15 November 1965

RSIC-490

STERILIZATION OF UNMANNED PLANETARY SPACECRAFT

by
John E. Terry

Research Branch
Redstone Scientific Information Center
Research and Development Directorate
U. S. Army Missile Command
Redstone Arsenal, Alabama 35809

ABSTRACT

This report presents a brief summary of the results of recent studies conducted on spacecraft sterilization. A recapitulation of the advantages and disadvantages offered by various sterilizing agents and methods is included. Also included are clean room requirements and concepts, personnel requirements for sterile vehicle assembly, concepts for the sterilization canister, handling and transportation requirements for the spacecraft and bus, concepts for terminal heat sterilization, and the potential contamination problems existing as the lander separates from the bus.

FOREWORD

This report was prepared for Manufacturing Engineering Laboratory, Marshall Space Flight Center, Huntsville, Alabama, as an effort to provide information on the following topics:

1) Present methods of sterilization that are most promising, and the effects these methods have on materials for vehicle components.
2) Processing and packaging practices as related to fabrication and assembly, and the problems existing with these practices.
3) Practices being developed and/or pursued to permit handling of the sterilized vehicles up to time of launch.
4) Procedures being used to measure cleanliness level in the sterilization laboratory.

Information sources for this report were obtained from International Aerospace Abstracts, NASA Scientific and Technical Aerospace Reports, open source literature contained in the Redstone Scientific Information Center, and conferences with persons in Marshall Space Flight Center who are working with the spacecraft sterilization problem.

ACKNOWLEDGMENT

Appreciation is expressed to Mr. R. G. Crawford, Marshall Space Flight Center, for furnishing verbal and written information on the subject.

CONTENTS

ILLUSTRATIONS

Section I. INTRODUCTION

Contamination of celestial bodies with earth microorganisms would very likely make studies of any extraterrestrial life impossible. Therefore, in 1959 and 1960, the National Aeronautics and Space Administration formulated official policy letters declaring that it was essential to sterilize spacecraft for the following reasons:

1) To preserve clues to the origin of life and of the universe which may be hidden beneath the luna strata or under the atmosphere of extraterrestrial bodies.
2) To prevent inadvertent seeding of extraterrestrial surfaces by earth-like cultures.
3) To protect the earth from mutual contamination.

As a consequence, many studies have been performed to determine the most feasible methods of sterilizing spacecraft which have a reasonable possibility of extraterrestrial impact. The various suggested techniques of achieving sterility of unmanned spacecraft to prevent biological contamination of other planets include sterilization by vacuum of outer space, by radiation, by chemicals, and by heat.

Experiments have shown that microbes remain viable after exposure to ultrahigh vacuum, even in tests up to 35 days.[1,2] Therefore, it is concluded that vacuum exposure of outer space will not decrease the probability of contamination.

Sterilization can be accomplished by both ultraviolet and ionizing radiation. Ultraviolet radiation reaches only directly exposed surfaces and is of no use for interiors, shadowed surfaces, and holes. In fact, the penetrating power is so low that organisms can be protected by a thin layer of dead organisms.[3] Although ionizing radiation is much more penetrating, it will damage semiconductors plus many plastics and elastomers, including solid propellants, as well as optical properties of many glasses and pigments when exposed to doses as great as 10^7 rad,[4] which is the approximate dosage required to ensure sterility.[3] Further, ionizing radiation is expensive, hazardous, and complex. Radiation may be useful for reducing the biological load.

An appropriate concentration of ethylene oxide is a good sterilizing gas and does not damage the great majority of spacecraft components.[5] It can, however, kill only microbes on exposed surfaces and cannot reach interiors such as gasket seats, flanges, closed screwholes, electrical connectors, and sealed components. Certain liquid chemicals,

such as formaldehyde in methanol, are good sterilants. Because of their high viscosity and surface tension, liquid chemicals will not penetrate many crevices that would be reached by gas. Moreover, liquid sterilants damage certain components such as electrical connectors.

Dry heat is the most promising means of spacecraft sterilization. Moist heat requires less time and a lower temperature than dry heat, but it cannot penetrate vacuum tubes, transistors, lubricants, sealants, plastics, etc. Heat causes a design problem because it creates structural distortion and because it lowers the reliability of some electrical equipment such as guidance and communications gear. Work is now being done to develop heat-proof components. Also, many solid fuels either come apart or refuse to burn at all after exposure to sterilant temperatures.[6] Some propellants, however, are completely unchanged by heat treating.

Although the techniques for spacecraft sterilization have not been firmly established, dry heat, in particular, and exposure to ethylene oxide gas appear to be the most likely candidates. It is probable that several kinds of treatment will be selected and used together. The only overall sterilization method approved now is dry heat, which is expected to kill organisms both on surfaces and inside solids. Gaseous ethylene oxide is approved for surface decontamination. Backup studies of other forms of sterilization and decontamination, including X-ray radiation, are continuing. Beginning with the ethylene oxide decontamination, an ultra-clean, or bioclean, environment will be required. Next in order will be reassembly, system check-out tests, encapsulation of the payload in its sterilization canister, an additional functional verification test, terminal heat sterilization, a gross system check, sterilization certification, and launch.

Section II. BASIC REQUIREMENTS

The basic requirements for sterilization of vehicles which will land on another planet is a NASA policy which is summarized as follows:[7]

1) The lander will be assembled in clean rooms at specified levels of assembly.
2) The lander will be subjected to an approved sterilization procedure.
3) The lander will be inclosed in a bacteriological barrier to maintain cleanliness and sterility. After decontamination, the inclosure will not be opened within any portion of the Earth's atmosphere which might re-contaminate the lander.

The requirement for terminal sterilization of vehicles which may land on another planet creates a severe design environment, especially for those landers of extremely large size as proposed for the Saturn V launch vehicle. Compatibility with the specified sterilization environment must be a basic design requirement from the inception of any program.

