A small test chamber will permit evaluation of materials subjected, not only to chemical sterilization conditions, but also to thermal conditions. Synergistic effects can also be studied with the aid of this chamber. The development of analytical methods for accurate and rapid determination of degradation products, structural modifications, phase transitions, etc. is essential for accumulation of data on the materials' behavior and reaction mechanisms.

3.7.2 STERILIZATION EFFICIENCY

The effectiveness of ethylene oxide and ethylene oxide-inert gas mixtures as sterilants is not yet fully established. Those parameters most in need of investigation are:

1. Humidity
2. Temperature
3. Pressure

It has been shown that there is a relationship between relative humidity and sterilizing action. Optimization of this relationship (while concurrently protecting components, parts, etc. from moisture attack) is necessary.

The increase in temperature of sterilization of a mere 10°C has been shown to increase the sterilizing efficiency of ethylene oxide (i.e., reduce the required exposure time for 100 percent kill) by a factor of 2.74 [9]. The range of temperatures studied (5-37°C) was limited; however, further investigation is required.

Little or nothing is known of the effect of higher than atmospheric ethylene oxide environment pressures. This should be studied along with the effects of combined humidity/temperature/pressure variations.

In addition to the above, further studies to obtain data on time/concentration effects should be initiated.

3.7.3 PERSONNEL HAZARDS

Ethylene oxide is dangerous both as a toxic material and as a highly combustible gas. Ethylene oxide has a maximum allowable concentration of 50 ppm in air and a minimum explosive limit in air of 13 percent. The 12 percent ethylene oxide - 88 percent Freon 12 mixture is not an explosive hazard in air; however, the health hazard remains. In view of this, handling procedures must be prescribed and safety equipment design and testing initiated.

In addition, since the rate of sterilization is apparently proportional to the concentration of ethylene oxide, the possibility of using higher concentrations of ethylene oxide should be investigated. It is recognized that this would increase the hazards associated with

ethylene oxide; nevertheless, it has been shown that ethylene oxide can be handled safely and efficiently using simplified procedures and observing safe handling regulations. Combining higher ethylene oxide concentration with slightly elevated temperatures (35-50°C) may provide a more efficient sterilization procedure.

Figure 3.7.3-1 illustrates that primary dependence upon ethylene oxide is not justifiable. There are reports that use of ethylene oxide alone may never reduce microorganism population to zero for a given organism [10]. The curve also illustrates the usefulness of ethylene oxide for reducing bacteriological load. The efficiency of this process is heavily dependent upon initial population. It is obvious that a reduction in initial load will vary the acceptable portion of the curve. Thus, ethylene oxide treatment is a useful technique at various points in the assembly and handling process.

3.7.4 RECOMMENDATIONS

It is recommended that a study of ethylene oxide sterilization to provide data upon which to base firm decisions be initiated.

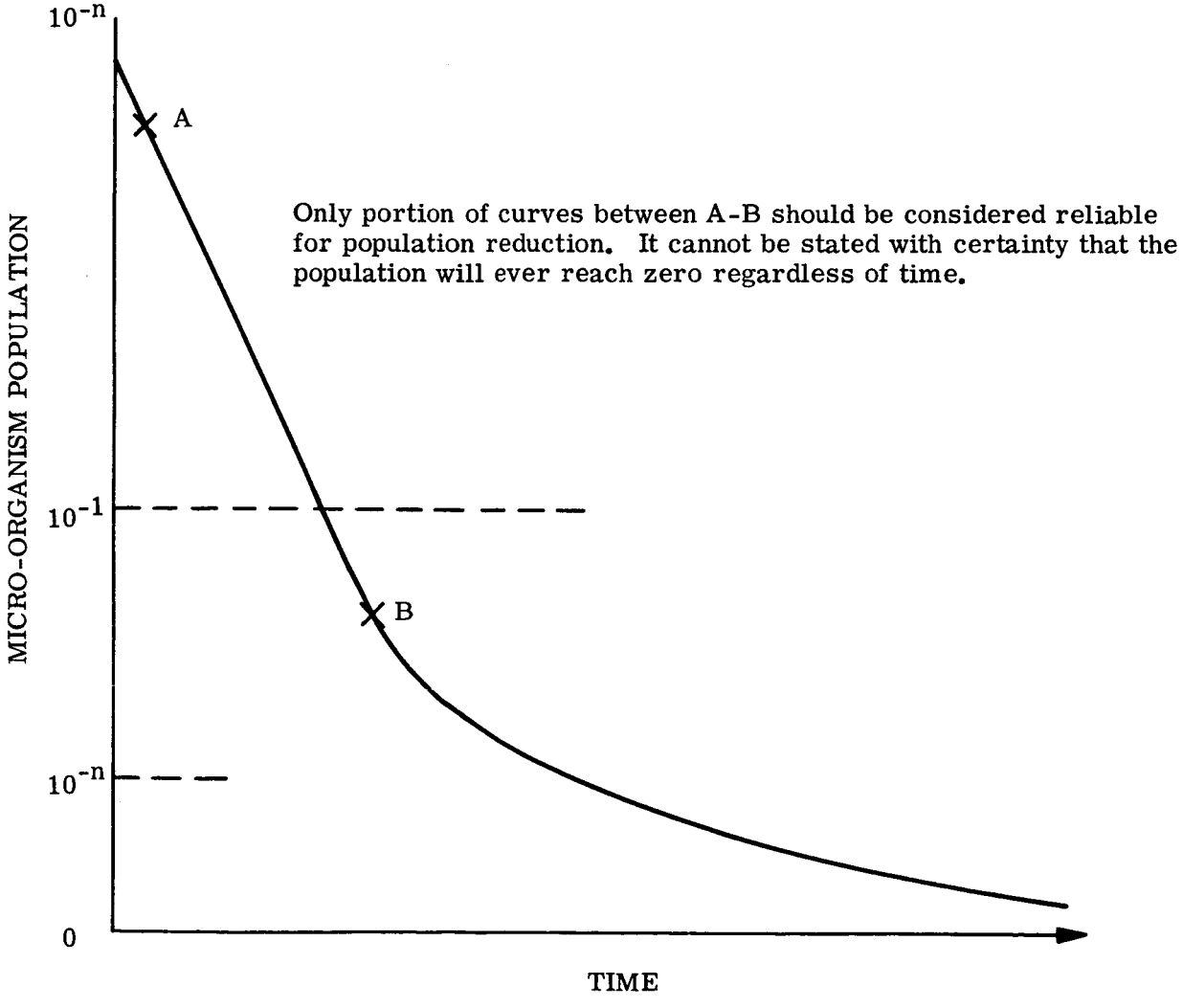


Figure 3.7.3-1. Typical Time Vs Microorganism Population at Given Ethylene Oxide Concentration

3.8 THERMAL STERILIZATION

3.8.1 DISCUSSION

Koesterer has conducted extensive studies on heat as a sterilizing medium. Dry heat has been selected as the primary method (over moist heat) to lessen the possibility of damage to the components of the spacecraft. It is not possible to accurately predict the resistance of a spore population to a lethal agent. With heat, the order of death of an organism population has been assumed to be logarithmic. This implies death is a function of the time-temperature relationship involved, assuming a lethal temperature is used. If the theory of logarithmic death functions were perfectly true, then by using techniques and theories long employed by the food industry, thermal-death rates and times could be easily predicted. Consistent data at temperatures of interest has not been available, but there is general agreement that the final terminal cycle of 24 hours at 135^{o}C will eliminate even the long lived exceptions to the heat-death theory, particularly in a population already exposed to the prior sterilization treatment described previously. Biological load reduction, then is considered to play an important part in constructing a sterile vehicle. It may be said that to some unknown extent, sterility treatments are additive.

It is important to differentiate here between the survivor curves of ethylene oxide and dry heat. It has been stated in the previous section that it is possible that no amount of ethylene oxide treatment can guarantee a sterile end-product. A curve of thermal treatment will tend to resemble the ethylene oxide curve with this exception. There is a temperature-time point where lethality is assured when using heat. The lowest possible completely lethal temperature for each organism is not known; however, 135^{o}C has been assumed to be above this lethal point when combined with long exposure. It is possible that future research may uncover organisms that survive this treatment. The alternatives at this time would be to raise the temperature, lengthen the exposure, or to start with such a low initial population that acceptable probability of sterility for any given vehicle is reached. The third alternative, described above, must be introduced into the recommended sterilization process, achieved by clean rooms and repetitive sanitization and sterilization treatment, from manufacturing on through launch.

Figure 3.8.1-1 illustrates a typical thermal population versus time curve, and Figure 3.8.1-2 is a time versus temperature curve. Only the straight line portions of this type data curve should be used.

3.8.2 VEHICLE DESIGN

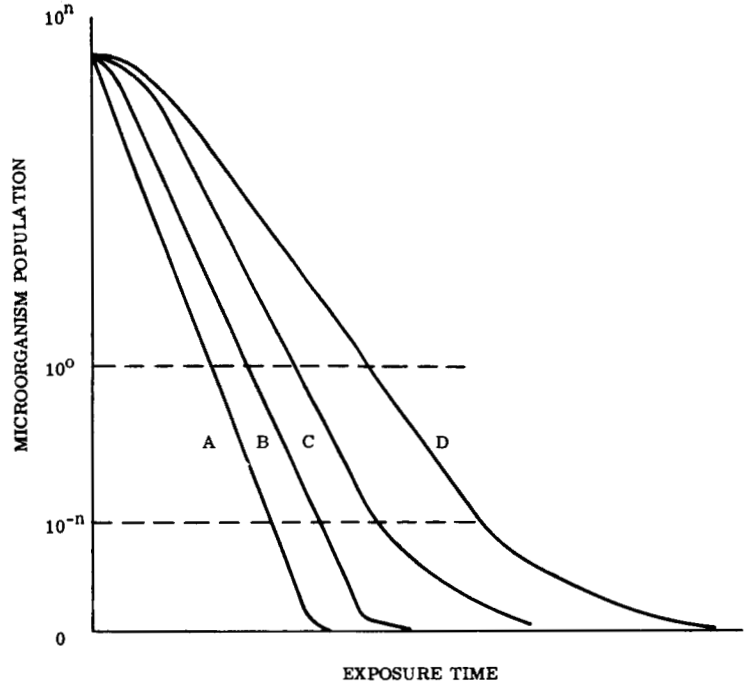
The need for sterile planetary entry vehicles imposes two strenuous conditions upon the vehicle design as follows:

1. The vehicle must survive an extended soak at elevated temperatures.

2. The vehicle must be fabricated in such a manner that it can be successfully decontaminated and then sterilized by dry heat.

The exposure to sterilization temperatures occurs prior to other design conditions. Thus the vehicle must pass through the sterilization cycle and still maintain all its functional capability and still possess adequate strength to perform its mission.

