

N72-19094



900-484  
PLANETARY QUARANTINE  
Semi-Annual Review  
Space Research and Technology  
1 July - 31 December 1970

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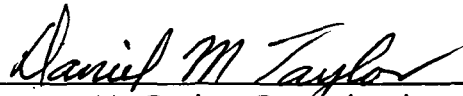
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PLANETARY QUARANTINE

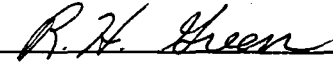
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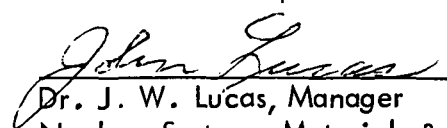


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## PREFACE

This document contains a report on Research and Advanced Development at the Jet Propulsion Laboratory during the period July 1, 1970 to December 31, 1970 sponsored by the Planetary Quarantine Branch of the NASA Office Space Science and Applications.

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SECTION I  
SPACECRAFT CLEANING AND DECONTAMINATION TECHNIQUES

## SECTION I

## SPACECRAFT CLEANING AND DECONTAMINATION TECHNIQUES

NASA No. 191-58-61-02-55

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## 1.1 INTRODUCTION

The initial Planetary Quarantine constraints, which called for complete and total sterilization of certain spacecraft, demanded the use of a method which would sterilize interior as well as exterior surfaces. Dry heat met these needs and was chosen as the process to be employed to achieve terminal sterilization as required.

Subsequent determinations indicated that the time and temperature specified to achieve sterility had a deleterious affect on certain spacecraft materials and components. As a result it was suggested that some method of pre-sterilization cleaning or decontamination be employed to reduce the microbial load on space hardware; thus, making it possible to reduce the time/temperature required to meet the established constraints.

Three basic decontamination methods were considered and have been, or are, in the process of being investigated and evaluated in terms of their effectiveness in microbial burden reduction and compatibility with hardware. The methods are: chemicals in liquid form, relying on physical removal as well as bactericidal or bacteriostatic action; chemicals used in the gaseous phase, relying only on bactericidal activity, and finally, mechanical cleaning resulting in physical removal of organisms.

Chemicals in liquid form were studied to establish standard methods of cleaning spacecraft parts, subsystems and systems, and to determine the effectiveness of these compounds and methods in reducing microbial load. The study was specifically designed to accomplish the following:

- 1) Survey available sporicides, germicides, fungicides, disinfectants, antiseptics, sanitizing agents, detergents, and cleaning compounds as well as bactericidal lubricants and attempt to determine by experimentation the bactericidal and physical cleaning effectiveness of these compounds.

- 2) Permit the generation of a list of approved chemical compounds which could be used to clean and decontaminate space hardware, tools and assembly areas.
- 3) Establish and recommend standard methods for using the approved compounds.
- 4) Give consideration to physical cleaning methods to be used in conjunction with the approved compounds.

Ethylene oxide was chosen as the gaseous chemical agent to be used for decontamination of space hardware.

Initially, research dealt primarily with the effectiveness and usefulness of ethylene oxide as a sporicidal agent to be used during production of spacecraft. Most of the studies were conducted using a non-explosive mixture containing 12% ethylene oxide and 88% dichlorodifluoromethane (Freon or Genetron), by weight. Spacecraft materials compatibility studies were also conducted utilizing this mixture under specified decontamination conditions.

Research in the area of ETO decontamination was originally designed to provide practical procedures for decontamination of spacecraft as a requirement of the Voyager project. The information obtained was to be used in the Sterilization Assembly Development Laboratory (SADL) and in surface decontamination studies related to spacecraft.

These studies were intended to determine the advantages and disadvantages of employing ETO in the NASA sterilization program, but they resulted in generation of confusion in specifying exact treatment procedures for ethylene oxide decontamination. It became apparent that the effect of ethylene oxide cycle variables could be severe enough to destroy the reliability and validity of planned treatments of spacecraft components. It was concluded that additional information would have to be obtained and research carried out under controlled conditions in order to have a better understanding of the precise effects of these variables and to provide a basis for controlling them during actual treatment cycles.