The methods and procedures for implementing these requirements have not yet been established but are receiving extensive study. It is likely that the degree of assurance of sterility will vary according to which planet the lander or orbiter is destined for.[8] Assuming that Mars does support some type of life, rigorous sterilization standards must be established and met for the first spacecraft that will land on this planet in order to allow the completion of biological experiments before contamination occurs. Some recent preliminary data obtained from the Mariner IV[9] vehicle suggests that the Martian atmosphere may not be conducive to life as previously believed. Jaffe[8] is of the opinion that the required degree of assurance against microbiological contamination of Venus can be modified by the chance that Earth organisms could not grow in that environment.

In a report on Mars Voyager Systems, Wooten and Merz[10] reiterated that spacecraft which enter a planet's atmosphere must be sterilized to the extent that the probability of introducing a living organism is less than 1 in 10,000. Vehicles which orbit the planet must be similarly sterilized if the probability of impacting is greater than 1 in 10,000. Sterilization is not required if the vehicle is assured of a minimum time of 50 years in orbit before impacting the planet. The 50-years-in-orbit criterion is considered satisfied by setting a minimum altitude of 1500 kilometers (810 nautical miles).

Section III. CLEAN ROOMS REQUIREMENTS

1. Basic Concepts

NASA's policy requires clean rooms and clean work stations for the manufacture, assembly, and testing of vehicles which are to be decontaminated or sterilized. However, there is a problem in maintaining bioclean requirements throughout the entire train of events, including testing, leading to the sterilization oven. For example, some test equipment, such as a shaker, will present unusual and difficult problems in clean room design because of its size and the foundation required to support it.[7] Also, the sterilization oven may be located at the launch site while the assembly plant is located at a different site. In both of these cases, the hardware would have to be removed from the assembly clean room to be transported to another location.

Proposals to maintain cleanliness throughout every stage of assembly and test include the use of rigid canisters, plastic bags, and portable controlled environment facilities.[7]

One concept[11] for maintaining cleanliness during assembly of a lander to be totally heat sterilized suggested the use of two buildings - one within the other. The exterior building would be for environmental protection, and the internal building would be divided into rooms in which the various steps in sterilization and assembly would be performed prior to terminal heat sterilization.

The Sterilization Handbook[12] describes the concept of a bacteriological barrier system for assembly as being both the physical barrier surrounding the hardware under fabrication (often an inexpensive, lightweight material which is impervious to the ingress of bacteria and other particular contaminants) and the procedural barrier. Fabrication personnel gain access to the hardware through glove ports in the walls of the isolator. If required, personnel may be completely encased in a plastic film so that they may move about in an insulator. A sterilizing entrance port is provided for contamination control of tools, parts, etc.; and an exit port is provided for removal of waste, equipment, etc. The atmosphere within the barrier, under a slight positive pressure, is constantly circulated and filtered to remove particles in the submicron range. Since the assembly personnel are a prime source of bacterial contamination, they wear surgical masks, clean clothing, and suitable protective gloves.

Recent indications by NASA[13] are that clean rooms, including portable clean rooms, used for control of biological contamination of spacecraft are to provide for laminar flow of air movement from ceiling to floor, and shall conform to Federal Specification 209, Class 100. Concepts for this type room are shown in Figures 1 and 2, and particulate contamination levels for clean rooms are shown in Figure 3. Where work benches are required, laminar airflow will have a horizontal movement toward the worker. Only decontaminated tools will be used on decontaminated parts. Biological loading in and on the spacecraft will not exceed 10^8 viable organisms at the time it is brought to the terminal sterilization oven. If there is evidence that the viable contamination exceeds 10^8, the spacecraft will have to be exposed to a higher temperature or longer heat cycle during terminal sterilization. Frequent samples from fallout air and surfaces of assemblies would have to be obtained to determine total viable particle count, and spore content, as practicable.

However, the above stringent requirements may be relaxed by an alternate method of lowering the biological load of viable organisms to 10^8. The method proposed[13] is to use low level heat cycles for internal decontamination in place of manufacture and assembly in clean rooms and clean work spaces. Parts so heated must be handled subsequently in clean facilities.

2. Assembly, Test, and Sterilization Facility

In studies for the construction of a new Assembly, Test, and Sterilization Facility performed by Daniel, Mann, Johnson, and Mendonhall,[16] two approaches for clean rooms are being considered:

1) The laminar flow approach in which high efficiency particulate air filters are used with vertical laminar air flow to maintain a low level of particulate and microbiological contamination.
2) The sterile assembly approach in which techniques developed by germ-free animal researchers are used to obtain and maintain a sterile environment.

The results of the studies and the ensuing decisions regarding the method to be used in the facility have not been made.