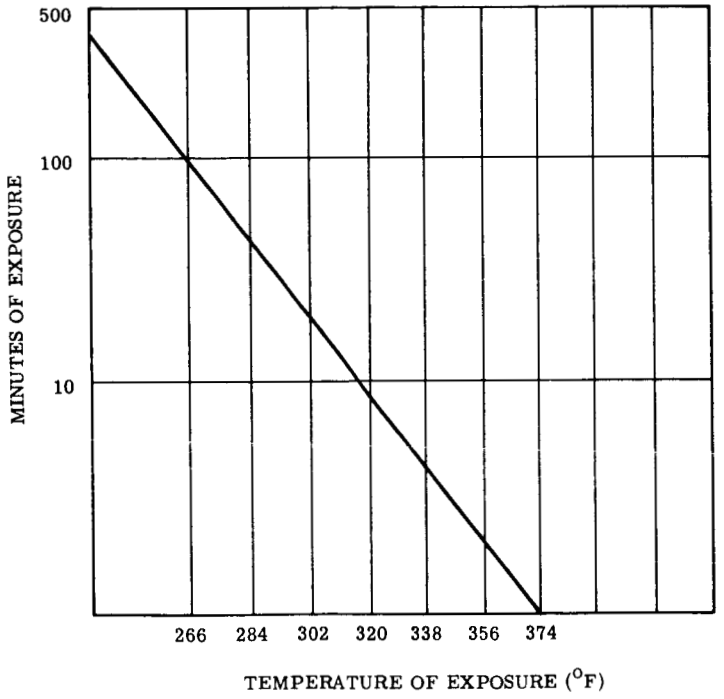
These requirements impose the problems of designing a structure for elevated temperature and for accommodating or minimizing the effects of thermal transients and gradients. The total time at temperature can be quite extensive due to thermal lag within the spacecraft. This may impose limitations on material selection to avoid effects such as overaging of some of the aluminum and magnesium alloys. The structure must not contain entrapped microorganisms.



Type Thermal

Each curve represents a different temperature. All temperatures in lethal range of organism.

Figure 3.8.1-1. Survivor Curves for Microorganisms Population Vs Exposure Time



Type Curve
Resistance of Spores to Destruction of Dry Heat

Figure 3.8.1-2. Resistance of Spores to Destruction by Dry Heat

Problem areas in design and fabrication imposed by these requirements and establishment of guidelines for preferred materials, design concepts and configurations, fastening and joining methods, manufacturing, assembly, and sterilization procedures for this type of vehicle are the objectives of a current study[11].

The ideal structure for elevated temperature would be statically determinate and free from residual stresses. It would be constructed of a material which had no noticeable loss of properties after the thermal cycle. Under these conditions, the temperature and thermal gradients would not play an important role. The thermal gradients would be important only in so far as they were not linear in nature.

For decontamination, the ideal would be a homogeneous, integral structure. The structure should be physically smooth to facilitate cleaning. For sterilization, the structure must be constructed so that all its components can be brought rapidly to sterilization temperature.

The above requirements are not necessarily mutually incompatible; however, they are not completely attainable because of other requirements on the structure. How far a design must vary from the ideal, as discussed above, will be a measure of the problems introduced by the sterilization requirement.

Three significant aspects of the sterilization process with regard to structure are readily apparent:

1. Rate of heating to and from soak temperature (thermal gradients)

2. Soak temperature

3. Time at soak temperature.

These must be investigated thoroughly for their effects on the structure and structural materials.

Based on investigations already performed by GE-MSD, several prime sources of structural difficulty can be pinpointed. Dimensional stability may be compromised by the thermal soak cycle. This is of particular importance for non-metallic or low yield strength materials, optical, and control instrumentation. Severe thermal gradients with accompanying stresses and possible excessive distortions occur wherever components of vastly different thicknesses are adjoining. Local concentrations of material should therefore be avoided. A like condition arises where thermally dissimilar materials are used next to each other.

The following structural areas are critical areas in respect to elevated temperature and are indicative of the problems which arise through sterilization rigors:

1. Sandwich panels and laminated structures, particularly where dissimilar materials are employed or where thermal gradients cannot be readily avoided.

2. Attachments into honeycomb and similar sandwich materials where application of heat may degrade the connections such that flight loads cannot be sustained.

3. Thin shells with massive stiffeners will be avoided because of the unequal heating rates of the two different masses which cause thermal stresses and distortions.

4. Various types of component support structure found both internally and externally to the vehicle such as composite beams, brackets, shear panels, etc. These are particularly susceptible where they mount components re-

quiring alignment accuracy such as optics, control nozzles, momentum wheels, antennas and similar instruments common to spacecraft. Permanent distortion due to the thermal effects of sterilization may be intolerable, and special mounting concepts may be required.

5. Sealed and pressurized structures, tanks, and highpressure vessels where the sterilization thermal cycle can damage seals by distortion or material degradation, and internal pressures may be increased during the sterilization process to excessive levels. Also, the physical support of these units can be significantly affected by heating and will warrant investigation.

6. Structural devices where preload must be maintained or devices which depend on specific spring rates that can be degraded by the temperature levels required for sterilization. An example of this is spring-deployed solar paddles or booms.

7. Structural components susceptible to degradation or damage due to strains from differential coefficients of thermal expansion such as lugs employing steel bushings pressed into aluminum or magnesium or various joints where close tolerances must be maintained, such that yielding due to temperature will degrade later performance at flight loads and vibration levels.

The areas listed must be investigated with the intent of fully defining the structural problems associated with the present concept of sterilization.

3.8.3 THERMAL CONSIDERATIONS

The use of heat for spacecraft sterilization makes it desirable that good heat flow paths exist between the external surfaces of the vehicle and the innermost potential bacteria site. When such heat flow paths consist of homogeneous solids, the thermal properties of the material itself are important for the establishment of minimum transient time during the heating cycle. Selection of materials and dimensions, such that desired thermal properties are obtained, will result in a dimensionless parameter of the proper magnitude to minimize the heating transient. These considerations apply equally to the cool-down procedure after sterilization.

The present generation of spacecraft which need to be sterilized are not homogeneous bodies, but consist of bolted, clamped, welded and otherwise joined assemblies. For this reason the thermal conductance through such composite structures must first be known and then be improved in order to minimize total heating time. The General Electric Company has investigated the problem of joint thermal conductance on a continuing basis for several years as shown in the published papers in References 12 and 13. This investigation is continuing.

The information obtained during this period is directly applicable to the evaluation of heating rates for spacecraft joints under consideration. To illustrate the variation of thermal joint conductance with contact pressure in a vacuum environment, several curves from References 12 and 13 are shown in Figures 3.8.3-1 to 3.8.3-3. Figure 3.8.3-4 shows the effects of non-metallic heat transfer promoting fillers.

When a spacecraft is designed, adequate heat flow paths are normally provided between heat generating and heat dissipating surfaces. These heat flow paths will be useful in the spacecraft heating cycle during sterilization. However, there are numerous appreciable "thermal masses" within a typical spacecraft, which are not heat dissipators and, therefore, are not provided with adequate heat flow paths to the vehicle skin. For this reason, one of the major efforts of the final design will have to include the identification and improvement of the heat flow paths for such non-heat generating mass concentrations.

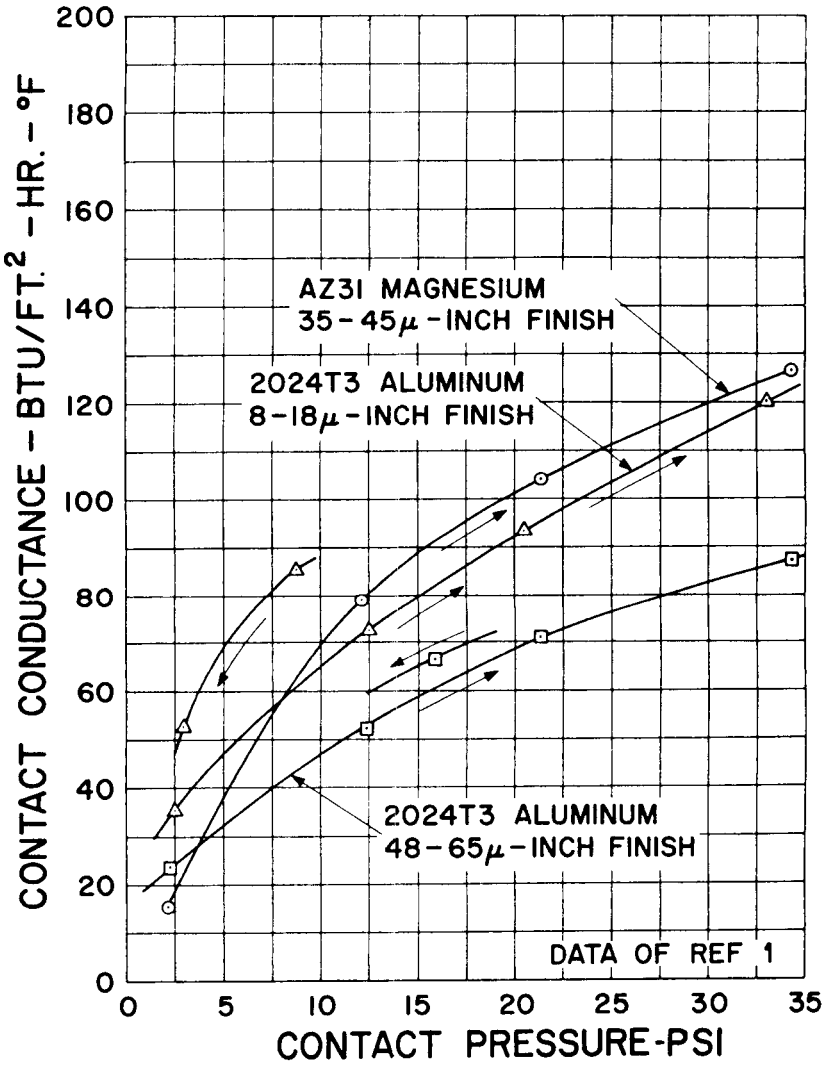


Figure 3.8.3-1. Thermal Contact Conductance vs Contact Pressure for Bare Metals in Vacuum