It was decided that existing decontamination procedures and ethylene oxide chambers could not be used to decontaminate space hardware or furnish the information required. Existing equipment did not have adequate control or readout of conditions within the chambers and did not possess the necessary

heating capability for the size and type of load presented by space hardware. The existence of certain engineering constraints prevented the use of available chambers in a manner which would have assured maximum decontamination. These constraints applied to the following:

- 1) Spacecraft components would have been subjected to too much moisture. The materials of construction of the components, in many cases, were not compatible with the high humidity specified by the manufacturer during the pre-moisturizing cycle and during ETO exposure. The specified high humidity was considered necessary to ensure destruction of microorganisms.
- 2) The high temperatures considered by many researchers as being necessary for successful sterilization of solid material surfaces (50 - 55°C), plus the presence of moisture, ethylene oxide and Freon within the heated chamber was found to be destructive to many components.
- 3) The space simulation tests to which spacecraft are subjected include high vacuum followed by backfilling with dry nitrogen. This treatment dehydrates microorganisms. Rehydration of the bacterial cells, to make them susceptible to sterilization with ETO, requires a high humidity environment at temperatures well above ambient for extended periods of time. This procedure introduces additional compatibility problems.

As a result of the conclusions reached from the foregoing studies, it was decided to initiate a task which would:

- 1) Permit the development of the necessary parametric information required to establish ethylene oxide cycles which would result in maximum sporicidal activity.
- 2) Utilize these data in the development of ethylene oxide cycles which would ensure compatibility with capsule system elements and proposed decontamination chambers while maintaining maximum sporicidal activity.

The approach used to develop the necessary data was an investigation of the effects on process efficiency of varying the parameters of temperature, humidity and ethylene oxide concentration as well as the duration of the humidification cycle used prior to ETO exposure. The evaluation of the sporicidal effects of variations in the stated parameters was carried out under closely controlled dynamic laminar flow conditions in a newly designed and fabricated chamber.

Mechanical cleaning methods which have been, and are being, investigated are wiping, brushing, vacuum, vacuum combined with ultrasound waves, low vacuum combined with brushing, vacuum followed by alcohol wiping, low vacuum using a hard nozzle through a screen, low vacuum with a hard nozzle touching the surface, and soaking the surface with isopropyl alcohol for a period of time prior to wiping.

The methods studied were evaluated in terms of removal of organisms from simulated or actual space hardware and with seeded or naturally occurring contamination.

These methods have been, and are being, studied in an attempt to identify alternate methods which can be used for cleaning and decontamination of space hardware to reduce the bioburden to acceptable levels.

## 1.2 SIGNIFICANT ACCOMPLISHMENTS

### 1.2.1 Liquid Cleaning and Biocidal Compounds

Certain liquids were surveyed and evaluated on their ability to physically remove organisms and non-viable particulates from materials, their ability to inactivate spores and vegetative cells, their compatibility with space hardware and their ability to remove oil and other chemical constituents.

The liquids were applied to parts with a brush or a lint-free cloth, and in some cases, parts were dipped into the liquid for a short time or allowed to soak for longer periods of time. The method of application and length of time that the liquids were allowed to remain in contact with the parts depended on, size of the part, compatibility of the part, compatibility of the materials of construction, results expected, i. e., germicidal activity, sporicidal activity or physical cleaning, and efficiency of the liquid as

determined by previous experience. No attempt was made in these studies to increase or decrease intensity of the treatment to correspond to an increase or decrease in bio-burden. As a result of initial work, it was decided to use an isopropyl alcohol wipe, in limited areas, to reduce burden.

Table 1-1 shows the results of this portion of the "Cleaning Task," on physical cleaning effectivity, biocidal action on bacterial and fungal spores and vegetative cells of bacteria, yeasts and molds, and spacecraft material compatibility.