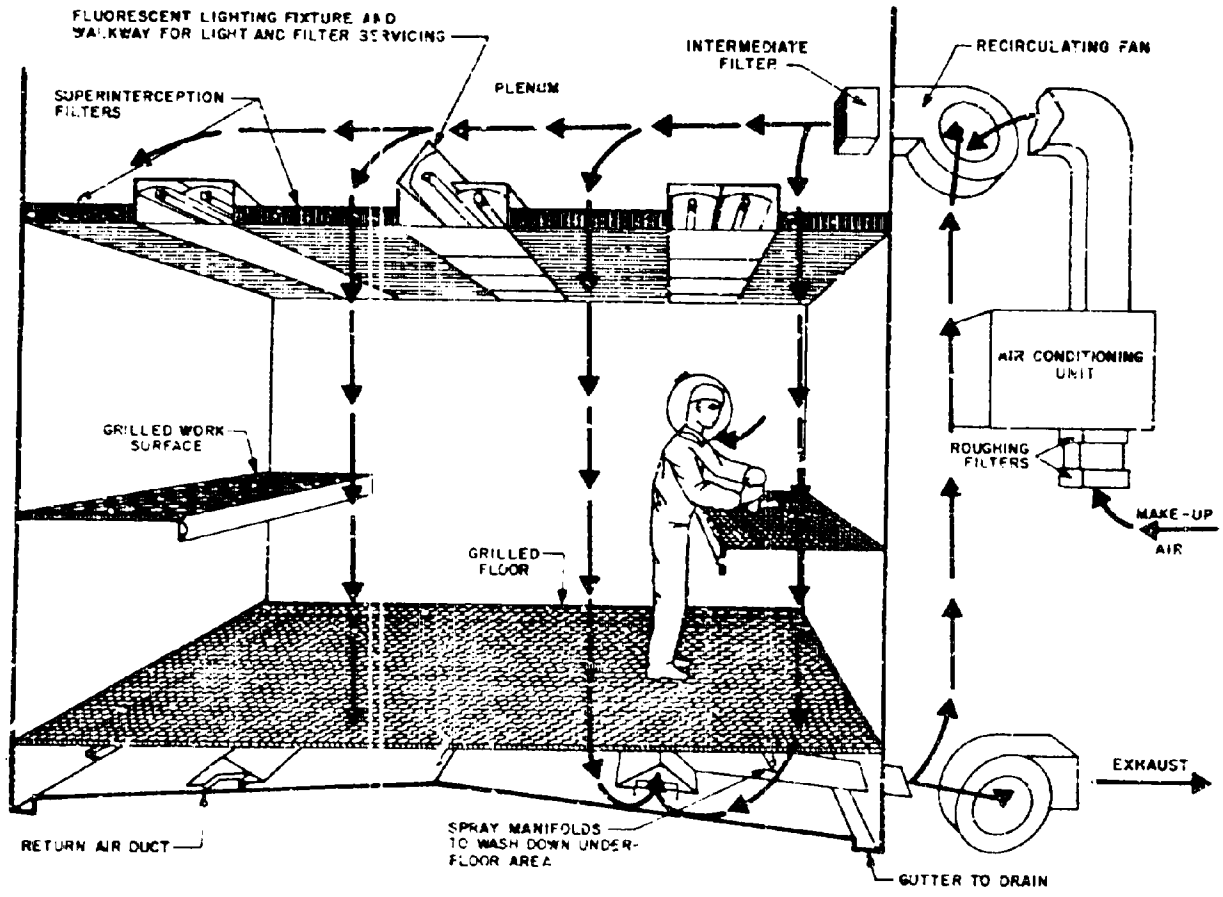


Figure 1. Laminar Flow/Downflow Air Distribution

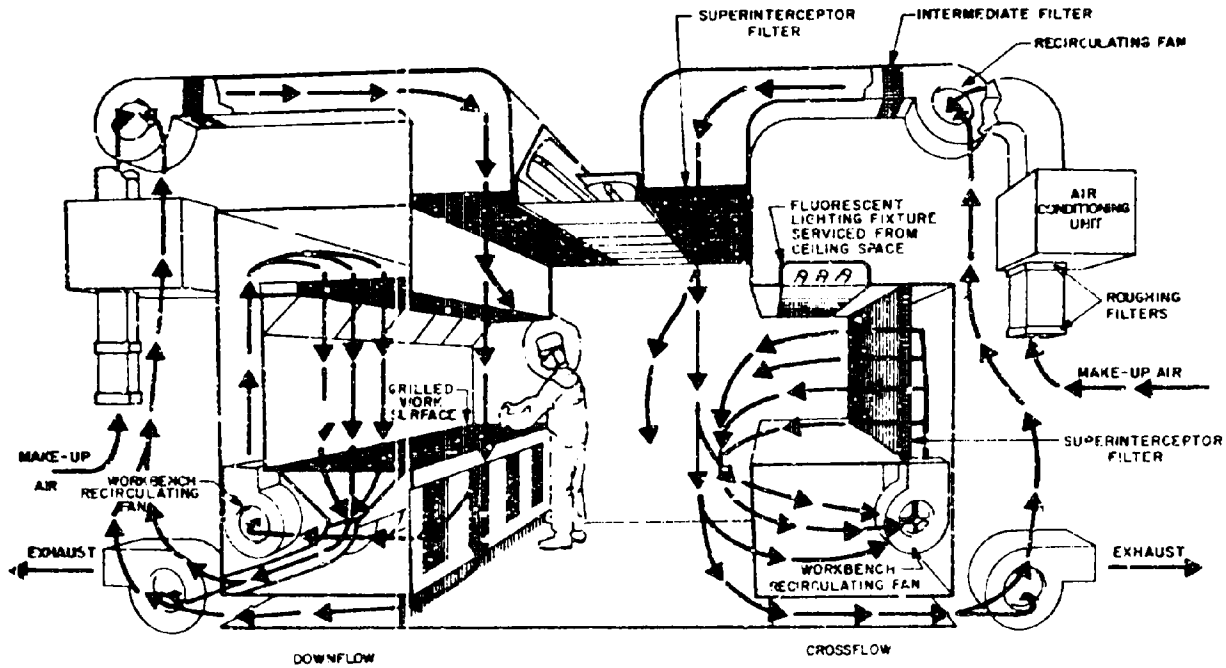
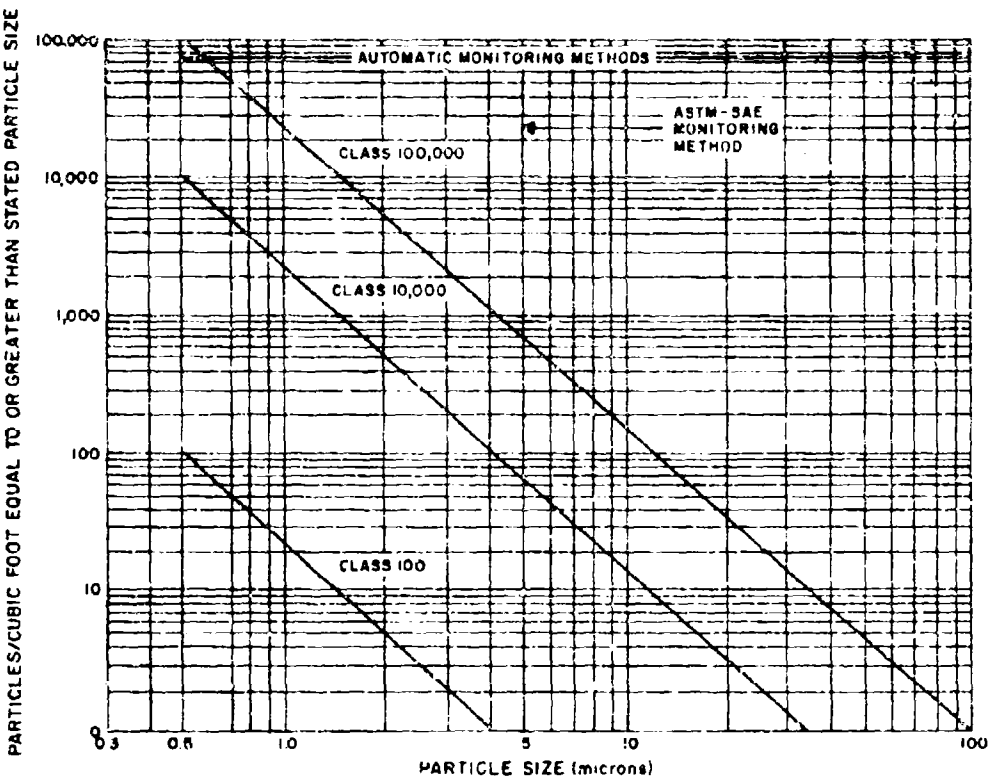