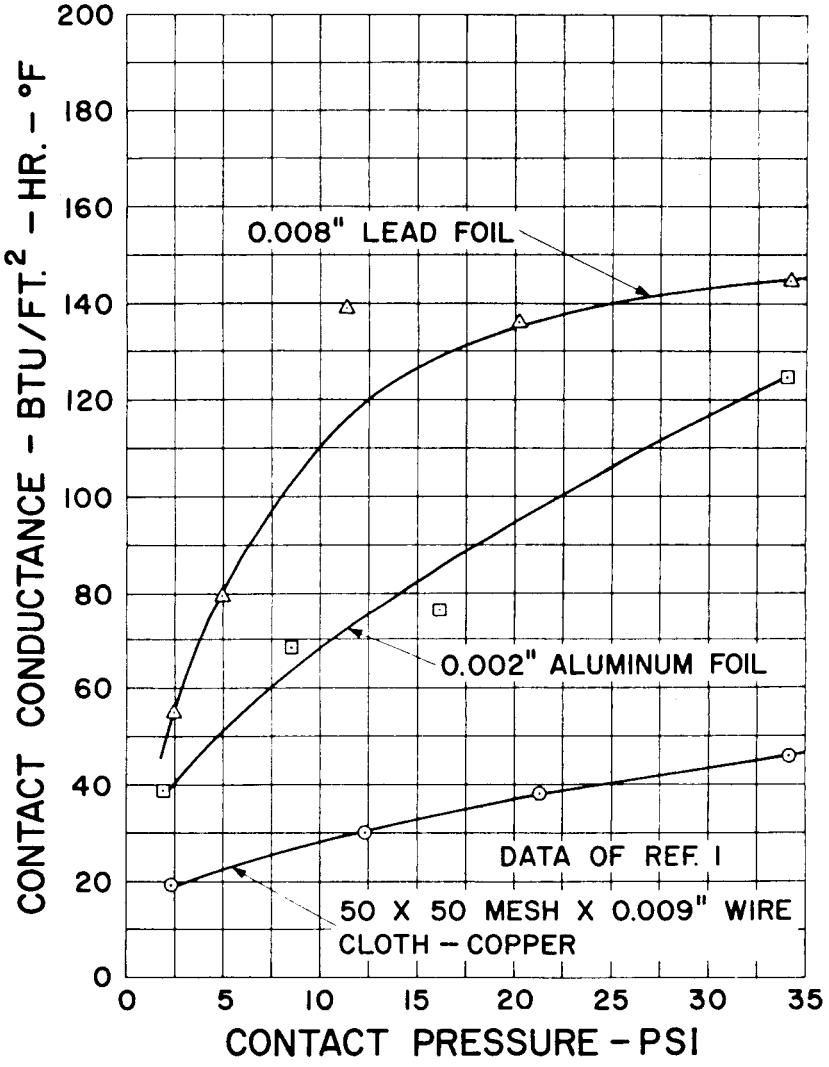


Figure 3.8.3-2. Thermal Contact Conductance vs Contact Pressure for Aluminum With Metal Shims

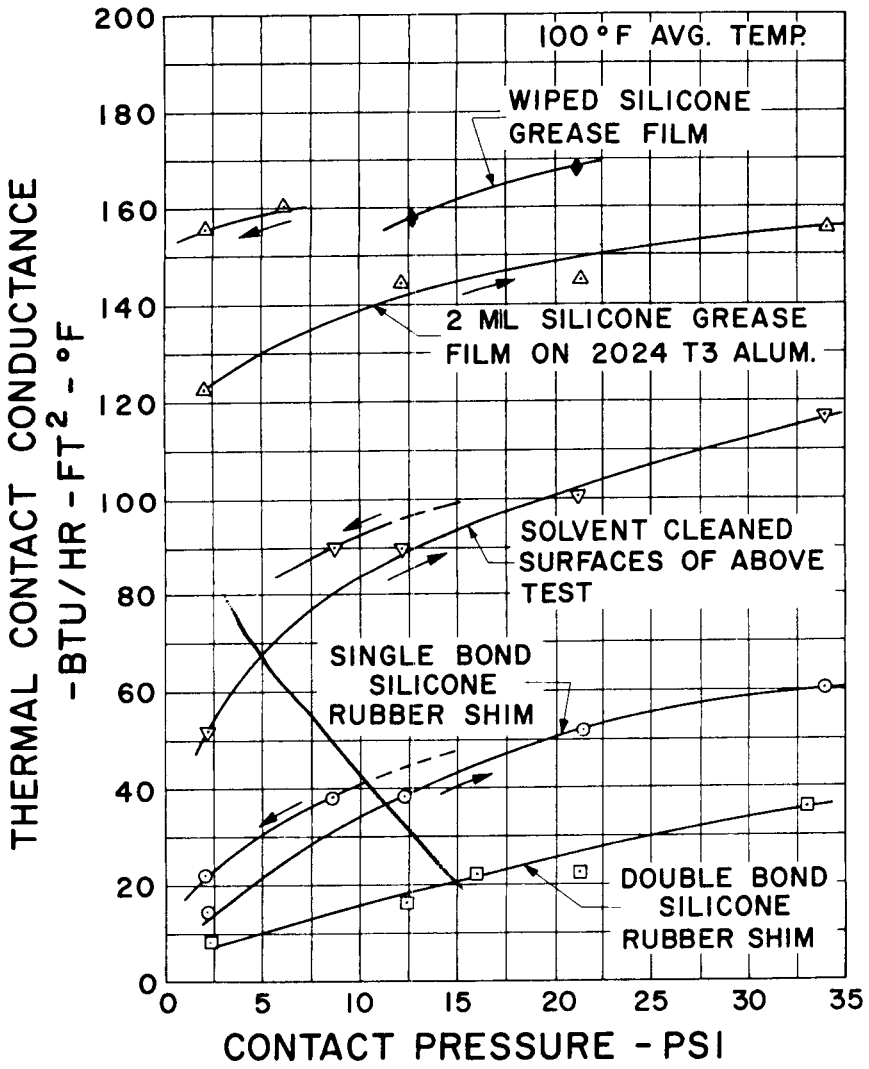


Figure 3.8.3-3. Thermal Contact Conductance vs Contact Pressure for Aluminum With Non-Metallic Shims

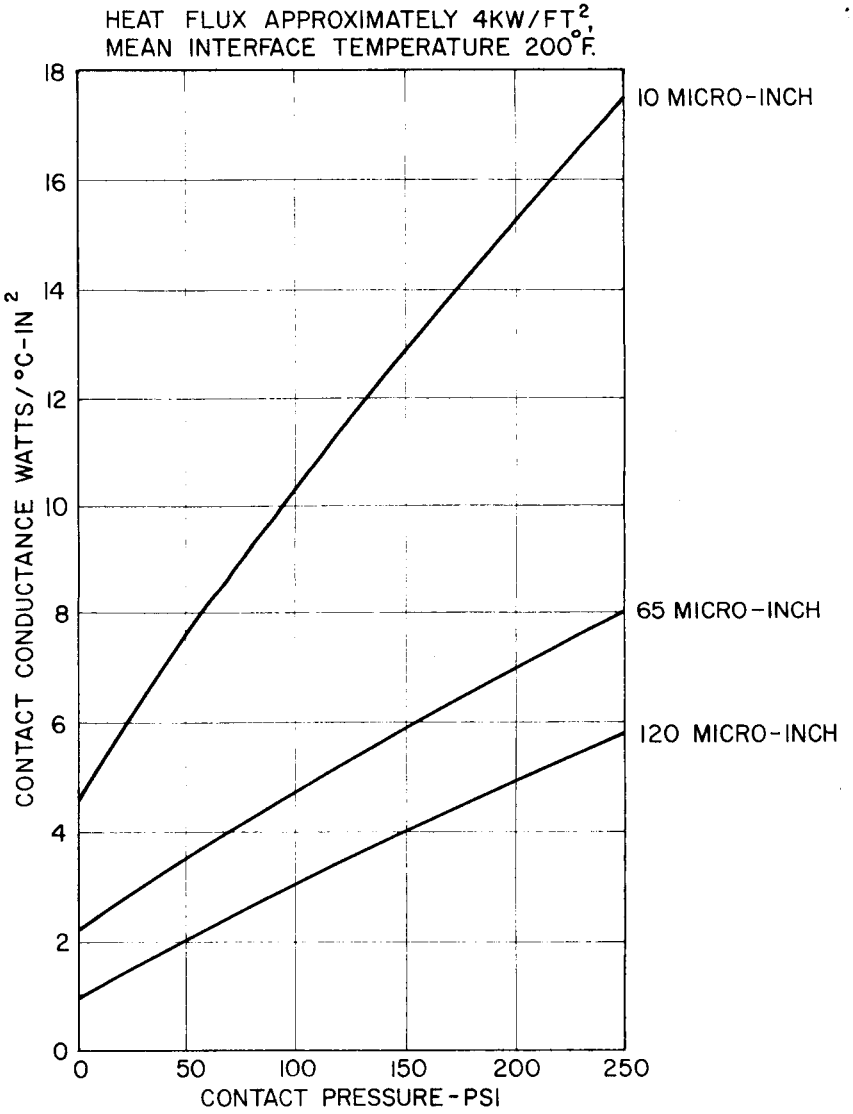


Figure 3.8.3-4. Thermal Contact Conductance vs Contact Pressure for Bare Aluminum Joints in Air as a Function of Surface Finish

Examples of such improvements include: reduction of heat flow path length, substitution of materials, elimination or reduction of contact resistances, re-distribution of masses, and improved fastening methods.

An atmosphere of nitrogen or helium or other inert gas is maintained during the heating cycle. This results in an appreciable reduction of the transient through heat transfer by gaseous conduction and convection as well as by solid conduction and radiation. The presence of an inert gas during heating, with gas removal after the 145°C soak temperature has been reached, appears to be an attractive solution; since, for example, the heat transfer across a spacecraft aluminum joint at 5 psi contact pressure is 20 times better in air or nitrogen at atmospheric pressure than in a vacuum as established by experimental data (Figure 3.8.3-1). Also, experiments performed using multi-layer reflective thermal insulation, a common spacecraft material, have shown that the transient temperature regime can be reduced drastically by maintaining several hundred microns pressure during the heating cycle. The use of forced convection heating also must be considered, since the transport of heat to remote components by conduction and radiation may impose severe temperature gradients.

Because of the difficulties inherent in instrumenting flight hardware for temperature monitoring with thermocouples, it is very important for the thermal conductivities of joints to be predictable. The study of structural joints for sterilization by externally applied heat must include the variations of properties as well as the properties themselves.

3.8.4 JOINING AND FASTENING METHODS

When the prospect of requiring joints and fasteners in space vehicle structures to be sterilized is considered, the number of problems involved is multiplied over those met when only structural integrity is important. Not only must the connections between structural members be considered but also those connections in tubes and pipes which carry working fluids and those connections of sheet metal pieces which make the vehicle itself a container. Three distinct problems arise: maintaining structural integrity of the joint, the sterilization of the joint and maintenance of that condition, and the requirement of zero leakage of fluids through joints in fluid carrying members.

The requirement that structural joints (as in frames, supports and vehicle skins) be sterile, while in use, means that many joining techniques are not adequate. The choice of the proper means of connection, i.e., nut and bolt, riveting, welding, brazing, etc., must be made, not only with the consideration of strength, but also with the consideration of the susceptibility of the joint to contamination. A particular joint must be designed so that it can be made sterile at the time of the assembly, but it must also be designed so that it may be maintained sterile while in use.