Figure 2. Conventional Air Distribution System with Laminar Flow Workbenches



Maximum number of particles per cubic foot 0.5 micron and larger	Class	Maximum number of particles per cubic foot 5.0 micron and larger
100	100	- - -
10,000	10,000	65
100,000	100,000	700

Figure 3. Federal Standard No. 209 - Particulate Contamination Levels for Clean Rooms

a. Laminar Flow

The essential elements of the laminar flow approach are described in the following paragraphs.

The main structure has a high bay assembly area. The high bay area will be a Class 100 clean room, utilizing laminar down-flow in accordance with Federal Standard No. 209. Air at 80 feet per second will enter the high bay through a special ceiling plenum, flow downward through high efficiency particulate air filter modules, and leave through a grilled metal floor. Plenums, blowers, and air balancing devices such as filters for handling the return air flow will extend below the floor level. In order to maintain bioclean standards, the high bay walls will be covered with nylon reinforced vinyl.

An area for operational support equipment (OSE) will be located just outside the clean area. In this way, OSE associated with a given capsule can be located near the capsule to simplify electrical and visual monitoring.

A dual-purpose, specially designed steel chamber is provided that will be used as a clean lock as well as providing for surface sterilizing (decontaminating) a capsule, major capsule components, large jigs, etc. Surface decontamination of the entire capsule or other large components is accomplished by means of an ethylene oxide (ETO) cycle. A separate dry test heat oven, located outside the building, is provided to sterilize the proof-test model capsule in its biological barrier.

A microbiological laboratory is provided for development and implementation of various microbiological techniques such as surveillance, monitoring, assay, and certification. This laboratory includes areas for sterile transfer, media preparation, sample handling, biological assay work, and various utility operations associated with microbiological investigations.

Floor space is provided for special processing of personnel. This includes air locks, air showers, suiting areas, locker rooms, and areas for medical examination. Parallel areas exist for men and women.

The main floor of the facility also includes a receiving area, a decontamination area, and a transfer area using plassclaves. Most heating, ventilating, air conditioning, and special electrical equipments are installed in the basement. The second floor includes a control room, a receiving area, and various areas for mechanical equipment.

b. Sterile Assembly

Essential elements of the sterile assembly approach are described in the following paragraphs.

The main structure has two high bay sterile assembly areas. To ensure sterility, all surfaces of the assembly room are decontaminated, all equipment entering the room is decontaminated, all air entering the room does so through glass filters, and all personnel entering the room do so in sterile barrier suits. The air filters and material passthroughs will provide a barrier against microorganisms which have been found effective by germ-free animal researchers. All cracks and seams in the room will be sealed. Walls will be smooth, epoxy coated, so that they may readily be washed down with a 2-percent peracetic acid or equivalent effective surface decontaminant.

An area is provided for operational support equipment. Part of this area is in the corridor between the two sterile areas for equipment requiring short electrical lines or close viewing and part of this area is on the second floor at one end of the building.

Two dual-purpose steel chambers are provided to perform the ETO decontamination and clean lock functions as in the case of the laminar flow system chamber. These chambers will also be used to dry-heat sterilize the capsule proof test model.

A microbiological laboratory is provided for development and implementation of various microbiological techniques such as surveillance, monitoring, assay, and certification. This laboratory includes areas for sterile transfer, media preparation, and various utility operations. However, because of the very low contamination levels expected, sterile transfer will be done under glove box conditions to ensure against contamination during the transfer.

A special air lock with a bactericidal wash will be provided to decontaminate the surface of the suits worn by personnel in each sterile area.

On the main floor are areas for several ovens and sterile locks, a tool room, a service aisle, and a receiving area.

The basement has areas for mechanical equipment, sterilization ovens, a boiler room, a chiller room, locker room toilets, a quarantine storage area where parts of questionable sterility are verified, and a

normal storage area. There is also a glove box area where sterile parts may be assembled without the need for personnel to "suit up" for the sterile assembly area.

The second floor, in addition to the OSE area, has a centrally located control room to monitor and control facility functions.

Section IV. PERSONNEL

Because personnel are a prime source of contamination during assembly in clean rooms, the following requirements will likely be implemented:[13]

1) All persons in the clean room will wear masks and approved barrier clothing. Barrier clothing is required for all portions of the body which reach from a level of 3 inches below and up along the spacecraft as mounted in the room.
2) No person shall enter the bioclean area who has open sores, noticeable dandruff, a cold, a fever, or diarrhea. This requirement was in the original NASA Interim Requirements for Bioclean Facilities, paragraph 4.12.
3) Sterile surgical gloves or sterile disposable plastic gloves will be used to handle decontaminated spacecraft parts.

The original (1963) Interim Requirements were cancelled and Federal Standard Number 209 was substituted; however, the essential provisions of paragraph 2.12 of the original requirements will be retained. The provisional draft for a subsequent Interium Document provides for the microbioassay of personnel.[16]

Assay shall be made (not less than one per week) of the quality of biological contamination on the skin of each person whose duties take him routinely into the clean room in which flight hardware is present. Samples shall be taken from the cheek, chest, back, forearm, palm, and any other locations and at any time required by the sterility control personnel or by the medical officers.

The following items have not been specified:[16]

1) The frequency of physical examinations.
2) The need for routine inspections by a physician.
3) The microbioassay of the skin.

It appears that NASA is inclined to dispense with the requirement for a routine examination by a physician and will rely on persons in the clean room to exclude persons with open sores. Personnel suffering from fever, colds, and diarrhea are to report these ailments to their supervisors.

General Electric Company[14] conducted a poll to determine the informal opinion of the NASA Bioclean Requirements, particularly with respect to the prescribed methods of personnel contamination control. Comments were solicited from five nationally-known pharmaceutical and chemical laboratories and from a medical officer, a psychologist, and two shop people at General Electric. There was a consensus on the following points:

1) Daily examination by a physician is nonessential.
2) Sterilized clothing is the most effective, practical means of minimizing contamination of hardware.
3) Reliance on the buddy system for monitoring is undesirable. A system of self-reporting must be founded on psychologically valid incentives.
4) Microbiological standards of acceptability will increase labor costs substantially.

Section V. STERILIZATION CANISTER

Three basically different approaches to the terminal sterilization canister are a flexible film container, a rigid container, and a combination of flexible and rigid materials.[7]

The advantages of using film isolators include light weight, ease of access, and visual inspection. However, film containers have been evaluated and rejected by General Electric because of several objectionable characteristics. One of the most objectionable characteristics is the difficulty in jettison and separation of a thin film from an object whose shape is relatively complex. An objectionable characteristic of film bags is their sensitivity to penetrations. Since films are easily ripped or punctured, it is not desirable to have the success of a space program supported by such a weak link.

The rigid canister will be much less susceptible to handling damage than the film canister, and it also lends itself to relative ease of separating mating elements in flight. However, the rigid canister has several design problems. Assuming that a gas is used within the container, internal pressure will build up during thermal sterilization and, unless properly vented, could damage the container. Upon cooling, the canister may draw a vacuum and be subjected to collapsing pressures unless sterile gas is added. If NASA's "no access" policy after terminal sterilization should be modified, a rigid canister would virtually eliminate access.

The combination of a flexible and a rigid canister combines the best design features of both. In essence, this type of container is a flying glove box or dry box. The rigid portions of these canisters could be made to fit the shape of the planetary lander, while asceptic entry ports and work stations could be located in a manner that would facilitate access if NASA's "no access" policy is relaxed.

It is expected that the "no access after terminal sterilization" policy will be relaxed if microbiologists can be convinced that an absolutely sterile entry to the capsule can be made.[17]

The general design criteria for the canister are as follows:[16]

1) Keep out bacteria, spores, and other organisms.
2) Be as light as possible, since it accompanies the capsule into space.
3) Be able to contain the capsule and any remote handling gear.

4) Incorporate sterile electrical connections for flight, checkout, and test.
5) Contain as few as possible electrical connections which should be in-flight disconnects. Sterile access through glove boxes may be necessary to make electrical disconnects
6) Act as a meteroid bumper, if weight penalty for such design can be tolerated and if retained until just prior to Mars entry.
7) Contain sterile plumbing fittings for liquids and gases, if required.
8) Remain unaffected by hot or cold ethylene oxide.
9) Remain unaffected by dry heat up to 145°C
10) Eject the capsule before Mars entry without compromising sterility.

Section VI. HANDLING AND TRANSPORTATION

A study was made by General Electric[19] to assess the problems associated with handling and transporting a canister in the sequence of events prior to launch. The study considered the terminal sterilization of the vehicle at the launch site and at the manufacturer's facility.

To sterilize at the launch site, the following steps were considered:

1) The vehicle is assembled and checked out under carefully controlled environment. This implies the existence of a clean room facility at the launch site which is as good as the facility where the spacecraft was assembled.
2) The spacecraft-canister combination is subjected to terminal sterilization and is mated with the orbiter.
3) Final checkout of the system is performed and the system is launched.

To sterilize at the manufacturer's facility, the following steps were considered:

1) The lander is assembled and checked out under clean conditions, then sealed in the containing canister and terminally sterilized.
2) The sterilized canister is shipped to the launch site. A shipping container for the canister-lander combination may be required to protect the canister from damage.
3) The canister is mated with the orbiter. No clean room facilities are required.
4) The system is launched.

By comparing the advantages and disadvantages of both of the above sequences, it was concluded that terminal sterilization at the launch site is preferred. The primary reasons for this choice are as follows:

1) It may be impossible to transport a fully assembled lander to the launch site.
2) The techniques for biologically monitoring a sealed canister over long periods of time are complicated and may penalize the canister design.
3) Terminal sterilization at the launch site would permit all pressurized liquids or fluid systems in the lander to be charged where safety procedures and techniques are well developed.

In a study for an assembly, test, and sterilization facility for the Voyager Landing capsules performed by Daniel, Mann, Johnson, and Mendenhall,[15] it was expected that facilities will be required at Kennedy Space Center to provide for the following functions:

1) Allow for loading pyrotechnics, squibs, rocket motors, and any other explosive devices into the capsule.
2) Allow terminal heat sterilization of the complete landing capsule within its biological barrier.
3) Allow for various tests to be conducted such as spin and balance, center of gravity location, etc.
4) Allow for operational checkout of the capsule upon completion of the above tests.

Section VII. TERMINAL STERILIZATION

Current policy indicates that landers will be subjected to a terminal dry heat soak at any of the temperatures and corresponding times shown in Figure 4.[18] Hardware qualification will be performed by three 36-hour heating cycles at 145°C.[16,20,21] Figure 5 shows a concept for a terminal heat sterilization oven. It should be understood that heating a vehicle to the temperatures and corresponding times shown in Figure 1 will not produce a sterile vehicle regardless of the state of cleanliness prior to heating. The specified sterilization procedure is based on a vehicle that has undergone biological load reduction prior to sterilization.[7]

Thermal sterilization in the presence of a conducting gas within the canister is preferable to sterilization in a vacuum.[22] The advantages gained in using a gas, such as nitrogen, include shorter thermal rise times, elimination of designing for atmospheric overpressures on the canister, and the elimination of the possibility of atmospheric contamination caused by leaks at the interface between mating sections in the canister. In one study,[23] the presence of a gas reduced the time to reach sterilization temperature almost 50 percent over the vacuum sterilization method. This method resulted in a reduction in total soak time at elevated temperatures and reduced the most extreme temperature gradients by a considerable factor. If thermal sterilization is conducted in a vacuum and afterward a sterile gas, such as ethylene oxide, is released within the canister, these advantages are negated.