Where connections are made to join fluid carrying tubes or pipes, potential contamination due to improper design is magnified. The requirement of a leakproof joint is present where the vehicle itself must provide adequate means to prevent contamination from an outside atmosphere or to an outside atmosphere. The vehicle is required to be a leakproof container. This results in many associated problems, such as the sealing of orifices through which shafts or antennas may project from the vehicle.

The problem of designing both structural joints and leakproof fluid connectors, such that they may be thermally sterilized during or shortly after assembly, requires even more stringent conditions on the hardware. Whatever means of sterilization used must ensure that the structural integrity of the joint and the leakproof characteristics of the fluid connector are maintained. Since the sterilization process includes temperature cycling, the use of some temperature sensitive materials for fluid connectors is immediately ruled out. Both in the case of structural joints and fluid connector joints, a reduction must be made in the number of surface crevasses and voids in the joint area. A criterion for design must be that voids, cracks, and crevasses be reduced or omitted completely since

contamination is closely associated with the number of voids in the materials and since sterilization becomes more difficult as the number and sizes of voids increase. Hence, conventional use of nuts, bolts, and rivets creates problems, whereas welding, brazing, and bonding techniques appear to be more suitable.

3.8.5 APPLICATION OF HEAT

Although thermal sterilization has been recommended by the NASA Ad Hoc Committee, and is endorsed by the study, the means of applying heat to the vehicle has not been discussed except to state that dry heat is an acceptable approach.

It is proposed that thermal sterilization be accomplished by use of an inert gas such as nitrogen or helium, which is heated gradually while circulating in and about the vehicle. Such an inert gas has the advantage of not reacting with any vehicle component or constituent. The use of a recirculating system, such as is shown in Figure 3.8.5-1, is recommended, since it can accomplish the tasks of circulation, heating and filtration quite efficiently. This conceptual heating method can be applied to the sterilization chamber.

The proposed system has the following features and advantages:

1. This method provides "self" temperature control, since gas temperature is limiting. Thus, regardless of the duration of the procedure, no part can exceed gas temperature.

2. The use of suitable baffles, splitters and guide vanes in conjunction with planned openings in the vehicle or Lander results in a sterilization system where the heated gas distribution offers a minimum heating period. In order to assure adequate gas distribution, model flow-visualization tests will be required.

3. As stated before, a number of openings must be left in the vehicle or Lander to permit entry and exit for the heated gas during the process.

4. Adequate heating of even the most remote part is assured by thermocouples placed and monitored in selected locations. To select these locations, heat transfer analysis on composite structures will be required. On the basis of current work on "Thermal Joint Conductance Studies" in progress at MSD, experimental and analytical tools to do this are available.

The major advantages of the proposed gas sterilization methods are: the reduction of temperature differentials between application point of the heating medium and any interior point following maximum thermal resistance, and a means to carry out thermal sterilization at the launch site.

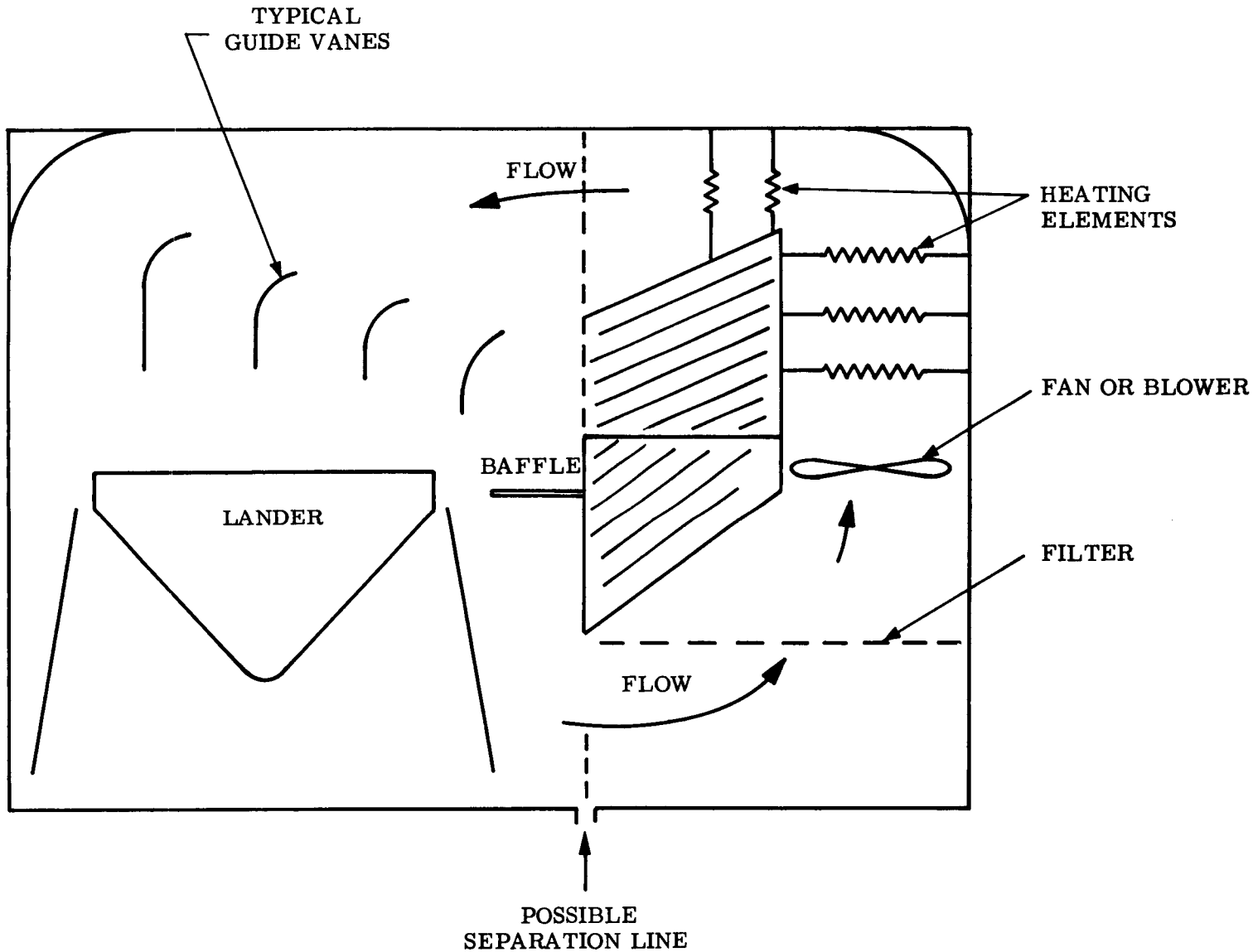


Figure 3.8.5-1. Method of Applying Dry Heat

3.9 CLEAN ROOMS

Figure 3.9-1 illustrates a typical laminar flow clean room enclosure. One end is a clean air supply and the other is a return module. A return air plenum connects the two via a double ceiling. Clean air moves through the room at the rate of approximately one mile per hour, filling the room from side to side and floor to ceiling. The air flow removes all but the heaviest particulate matter from personnel and parts as soon as it becomes airborne. Essentially, there are 100 air changes a minute across any one foot section.

The usual incidentals of clean rooms such as air showers, shoe cleaners, etc., are unnecessary since dust from clothing is continually carried out of the room by the laminar flow as soon as it becomes airborne and since it has no place to accumulate. A clean room of this type may be shut down for extended periods with little loss in efficiency. The dust count can be expected to be less than 1000 particles per cubic foot. Figure 3.9-2 graphs the dust levels of various types of clean room facilities as compared to the laminar flow method. It is proposed that an enclosed clean room of this type be utilized where parts or modules are assembled prior to part sterilization as outlined in the flow diagrams.

A similarly designed system would be utilized for major assembly and test operations. Figures 3.9-3 and 3.9-4 illustrate an open ended laminar flow clean room operation. This is particularly useful inasmuch as free access of personnel and equipment is permitted.

As stated before, clean room operation should be done throughout the system at every stage of manufacture and assembly, except during metal pouring, molding, and casting operations.