On some vehicles, such as the Voyager Venus probes, thermal insulation may be required for internal equipment, batteries, for instance, to prevent excessive temperature rise during entry at Venus. This insulation could add many hours to each sterilization cycle.[22]

Elevated temperatures lower the reliability of some electrical instruments and components. Consequently, any component or part that is adversely affected by heat must be carefully selected, and special developments will likely be required. Studies have been made to determine the effect of temperature on components, and other studies are in progress.

The design of pressure vessels becomes an important consideration in structural design for sterilization. Although NASA's requirements prohibit access to the sealed canister after terminal sterilization, Tenny, Fried, and Crawford[22] have suggested that it may be advantageous to sterilize gases and liquids separately and charge the system after

sterilization of the vehicle and tank. These authors have stated that "since a relatively high weight penalty is imposed on a planetary lander when the large-volume, high-pressure vessels are designed to withstand terminal heat sterilization with the tanks charged, it becomes advantageous to study other sterilization methods which may minimize or eliminate this weight penalty. An alternate method that minimizes the weight penalty is to heat sterilize the vehicles with the tanks installed but not charged, then charge them with a sterile gas. This technique eliminates a hazardous condition during sterilization and deserves further study."

When thermal sterilization is used, the major problems with the vehicle structure are the effects of transient thermal gradients and the material degradation due to temperature-time exposure. Tenny, Fried, and Crawford[22] show that the severity of the thermal gradients and the subsequent thermal stresses and distortions are governed in part by the rate of heating and cooling, the method of heat application, and the magnitude of the thermal resistance paths between the heat source and the heat sink. The material degradation is affected by the temperature level and duration. As a result of their study of a model, these authors arrived at the following conclusions:

1) High thermal conductivity materials and joining techniques should be used as much as possible in the vehicle structure. Examples are brazed core honeycomb sandwich in preference to bonded sandwich and welded joints in preference to bolted, riveted, or bonded joints.
2) Programmed heating and cooling is desirable and necessary in order to minimize thermal gradients in the vehicle structure. Techniques for heating and cooling the containing canister warrant further study.
3) Thermal sterilization in the presence of a gas is far more efficient than in a vacuum, both in terms of minimizing total sterilization time and in reducing thermal gradients.

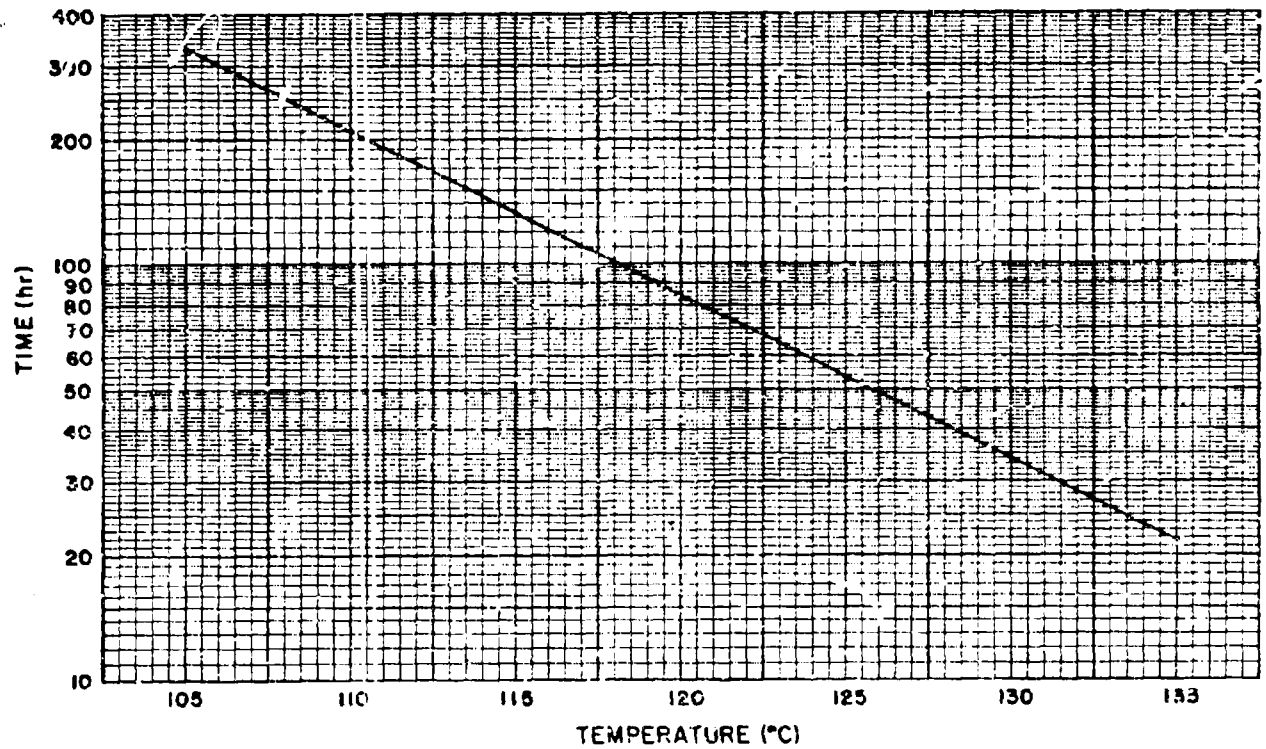


Figure 4. Thermal Cycles Approved for Dry Heat Sterilization

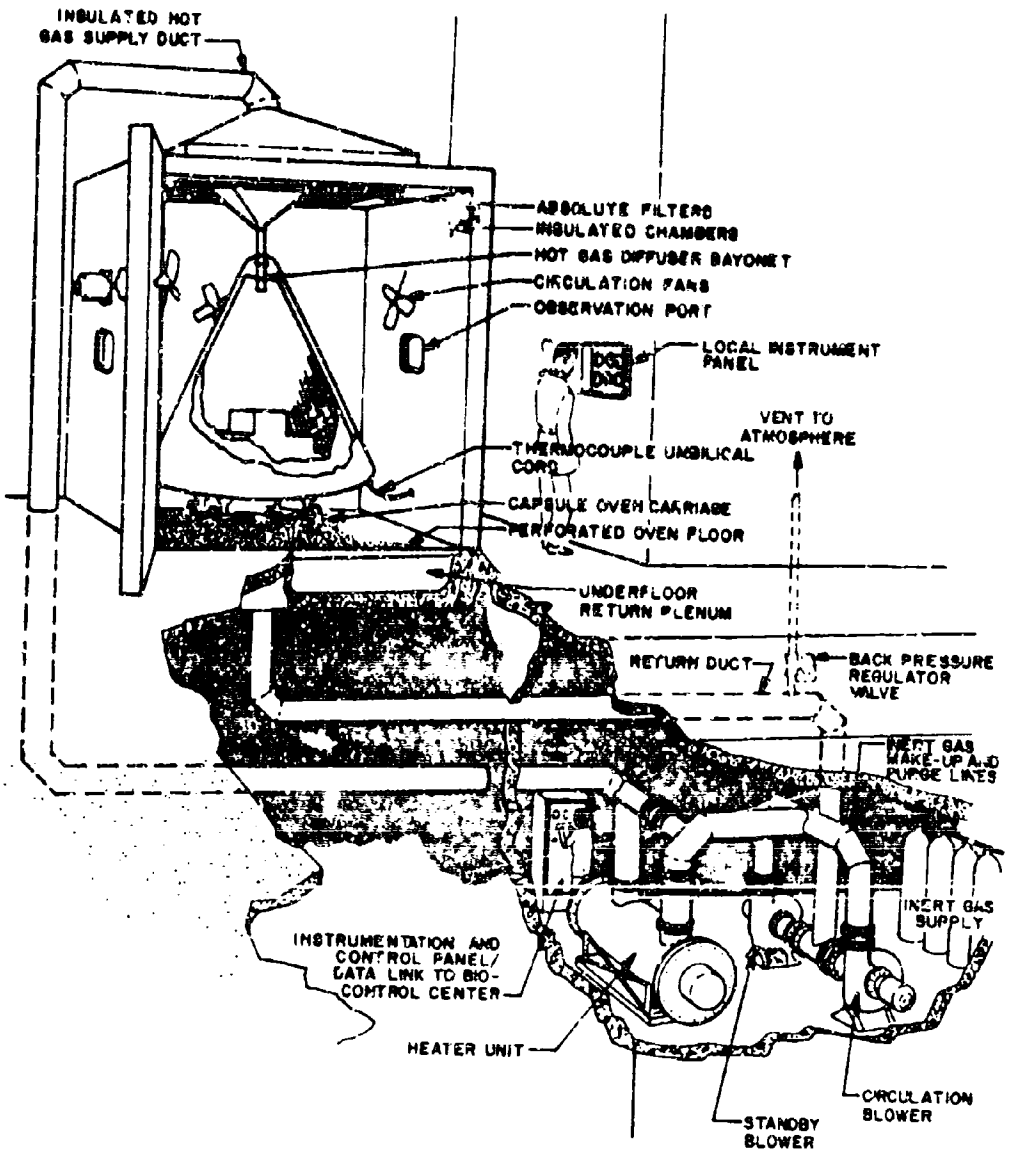


Figure 5. Thermal Heat Sterilization Oven

Section VIII. LANDER SEPARATION

After the sterilized spacecraft has been launched, the possibilities for contamination have not been removed unless provisions are made early in the design cycle to eliminate them. Several potential sources of contamination exist when the protective canister is separated and jettisoned. These sources include contamination from particle impingement from the orbiter and canister and, in particular, from [24] squib actuated devices, solid propellant engines, cold gas attitude control systems, and outgassing from coatings, greases, paints, etc.

A study by General Electric[18] pointed out the following considerations which affect design and manufacturing sequences:

1) There may be a need for biological load reduction on the spacecraft dependent upon when the sterile canister is opened. If the canister remains sealed until shortly before entry into the Mars atmosphere, the requirements for cleanliness will not be as stringent as if the canister is opened shortly after the spacecraft leaves the atmosphere.
2) Ejection of the upper half of the canister must be accomplished so as not to contaminate the lander on Mars. It may be desirable to repressurize the canister just prior to opening so as to maintain an outflow of gas as separation occurs. Addition of a gas bottle invokes a weight penalty.
3) When the upper half of the canister has been removed and the lander is still attached to the spacecraft and if attitude correction of the spacecraft is required, the attitude control gas must not contaminate the lander. This may mean sterilizing the attitude control gas system of the spacecraft with attendant weight increase in the pressure vessels and piping and attendant complications in the spacecraft (bus) system.
4) Umbilical connections between the canister and the lander must be separated in flight. Any debris caused by separation must not contaminate the lander.
5) Prior to planetary entry, the lander is separated from the spacecraft, and the spacecraft is reoriented and given a velocity change. This means that the lander, when it is propelled by the ΔV rocket, must pass through space which is diffused with gas from the spacecraft. Consideration must be given to the rate of dispersion of the gas and, if particulate impingement does occur, to the probability of contamination of the lander.

LITERATURE CITED

1. D. M. Portner, D. R. Spiner, R. K. Hoffman, and C. R. Phillips, EFFECT OF ULTRAHIGH VACUUM ON VIABILITY OF MICRO-ORGANISMS, Science, Vol. 134, No. 3495, p. 2407, 22 December 1961, (U62-11134).

2. F. A. Morelli, F. P. Fehlner, and C. H. Stembridge, EFFECT OF ULTRA-HIGH VACUUM ON BACILLUS SUBTILIS VAR. NIGER, Nature, Vol. 196, pp. 106-107, 13 October 1962.