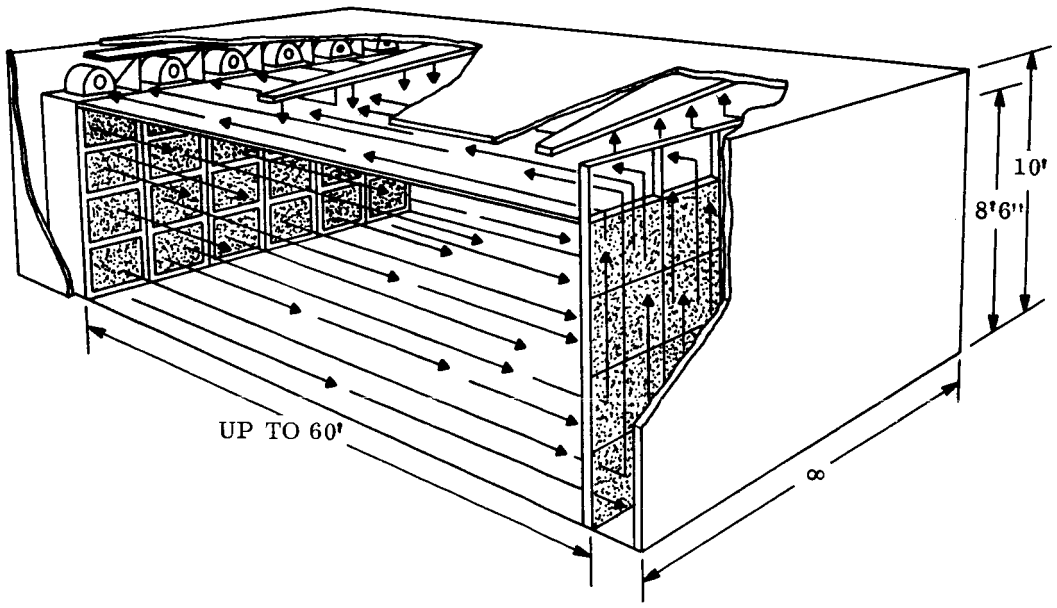


Figure 3.9-1. Typical Laminar/Cross Flow Clean Room

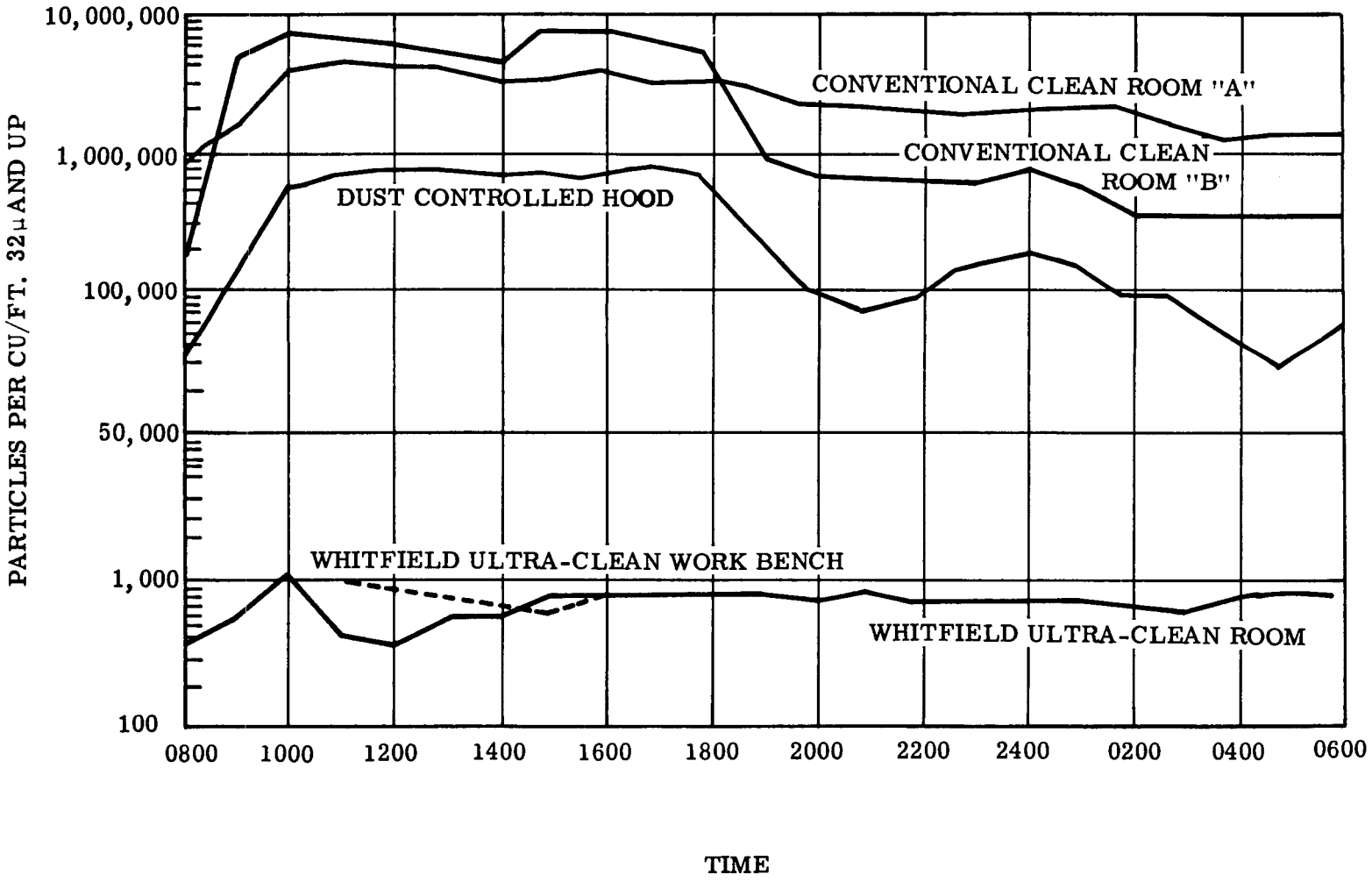
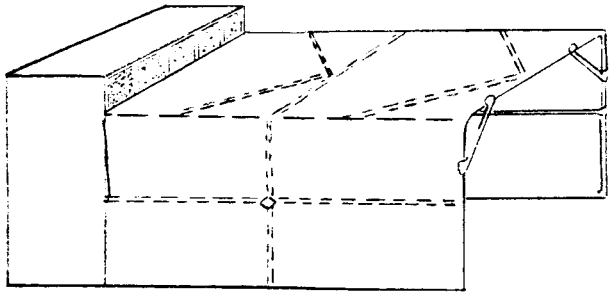
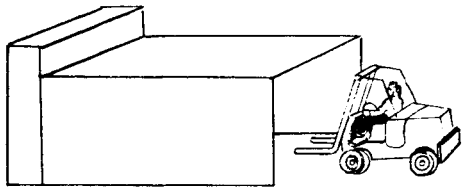


Figure 3.9-2. Dust Levels of Various Dust Controlled Areas



This walk-in ultra clean work station will meet Class IV dust level requirements as stated in U. S. Air Force Tech. Order 00-25-203 and will meet the standard clean room dust level requirements as stated in the proposed revision to USAF T.O. 00-25-203. It will meet dust count requirements of all three classes of clean rooms as stated in the proposed Federal Standard on Clean Rooms. The dust count is guaranteed to be less than 1,000 particles per cubic foot above 0.3 microns in size, which is 10 times cleaner than the average hospital operation room.

Figure 3.9-3. Open Ended Clean Room with Removeable Sections



A truck can be driven in its open end (the air is clean for many feet beyond): unload parts, and as fast as the truck leaves the room is clean again (the space between the modular blower/filter wall and the truck stays less than Class 10,000 or better at all times).

Figure 3.9-4. Open Ended Clean Room Operation

3.10 STERILITY CONTROL GROUP

3.10.1 CONCEPT

Opfell[2] has stated that, "The effect of any sterilization process will be a function of the entire history of the components that come in." The Voyager program will depend heavily on the development of a qualified reliable sterilizable parts list during this latter program. Parts selection and qualification must begin immediately (1963) if Voyager launch windows are to be met. Following selection and qualification of parts, it is critical that all materials and processes in the fabrication of Voyager equipment be surveyed and continuously monitored. For flight hardware, total reliance must be placed upon procedures in order to assure requisite reliability and sterilization. The Sterilization Manufacturing Program plan outlines this requirement in further detail.

Although the final assembly contractor is responsible to NASA for the entire process, a tremendous amount of manpower would be expended if each and every step of every subcontractor operation were to have a prime contractor inspector check for violations of sterility. Subcontractor selection, with respect to the sterility requirement, must be undertaken with great care. The prime contractor must institute a motivation and training cycle for his subcontractors. This duty would fall on the Sterility Control Group.

3.10.2 DUTIES

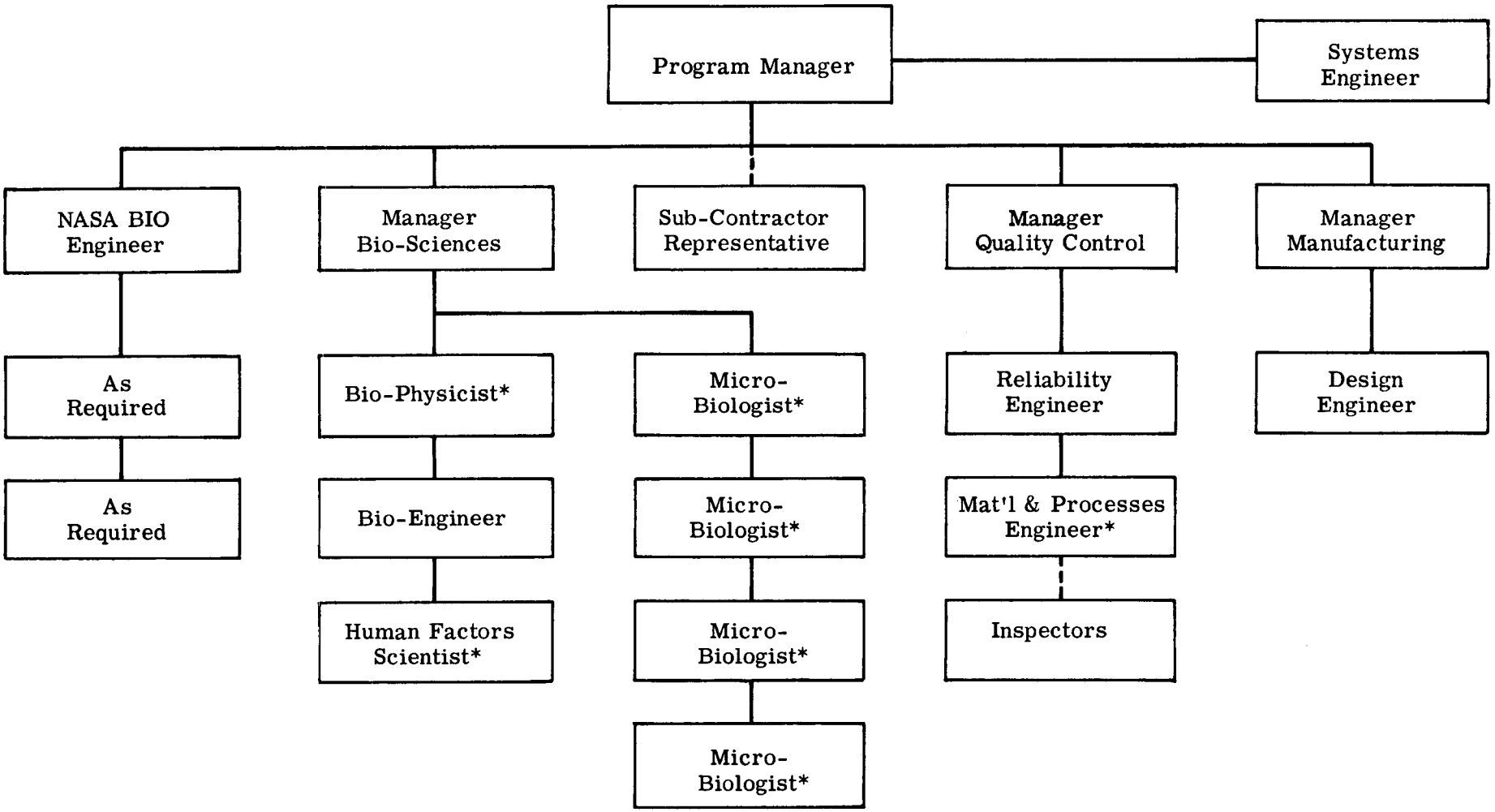
The Sterility Control Group will provide continuing surveillance of the sterilization requirements in the areas of:

1. Personnel training
2. Handling procedures
3. Storage requirements
4. Certification requirements
5. Shipping conditions
6. Assembly procedures
7. Interface considerations
8. Materials selection and acceptance
9. Biological testing and certification
10. Design review
11. Reliability assessment.

3.10.3 MEMBERSHIP, AUTHORITY, AND CONTROLS

Professional bioengineering personnel will review each step of the manufacturing process for every component, together with the subcontractor personnel. The motivation and training of the operation and assembly personnel would be done by the subcontractor for his own personnel. Each subcontractor will appoint a leadman for his own effort. This leadman will become a member of the Sterility Control Group. A member of this group will physically review and inspect critical points of the assembly. The prime contractor will, where possible, take non-statistical samples and subject them to destructive assay to determine sterility. There is, thus, a requirement for a biological assay laboratory on the premises of the prime contractor.