3. Carl-Johan Clemedson, STERILIZATION OF LUNAR AND PLANETARY SPACE VEHICLES--A REVIEW, International Astronautical Congress, 13th, Varna, Bulgaria, Proceedings, Vol. 1, September 1962, (A64-28456).

4. L. D. Jaffe, PROBLEMS IN STERILIZATION OF UNMANNED SPACE VEHICLES, Fourth International Space Science Symposium, Warsaw, Poland, 3-11 June 1963, Report No. NASA CR-51245, (X63-15594).

5. General Precision, Incorporated, Librascope Division, Glendale, California, THE EFFECT OF GAS STERILIZATION (ETHYLENE OXIDE) ON VARIOUS ELECTRONIC COMPONENTS by O. A. Schwartz, 5 May 1964, Report No. NASA CR-58374, X64-16150.

6. EARTH COULD INFECT MARS, Science News Letter, Vol. 88, No. 4, p. 50, 24 July 1965.

7. General Electric Company, Spacecraft Department, Philadelphia, Pennsylvania, DESIGN CRITERIA FOR PLANETARY SPACECRAFT TO BE STERILIZED BY HEATING, Second Quarterly Progress Report, 31 December 1964, Report No. NASA-CR-60847, X6-12863.

8. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, STERILIZATION OF UNMANNED PLANETARY AND LUNAR SPACE VEHICLES--AN ENGINEERING EXAMINATION by L. D. Jaffe, 25 March 1963, Report No. N63-15243, National Aeronautics and Space Administration, Contract No. NAS7-100.

9. Kliore, Arvydas, et al., OCCULATION EXPERIMENT: RESULTS OF THE FIRST DIRECT MEASUREMENT OF MARS' ATMOSPHERE AND IONOSPHERE, Science, Vol. 149, No. 3689, pp. 1243-1248, 10 September 1965.

10. R. W. Wooter, and E. J. Merz, MARS-VOYAGER SYSTEMS, AIAA Unmanned Spacecraft Meeting, Los Angeles, California, 1-4 March 1965.

11. Avco Corporation, Research and Advanced Development Division, Wilmington, Massachusetts, VOYAGER DESIGN STUDIES, VOL. III, 15 October 1963, Report No. NASA-CR-51830, X64-36238, National Aeronautics and Space Administration, Contract No. NASw 697.

12. Dynamic Science Corporation, South Pasadena, California, STERILIZATION HANDBOOK, FINAL REPORT by J. B. Opfell, C. E. Miller, N. S. Kovar, P. E. Naton, and R. D. Allen. 26 August 1964, Report No. NASA-CR-62837, N65-24296.

13. Lawrence B. Hall to O. W. Nicks, DRAFT LETTER, 16 August 1965.

14. Daniel, Mann, Johnson, and Mendenhall, Los Angeles, California, CRITERIA DEVELOPMENT STUDIES FOR AN ASSEMBLY, TEST, AND STERILIZATION FACILITY, April 1964, Subcontract from Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, under National Aeronautics and Space Administration Contract No. NAS 7-100.

15. Daniel, Mann, Johnson, and Mendenhall, Los Angeles, California, PRELIMINARY ENGINEERING REPORT FOR ASSEMBLY, TEST, AND STERILIZATION FACILITY, August 1965, Subcontract from Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, under National Aeronautics and Space Administration Contract No. NAS 7-270(F).

16. General Electric Company, Missile and Space Division, Philadelphia, Pennsylvania, MANUFACTURING PROCEDURES FOR PLANETARY SPACECRAFT TO BE STERILIZED BY HEATING, 5 August - 4 September 1965, Monthly Progress Report No. 4, Part II, National Aeronautics and Space Administration, Contract No. NAS 8-11372.

17. Private Communication with R. G. Crawford, Propulsion and Vehicle Engineering Laboratory, Marshall Space Flight Center, Huntsville, Alabama, 30 September 1965.

18. General Electric Company, Missile and Space Division, Philadelphia, Pennsylvania, DEVELOPMENT OF MANUFACTURING PROCEDURES FOR PLANETARY SPACECRAFT TO BE STERILIZED BY HEATING, 5 August 1965, First Quarterly Progress Report, Part II, Document No. 65SD4406, National Aeronautics and Space Administration, Contract No. NAS 8-11372.

19. General Electric Company, Missile and Space Division, Philadelphia, Pennsylvania, DESIGN CRITERIA FOR PLANETARY SPACECRAFT TO BE STERILIZED BY HEATING, 30 June - 30 September 1964, First Quarterly Progress Report No. NASA-CR-59561, National Aeronautics and Space Administration, Contract No. NAS 8-11372.

20. Donald P. Hearth, VOYAGER, Astronautics and Aeronautics, Vol. 3, No. 5, pp. 16-21, May 1965.

21. Carl Sagan and Sidney Coleman, SPACECRAFT STERILIZATION STANDARDS AND CONTAMINATION OF MARS, Astronautics and Aeronautics, Vol. 3, No. 5, pp. 22-27, May 1965.

22. J. B. Tenney, E. Fried, and R. Crawford, THERMAL STERILIZATION OF SPACECRAFT STRUCTURES, AIAA Unmanned Spacecraft Meeting, Los Angeles, California, 1-4 March 1965, AIAA Publication CP-12, A65-19502.

23. School of Aerospace Medicine, Brooks Air Force Base, Texas, CONTROLLED CONTAMINATION: A PRACTICAL APPROACH FOR DEVELOPING STERILIZATION PROCEDURES FOR SEALED COMPONENTS OF SPACECRAFT by J. T. Cordaro, H. Buchanan, B. Mann, and A. K. Miller, September 1963, Report No. N64-25040, SAM-TDR-63-73, AD-437645, Contract No. AF 41(609)-1522.

24. J. B. Tenney, Jr. and R. B. Crawford, DESIGN REQUIREMENTS FOR THE STERILIZATION CONTAINERS OF PLANETARY LANDERS, AIAA Second Annual Meeting, San Francisco, California, 26-29 July 1965.