Authority for approval of processes and procedures must be absolute and rest with the Sterility Control Group selected by NASA, biosciences investigators, and the prime contractor. It is expected that a bioengineer of the NASA staff would be a permanent member of the Control Group. As in any organization, decision making will be at the top level. The function of the Sterility Control Group inspectors will not include the authority to make procedural decisions but is rather restricted to observing and reporting violations of the procedural flow. To reduce costs, the Quality Control inspectors would be given a brief course in biological techniques and theory. The Quality Control staff thus becomes the working arm of the Sterility Control Group. Figure 3.10.3-1 illustrates the suggested formulation of the Sterility Control Group.



*Full Time Personnel

Figure 3.10.3-1. Sterility Control Group

3.11 MICROBIOLOGICAL ANALYSIS

3.11.1 CONCEPT

Methods for detecting and identifying microbiological contamination are well established and documented in the technical literature. Difficulties in establishing proper culture media and swabbing techniques indicate that conventional methods may not be fully adequate for Voyager sterilization. The "seeding" of selected parts and components, previously mentioned, would utilize spores of relatively rare organisms. Utilizing spores of known resistance to thermal sterilization techniques, rapid analysis can be run on parts and components as a part of qualification testing. It is felt that only by the use of controlled seeding techniques and the subsequent proof of sterilization established by such techniques, can prescribed sterilization procedure be verified. Use of thermally-resistant containers to contain the parts and sterilization of the containers with ethylene oxide after removal from the thermal chamber (or in some instances thermal sterilization within the glove box) will protect the interior of the component from post-sterilization contamination.

3.11.2 TECHNIQUE

Discussion of the specific assay technique must be withheld until a particular trial organism is selected and a test part chosen. The methods involve destructive testing and the actual flight vehicles would not be so assayed.

The use of protective containers for parts makes possible the bio-assay at a central location. Numerous small laboratories should be avoided. The work of Wilmot-Castle, Millipore, J. P. L., and others, is sufficiently detailed in the open and commercial literature as to provide preliminary guidelines for this activity.

The Sterilization Control Group will review all bio-assay reports. In the event of a positive finding, an investigation would be made of all the steps involved in manufacture and assembly of the component to determine how and when contamination occurred. The investigation would include a review of the bio-assay and the technique utilized.

3.11.3 RECOMMENDATIONS

Future work in this area is a requirement for better biological growth media to develop the cultures of heat resistant bacteria. Additional studies to determine "swabbing" techniques should also be undertaken. The variety of materials involved indicates this will be a task of considerable magnitude.

3.12 QUALIFICATION

The Qualification Program discussed in another section of the report has been predicated upon the assumption that functional reliability, as demonstrated by tests performed on similar but non-sterilized parts, will not be degraded by sterilization techniques.

Prior to functional qualification, every item of hardware in the program will have been a prototype qualified at 145°C for three cycles of 36 hours. Those items in Class I will be qualified at the component level for reliability as well as for thermal qualification. Within the assembly process they normally would get functional qualification tests. Each component of Class I, II and III will be required to withstand an extended ethylene oxide soak at operating temperatures. Rapid pressure drops will be a part of the qualification cycle to determine the effect of rapid outgassing.

The ethylene oxide qualification shall be done after the vibration, humidity, etc. tests that normally would be used with the completed flight vehicle. This qualification shall also include sampling techniques to determine sterilization efficiency. The sampling techniques would utilize biological "seeding."

3.12.1 ETHYLENE OXIDE TEST FACILITY

The qualification of materials, parts, etc., requires the acquisition, installation, and calibration of a material test facility capable of performing exposure to ethylene oxide-Freon 12 mixtures under controlled humidity and temperature environments and will include capability for thermal sterilization in air or inert gas. The system will include:

a. Test chamber

b. Temperature programmer - controller recorder

c. Humidity controller - recorder

d. Inlet outlet facilities for ethylene oxide and inert gases

Construction of the chamber will be stainless steel. The blower motor should be enclosed and explosion proof.

3.13 MATERIALS, COMPONENTS & DESIGN

3.13.1 GENERAL

Sterilization imposes an additional environmental stress on spacecraft materials, which must be considered during the design and development stages of the program. Sterilization, as has been discussed is a materials problem in addition to a biological problem. Information on the compatibility of materials, parts, and components with sterilization requirements will provide data in support of an approved materials and parts list for sterilizable spacecraft.

3.13.2 STERILIZATION EFFECTS ON RELIABILITY AND PERFORMANCE

A major problem area associated with sterilization is the potential lowering of functional reliability. Although reliability may be degraded by sterilization, very little information is available on the quantitative effects. Two major areas for the determination of such effects involve encapsulated electronics and thermal control coatings. Information obtained in these areas would advance the state of the art associated with sterilization effects and would be of considerable benefit to the Voyager Program.

Some reliability studies of encapsulated electronics and thermal control coatings have been performed. These studies, however, have been very limited. The approach to incorporating sterilization effects into reliability testing involves initial property evaluations of electronic parts, encapsulants, and coatings before and after exposure to sterilization cycles. Parts and materials are then selected for long-life operational exposure after sterilization. Representative electronic modules should be fabricated, sterilized and operated under electrical load in thermal-vacuum environment for mission lifetime. Thermal control coatings selected after initial sterilization should be exposed to a UV-thermal-vacuum environment. Analyses include determination of adhesive strengths and surface optical properties.

Such an evaluation of materials and parts will provide the following information:

a. Determination of property degradation

b. Establishment of an approved parts and materials list, with estimates of reliability

c. Definition of critical materials and parts problem areas.

This task will involve exposure of various materials and parts to chemical and thermal sterilization processes. The materials and parts to be selected should be those which are expected to be most susceptible to damage, on the basis of present information. Each subsystem should be examined for candidate materials and parts. Performance criteria should be evaluated for changes due to sterilization treatments. Tests include measurement of physical properties, mechanical tests, thermal radiative properties and metallographic analyses. Typical materials to be evaluated include:

a. Adhesives

b. Solders

c. Valve seats

d. O-rings

e. Diaphragms

f. Encapsulants

g. Honeycomb

h. Coatings

i. Insulation

j. Heat shield materials

Based upon the materials and parts studies, re-examination of components must be undertaken. It would be expected that substitution and replacement of parts and materials would require re-design of some parts in order to conform to the sterilization and assembly flow. Increased reliability, exemplification of the sterilization process, and a closer approach to the complete terminal thermal concept would be the goal of this effort.

3.13.3 DAMAGE SENSITIVITY

Experience developed as a result of reliability physics studies on advanced space reliability projects and as a result of laboratory physical failure analyses on parts and components through development-product cycles, has lent an insight into the inter-relationship of load, environment, and time to failure.

One essential fact is that system failure is a result of physical changes at the level of the materials of part or component construction. These changes may be induced by human error or by normal operation. Pre-treatments such as a thermal sterilization cycle will have physical effects which in many cases will decrease the life expectancy of materials in an engineering application.

One way of evaluating damage is the concept of thermal equivalency to damage based on chemical kinetics. In this approach, the basic Arrhenius rate expression, or the more recent Theory of Absolute Reaction Rates are used empirically. Failure, as defined by a certain value of change, is used for the evaluation of equivalency. Mechanical, electrical, and environmental factors are evaluated on the same basis as thermal factors in determining end-of-life limits.

The segregation of items into sensitivity categories is a relatively high-risk undertaking since so much depends on the application and the function to be performed. Damage, in the sense used here, is primarily related to changes in nominal output, such as resistance changes in a resistor, or decreases in engineering properties such as relaxation in springs or gaskets.

The following types of information are required, some of which have been obtained during the study phase:

A. Materials

Existing materials lists which are available from other programs have been reviewed initially, with each material categorized as to its tolerance to sterilization temperatures and ethylene oxide-Freon vapor. No specific problems were found with the ethylene oxide-Freon vapor. The results of the temperature compatibility evolution are given in Table 3.13.3-1. As a more specific Voyager materials list is developed, each material should be categorized Class I, Class II, or Class III. Special attention should be paid to plastic films, particularly those of the Polyimide family, which should be tested for their applicability to sterilization resistant seals, and greases, where a selection is required of approved compounds for lubrication of moving parts and for thermal joints.

TABLE 3.13.3-1. MATERIALS COMPATIBILITY WITH STERILIZATION
(Estimated Compatibility with 145°C, 36 hours)

Material	Yes	No	Maybe	Comments
ALUMINUM ALLOYS				
1100	X			
2000 series -O condition	X			
T6, T8			X	Possible overaging, loss of strength
3000 series	X			About 10 percent loss of strength at temperature reversible
5000 series	X			(Same as 3000 series) reversible loss of strength of 10-20 percent
6000 series -O condition	X			
T6			X	Possible overaging loss of strength
7000 series -O condition	X			
T6			X	Overaging, 10 percent loss of strength
MAGNESIUM ALLOYS - GENERAL			X	20-50 percent reversible loss of strength at 300°F.
AZ 81A, ZK60A-T6			X	Approx. 10 percent irreversible loss of strength. These alloys have extremely low creep strength (1000 psi for 0.2 percent creep 100 hrs. at 300°F).
AZ 92A, ZH62A			X	Low creep strength
TITANIUM ALLOYS	X			
BERYLLIUM ALLOYS	X			
STEELS, STAINLESS STEELS	X			
SOLDERS (LEAD-TIN)			X	70-75 percent loss in strength at 300°F-reversible
COPPER BASE-Be-Cu	X			
RUBBERS				
Polysulfide		X		Depolymerize, become soupy
Butyls neoprene, acrylenitriles, silicones	X			Surface effects (hazy, powdery)
RTV			X	Loss in adhesion shear strength 17 percent; outgassing
Fluorocarbon rubber (Viton)	X			
ORGANICS				
Thermosetting Resins	X			
Phenolics, polyesters diallyl phthalate, aromatic amine, anhydride cured epoxies, urea and melamine formaldehyde				
Room temperature cured		X		Discoloration, embrittlement, cracking and crazing - soft at temperature

TABLE 3.13.3-1. MATERIALS COMPATIBILITY WITH STERILIZATION (Cont'd)

Material	Yes	No	Maybe	Comments
Room temperature cured epoxies - reinforced (glass or synthetic polymer fabric or fibers)			X	Less strength loss than non-reinforced
Thermoplastic Resins			X	Most, except fluorocarbons, soften, flaw, sublime, char or distort
Mylar	X			
Teflon	X			
Kel-F	X			
Nylon, penton, lexan (polycarbonate)	X		X	Most types O.K. Some nylons questionable
Polyethylenes, polypropylene		X		Soften
DuPont HT-1 (Polyamide)	X			
Polyimide - H film	X			
Plasticized types (vinyls)		X		Loss of plasticizer, outgassing
Dacron (polyester)	X			
Delrin		X		

TABLE 3.13.3-2. ENTRY/LANDER SUBSYSTEMS

STRUCTURE AND SHIELD SUBSYSTEM

THERMAL CONTROL SUBSYSTEM

- Water Tank
- Solenoid Valve
- Water Boiler
- Heat Exchangers
- Gear Pumps
- Electric Motors
- Squib Valves
- Guillotines
- Check Valves
- Surface Radiators
- Plumbing, Fittings, Tubing
- Accumulators
- Component Surface Plates
- Modulation Valves
- Temperature Controller
- Temperature Sensor

ELECTRICAL POWER AND DISTRIBUTION SUBSYSTEM

- Radioisotopic Thermoelectric Generator
- Battery Charging Regulator
- Battery
- Power Distribution Board
- Power Controller
- Harness

PROPULSION AND SEPARATION SUBSYSTEM

- Inflight Disconnect
- Explosive Bolts
- Reservoirs
- Squib Valves
- Nozzles
- Retro-rocket

RETARDATION SUBSYSTEM

- Thermal Battery
- Arming Relay
- Programmers
- Time Delays
- Drogue Mortar
- Parachutes
- Explosive Bolts
- Inflight Disconnect
- Parachute Swivel
- Reefing Line Cutters
- Cut-off Fittings

TABLE 3.13.3-2. ENTRY/LANDER SUBSYSTEMS (Cont'd)

ORIENTATION SUBSYSTEM

- Impact G Switch
- Arm Relay
- Disarm Relay
- Mercury Switches
- Motion Detector
- Time Delay
- Gear Train Motor
- Deployment Mechanisms
- Electromechanical Actuator
- Tilt Bar
- Harpoons
- Orientation Rockets

COMMUNICATIONS SUBSYSTEM

- VHF Transmitter
- S-Band Power Amplifier
- VHF & S-Band Diplexer
- VHF Receiver
- Command Demodulators
- Antennas
- High Voltage Power Supply
- Transponder
- Command & Computer Subsystem
- Thermoplastic Recorder
- Buffer Storage Unit
- Data Processing Unit
- Vertical Sensor
- Antenna Drive
- Sun Sensors
- Control Electronics
- S-Band Switch
- Power Conversion & Control Unit

DIAGNOSTIC INSTRUMENTATION SUBSYSTEM

- Temperature Sensors
- Accelerometers
- Pressure Sensors
- Ablation Sensors
- Ablation Converter
- Events Deployment Monitors
- Pressure Transducers
- Power Supply

SCIENTIFIC EXPERIMENTS SUBSYSTEM

- Radar Altimeter
- Panoramic TV Camera
- Sample Gatherer, Drill and Pulverizer
- Seismograph
- Precipitation Detector
- Anemometer
- Surface Hardness Tester

TABLE 3.13.3-2. ENTRY/LANDER SUBSYSTEMS (Cont'd)

SCIENTIFIC EXPERIMENTS SUBSYSTEM (Cont'd)

Microphone
Light Detector
Temperature Sensors
Turbidity Detector
Gamma Ray Back Scatter Densiometer
Atmospheric Composition Detector (Gas Chromatograph)
Langmuir Probe
Radiosotope Detector
Multiple Chamber Growth Detector
Photoautotroph
Microscope
Pressure Sensors
Surface Moisture
Surface Gravity

B. Structural Design

The elements which comprise the Entry/Lander's structure shall be investigated for sensitivity to differential expansion and thermal growth resulting from heat sterilization. A mathematical model shall be used to afford an estimate of the structural effect which results with a controlled heat flow and resultant structural temperatures. Elements to be considered include laminated structures, sandwich panels, honeycomb, and thin shells with massive stiffeners.

C. Parts and Components

Parts and components which are anticipated for Voyager use shall be reviewed and sterilization techniques recommended. A compilation based upon the present Entry/Lander design is given in Table 3.13.3-2. The items that present difficulties in withstanding the sterilization cycle are discussed in the following section.

3.13.4 SPECIFIC PROBLEM AREAS

A. Liquids and Gases

Liquids and gases are readily sterilized by filtration, utilizing a suitable bacterial filter such as Linde's L425 or Millipore filter pads with the Vacudent Company's special filter holder. Accordingly, where thermal sterilization results in excessive liquid and gas temperatures or excessive tankage weight, filtration could be used. Thermal sterilization could then be conducted upon empty tanks, which would be later filter-filled affording sterile tanks and contents.

B. Batteries

Material considerations indicate that thermal sterilization of batteries is feasible at the present time with nickel-cadmium cells. However, the effects upon their operating life have not yet been fully established although some testing is in progress.

Silver oxide-zinc and silver-cadmium batteries are not suitable for thermal sterilization in presently available configurations. However, silver-oxide batteries can probably be developed for sterilization if sterile assembly techniques are employed and batteries are charged after sterilization. Some typical techniques which could be employed are listed in Table 3.13.4-1.

TABLE 3.13.4-1. BATTERY STERILIZATION

Part	Material	Technique	Remarks
Cathode	NiO Ag_2O	Thermal or Radiation	
Anode	Zn Cd	Thermal Thermal	
Electrolyte	KOH	Filtered	Linde L-425 filter
Separator	Nylon Cellophane Fiberglass		Substitute DuPont Polyimide-thermal sterilization or Nylon-thermal sterilization
Structural Parts	Plastics Metals Rubber	Thermal Thermal Thermal	

Following the thermal sterilization of parts, assembly shall be effected in a sterile assembly facility under an ethylene oxide environment.

C. Parachutes

DuPont HT-1 is recommended as the most satisfactory parachute fiber for high temperature and heavy-duty exposure. Tests have shown that HT-1 retains its strength up to 600°F, without the marked stiffening which occurs to most nylon materials. The material is not yet in large-scale production, although it is available in nominal quantities and production is expected to increase in the near future.

D. Electro-Explosive Devices

It is not safe to assume that devices are self-sterilizing during operation. Microorganisms have been shown to effectively resist pressures beyond that to be expected during the operation of the devices. Even though the temperatures reach those of sterilization, the time element is too short to effect sterilization of the component and its remnants. If an electro-explosive device failed to function and sterility were dependent upon operation, impact upon the target would result in contamination.

Sterilization is a new field to the explosives and device manufacturer. Several organizations are now marketing, or preparing to market, devices that are claimed to meet the thermal requirements for sterilization. Reliability data (after thermal soak and an extended dormancy period) is inadequate. It is most probable, however, that explosive devices can be designed to meet temperature and reliability criteria, and for this reason it is recommended that such devices be used throughout the Voyager system wherever good design practice and weight trade-offs indicate their use.

Due to the large number of tests required for statistical reliability verification, the requirement for real-time dormancy surveillance studies and the lead times required for any new design and development, a program to design and qualify explosives and devices should be started immediately.

E. Propellants

Sterilization by thermal methods is possible for propellants used on the Lander vehicles. It is the recommended solution for Voyager. It is additionally possible, as demonstrated by work at JPL, to introduce ethylene oxide into the propellant during manufacture (6

percent by weight) without critical loss of impulse. The construction of a sterilizable rocket, propellant and casing has not been completed and tested but JPL is currently studying its production.

Sterilization by thermal methods involves safety considerations, physical shrinkage and chemical change possibilities. Based upon present development, it is planned to have the rocket attached to the Lander at the time of final thermal treatment. Due to the advisability of sterilizing the Lander-Orbiter interface at the time of heat treatment, it would be extremely difficult to have a sterile assembly of the large Lander rocket following the thermal chamber treatment.

The question of safety must be resolved by means of full qualification testing. It is certain that range safety officers and plant safety officials will not allow propellants to be heated unless they have full possession of data indicating that no hazard is present. The safety area represents a large consideration in the GSE planning and equipment flow.

F. Heat Shield

Existing data on G. E. 's re-entry heat shield materials indicate that Phenolic nylon is marginal for thermal sterilization at 145°C. Accordingly, use is contemplated of the modified silicone foams, designated ESM-1000 series materials. These latter are suitable for continuous use at 300°F.

3.13.5 SCIENTIFIC EQUIPMENT

The scientific payload, like other Lander equipment, requires sterilization. Accordingly, the estimated suitability of each experiment to sterilization stresses is tabulated in Table 3.13.5-1.

TABLE 3.13.5-1. SCIENTIFIC PAYLOAD SUITABILITY TO STERILIZATION

SCIENTIFIC PAYLOAD	135°C DRY HEAT CYCLE	ETHYLENE OXIDE CYCLE	145°C CYCLES	REQUIRING MODULARIZATION
Temperature	OK	OK	OK	NO
Pressure	OK	OK	OK	NO
Density	OK	OK	OK	NO
Gas Chromatograph				YES
Radar Altimeter	OK	OK	OK	NO
Television		OK	NO	YES
Insulation	OK	OK	OK	YES
Anemometer	OK	OK	OK	NO
Radioisotope Detector	OK		OK	YES
Turbidity & pH (Growth Det.)			NO	YES
Multiple Chamber Biochem.	NO	NO	NO	YES
Photoautotroph	NO	OK	NO	YES
Petrographic Microscope		OK	NO	NO
Seismograph	OK	OK	OK	NO
Langmuir Probe	OK	OK	OK	

TABLE 3.13.5-1. SCIENTIFIC PAYLOAD SUITABILITY TO STERILIZATION (Cont'd.)

SCIENTIFIC PAYLOAD	135°C DRY HEAT CYCLE	ETHYLENE OXIDE CYCLE	145°C CYCLES	REQUIRING MODULARIZATION
Microphone	OK			NO
Soil Moisture*	OK	NO		YES
Surface Hardness Tester	OK	OK	OK	NO
Gravity				
Precipitation Detector	OK	OK	OK	NO
Sample Gatherer (Drill)	OK	OK	OK	YES
Pulverizer	OK	OK	OK	NO
Bolts, nuts and hardware	OK	OK	OK	
Harness Cabling	OK	OK	OK	YES
Diagnostic Instrumentation	OK	OK	OK	NO
Ablation Sensor	OK		OK	NO
Temperature Sensors	OK	OK	OK	NO
Accelerometers	OK	OK	OK	NO
Ablation Converter	OK		OK	NO

*With dry ethylene, YES

3.14 HUMAN FACTORS

It has been assumed throughout this sterilization study that human error plays no role while in fact the successful conduct of this phase of the Voyager program depends ultimately on meticulous human attention to detail, the scrupulous observation of procedures and a high level of motivation and dedication to the sterilization concept. In many ways, the problem of sterilization parallels the problem of reliability. It cuts across all lines and is a major design principle.

The application of human factor principles to problems such as reliability and other areas of specialized manufacture and assembly have indicated personnel problems in selection and training of the individuals involved. They have indicated the role of reward and special working conditions on productivity and adherence to procedures.

An element of some importance in the conduct of the Voyager program will be the careful study of the human engineering aspects of manufacture, assembly, and test as well as the complex operations at the launch site and the development of general and detailed training programs tailored to the requirements of the particular individuals and their job responsibilities. Human factors personnel will play an important role in the development and standardization of procedures designed to assume the high level of personnel performance required for program success.

SECTION 4. CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

A biologically sterile spacecraft is technologically feasible and within the state of the art expected by 1967. There are a substantial number of areas where intensive effort must be concentrated if hardware reality is to be attained within this time period. A complete thermal sterilization for Voyager with its present mission could not be done with components available today; however, if the recommended development programs are carried out successfully, thermal sterilization, as outlined in the report, is possible. If unsuccessful, it is doubtful if the assembled vehicle in a protective barrier can be completely terminally heat sterilized. The presence of liquids, gases, radio-active power supplies, requirements for late assembly of explosives and practical handling difficulties indicates that some post-thermal treatment sterile assembly may be required. Studies to this end should also be undertaken.

4.2 RECOMMENDATIONS

4.2.1 STERILIZATION TECHNOLOGY

It is recommended that:

A. Clean Rooms be Class 10,000. To effect organism load reduction, soil and dust must be excluded. Class 10,000 affords a practical state-of-the-art solution.

B. All parts be handled, shipped and stored in biological protective containers. The theory of biological load reduction at various stages of manufacture and hardware assembly require a controlled product at all stages. Additive sterilization techniques increase the likelihood of an aseptic end product.

C. Microbiological assay procedures be conducted by a single laboratory. Microbiological assays are only valid when procedural changes are limited and techniques identical. The best assurance of this is to have the same group do all work.

D. Methods, techniques, and reliability of biological seeding be investigated. Present studies have been aimed at determination of the problem. These techniques do not indicate that the most efficient or reliable method of microbiological assay of space components have been attained. Methods useful for determination of gross contamination may give misleading information when 1×10^{-4} contamination probability is being tested.

E. The studies of the combined effects of different sterilization techniques be extended. Firm data as to the additive, multiplicative or non-effective end results of combining different sterilization techniques is not available. Firm data may lead to substantial cost reduction for the vehicle.

F. The parameters and reliability of ethylene oxide sterilization be further investigated. There is insufficient data to judge the sterile assembly technique.

4.2.2 MATERIALS TECHNOLOGY

It is recommended that:

A. The expansion of the materials and components classification system be undertaken at once. To eliminate Class II and III from the sterilization

program, it is imperative that materials, components, and potential substitutes be identified with respect to their thermal characteristics.

B. The construction of a materials-test facility, capable of handling ethylene oxide under varying conditions of humidity and temperature be undertaken. Spacecraft materials in general have not been tested with ethylene oxide. Estimates of material durability have been mainly derived by analogy with the reactions of ethylene oxide on medical supplies. This is not good enough information upon which to base a final design. Facilities designed for spacecraft are as yet non-existent.

C. Studies on encapsulated electronics and thermal-control coatings be extended. The extent and present rate of progress in this area will not produce required information within the time limits set for Voyager design. The studies have shown enough progress to make it worthwhile to go deeper.

4.2.3 COMPONENT TECHNOLOGY

It is recommended that:

A. Class II items be modularized to facilitate sterile assembly when required. To insure that the terminal heat sterilization is effective, a low organism load is required. Sterile assembly and protection of the sterile package by modularization would permit more confidence in the terminal heating process.

B. A list of space qualified (for sterility and reliability) components be assembled for design use. When design can be done using known factors, cost goes down and reliability increases. Such a list will pinpoint areas and components where further research is required.

C. An electro-explosive device and propellant sterilization study, with attention to reliability and safety, be initiated. Reliable data in this area is practically nonexistent. Parametric studies indicate that all sterilization requirements can be met, but specific devices, suitable for flight, cannot be identified. Requirements for real-time testing make an immediate start on this problem very important

4.2.4 OTHER RECOMMENDATIONS

It is recommended that:

A. A human factors and motivation study be undertaken to determine the best method of indoctrinating manufacturing and assembly personnel with sterility concepts. Evaluation of the work accomplished under the Minuteman parts program and motivation studies provide a valuable base for this investigation.

B. Efforts to eliminate Class III components and scientific equipment via design be intensified.

C. Terminal thermal sterilization be done at a field site. Difficulties in transporting, testing and assaying a sterile vehicle indicate that reliability and sterile integrity can be attained by terminal sterilization late in the factory-to-launch sequence.

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APPENDIX A. ORBITER STERILIZATION OF MARS 1973 VOYAGER

1. INTRODUCTION

The orbit which is proposed for the Mars 1973 mission necessitates the Orbiter's being sterilized. The plan which had been developed for the Lander will be applied to the Orbiter-Lander as a combination, with the sterile interface transposed from the Orbiter-Lander to the Booster-Orbiter.

2. EQUIPMENT STERILIZATION REQUIREMENTS

2.1 ELECTRONIC EQUIPMENT

Thermal sterilization of electronic equipment will be afforded with the use of parts from the Approved Parts List. When Class II items must be utilized for their particular functions, the bacterial load shall be reduced with the gaseous sterillant, ethylene oxide-freon enabling the thermal sterilization to be effective at 135°C.

Microelectronics and the tape recorder can be designed to be thermally sterilizable with no significant reliability degradation by utilizing thermally stable materials (Recommended Materials List) in conjunction with a compatible design. For example, Thermal Plastic Recording for the tape recorder which of necessity utilizes a high temperature film coating on glass plates.

Vidicon and image orthicon tubes are expected to require special development efforts to enable thermal sterilization. Weaknesses in these result from the light sensitive materials which generally are thermally sensitive. Accordingly, efforts in this area would be directed at the development of suitable, high temperature, photo-conductive coatings.

2.2 PROPULSION AND THRUST VECTOR CONTROL

The propellant and oxidizer of the Orbiter engine is hydrazine and either nitrogen tetroxide or IRFNA. The latter (N_2H_4-N_2O_4) is not thermally sterilizable and requires bacterial filtration. The other combination is thermally sterilizeable, however, with little tankage weight penalty.

Secondary injection or gimbaling is used for thrust vector control. The particular choice is dependent upon the dynamics of the guidance control loop which is still being studied. Sterilization for either system is readily accomplished. An hydraulic actuating system is thermally sterilizable, while the secondary injection fluids can be filtered.

2.3 MECHANICAL AND ELECTROMECHANICAL EQUIPMENT

The mechanical and electromechanical equipment sterilization approach will be analogous to that used for electronic equipment, included in the Approved Parts List. Mechanical and electro-mechanical equipment's sterilization depends upon the use of materials from a Recommended Materials List. These lists are application oriented, incorporating all the information required to describe limiting materials' properties pertinent to thermal sterilization.

Undoubtedly difficulties will become apparent in that some desired components incorporate materials which are not suitable for thermal sterilization. This in turn will necessitate development, for a substitute material, part or component. A list of proposed components for this vehicle is shown as Table A-1. The components have been examined to determine major problems specifically applicable to the 1973 Orbiter.

TABLE A-1. EVALUATED EQUIPMENT LIST, MARS 1973 ORBITER

EQUIPMENT ITEM	PRESENT STATE OF ART		ANTICIPATED STATE OF ART		REMARKS
	145°C	Ethylene Oxide	145°C	Ethylene Oxide	
VHF Antenna	OK	OK		OK	a
VHF Diplexer	OK				a, b
VHF Receiver	OK				a, b
VHF Demodulator	OK				a, b
Data Processor	OK				a, b
Programmer	OK				a, b
Command Demodulator	OK				a
Hi-Gain Antenna	OK				a, b
Diplexer	OK				a, b
Transponder	OK				a, b
Camera Selector	OK				a, b
Image Orthicon	No		No		d
HV Power Supply	OK				a, b
Klystron	OK				a, b
Gyro	OK				a, e
IR Scanner	OK		OK		f
Antenna Drive	OK				a, b
Programmer and Decoder	OK				a, b
Timer & Guidance Control	OK				a, b
Switching Amp.	OK				a, b
Auto Pilot	OK				a, b
Logic Storage & Relays	OK				a, b
Earth Sensor		Nortronics, mag. vib. reed and photomultiplier			
Canopus Scanner		Photoemissive material			
Accelerometer	OK				a
Sun Sensors	No		OK		a, b, g
Hi Press. Transducer	OK	OK			a, b
Low Press. Transducer	OK	OK			a, b
Temp. Sensors	OK	OK			a
Nozzles	OK	OK			a
Tubing	OK	OK			a
Power Divider	OK	OK			a, b
Multicoder	OK	OK			a, b
Tubing	OK	OK			a
Power Amplifier	OK	OK			a, b
Power Divider	OK	OK			a, b
Multicoder	OK	OK			a, b

TABLE A-1. EVALUATED EQUIPMENT LIST, MARS 1973 ORBITER (cont'd)

EQUIPMENT ITEM	PRESENT STATE OF ART		ANTICIPATED STATE OF ART		REMARKS
	145°C	Ethylene Oxide	145°C	Ethylene Oxide	
Buffer Unit	OK	OK			a, b
Thermoplastic Rec. Unit			OK		a, b
Power Conversion & Cont.	OK	OK			a, b
Coax Cabling		OK			a, b
Proton Telescope	OK	OK			a, b
Electron Telescopie	OK	OK			a, b
Magnetometer	OK	OK			a, b
Mass Spectrometer	OK	OK			a, b
Electron Probe	OK	OK			a, b
Fuel & Oxidizer Sys.	OK				
Tanks	OK				a
Thrust Chamber	OK				a
Filters	OK				a
Regulators	OK				a
Fill & Purge Valves	OK				a
Orifices	OK				a
Latch Valves	OK				a
Transducers	OK				a, b
Shielding	OK				a
Harness	OK				a
Lines	OK				a
Brackets	OK				a
Gimbal System					
Hyd. Power Pack	OK				a
Actuators	OK				a
Servo Valves	OK				a
Accumulator	OK				a
Plumbing	OK				a
Oil	OK				a
Bearings	OK				a
Thermal Control					
Insulation	OK				a
Active Control	OK				a
Timers	OK				a, b

TABLE A-1. EVALUATED EQUIPMENT LIST, MARS 1973 ORBITER (cont'd)

EQUIPMENT ITEM	PRESENT STATE OF ART		ANTICIPATED STATE OF ART		REMARKS
	145°C	Ethylene Oxide	145°C	Ethylene Oxide	
Paint	OK				a
Grease	OK				a
Heaters	OK				a
Structure	OK				a

(a) Based upon applicability of materials whose properties are not adversely affected by the sterilization sack.
(b) Based upon applicability of electronic parts whose performance is not adversely affected by the sterilization sack.
(c) In accordance with a General Electronics proposal for the development of a heat sterilizable vidicon.
(d) The sterilization temperatures result in evaporation of all the light sensitive coatings which are currently feasible.
(e) Brominated fluorocarbon floatation fluids become very corrosive at sterilization temperatures; straight fluorocarbons OK, accordingly the latter's reduced density will require a larger float.
(f) Barnes tracker utilizing a deposited thermocouple array which is believed sterilizable, or GE Co. 's Thermacon (IR Vidicon) which is sterilizable.
(g) Nortronics sensor utilizes cadmium sulfide cells with an indium solder.