As a result of the data obtained from the initial phase of the study, it was determined that chemical compounds, used in the liquid phase, which were effective against spore forms of microorganisms, were generally not compatible with spacecraft materials. Further investigation led to the conclusion that material compatibility studies would be required of all proposed cleaning or decontamination agents or devices and all space hardware coming in contact with them. Compatibility studies were not considered because of the extensive and complex testing program which would be required to yield significant data.

As a result, the decision was made to discontinue that portion of the task dealing with chemicals in liquid form.

It was further decided that work in the area of spacecraft cleaning should be concentrated on mechanical/physical methods of reducing bio-burden.

#### 1.2.2 Ethylene Oxide

A Fixed Cost Contract of 14 months duration was issued to Becton Dickinson Company (B-D) on 13 September, 1968. The contractor was to provide practical and effective procedures for decontamination of spacecraft with ethylene oxide and to evaluate the sterilizing efficiency of varying the decontamination parameters of gas concentration, time, temperature and relative humidity under dynamic conditions instead of static conditions employed by equipment commercially available at that time.

The study was divided into two phases. During Phase I the following tasks were accomplished:

- 1) Preparation and certification of an aqueous suspension of Bacillus subtilis var. niger spores. The spores were obtained from Fort Detrick as a lyophilized culture. The final clean, (free from vegetative cells and residual debris) stock suspension contained  $1.4 \times 10^{10}$  viable spores per ml.

Studies on the relative resistivity of the spore preparation to ethylene oxide were conducted. Paper strips containing  $1 \times 10^5$  of these spores were exposed along with a similar number of commercially prepared B-D spore strips containing the same number of spores.

Results from replicate trials indicated that the spore suspension prepared for the JPL contract studies was somewhat more resistant to ETO than the commercial B-D preparation; i. e., the time required to inactivate 50% of the spores was 9.2 minutes for the JPL spore strips and 7.5 for the B-D strips.

- 2) Selection and procurement of test pieces. The following test pieces were chosen as being representative of various configurations associated with spacecraft.

Test tubes - capped

Glass tubes - open

Capillary tubes

Glass strips

Metal strips

Plastic strips

- 3) Inoculation and biologic assessment of test pieces. 1250 each of the six test pieces were sterilized, then each piece was inoculated with  $1 \times 10^6$  spores and allowed to dry in an incubator at 30 - 35°C. A comparative study using 0.25 ml glass pipettes as well as an Eppendorf, Oxford, and Hamilton pipetting devices, followed by statistical analysis, indicated that the most sensitive method, in terms of controlling the amount of inoculum, was the 0.25 ml

pipette. In spite of some loss in sensitivity over the pipette it was decided to use the semi-automatic Eppendorf device, based on the requirement for maximal reproducibility in the quantitative inoculation of all 7500 test pieces.

- 4) Vacuum exposure of test pieces. All test pieces were exposed at one time in a large chamber located in the Department of Aero-Space Science at the University of North Carolina, Raleigh. Vacuum exposure was at  $1 \times 10^{-5}$  to  $1 \times 10^{-6}$  torr for a period of two weeks. The chamber was backfilled with  $N_2$  gas after exposure.
- 5) Assay of vacuum - treated test pieces. Spore assessment after exposure to vacuum and after 10 months storage (waiting for completion of the chamber) both revealed a wide range and variance as can be seen in Table 1-2.

Phase II of the study was concerned with the fabrication of the test chamber, purchase of other required equipment and materials, exposure of the test pieces to ETO, and biologic assay of the pieces.

Becton Dickinson issued a subcontract to the S. Blickman Company for fabrication of the chamber. Difficulties encountered in the design, fabrication (a three month strike), and testing of the chamber, plus relocation of B-D Research Center from Cockeysville, Maryland to Raleigh, North Carolina, caused an extensive delay in completion of the contract. This delay led to an additional loss of spore viability of the test piece organisms. As a result, test pieces showing the greatest losses were cleaned, reinoculated and exposed to a vacuum of  $10^{-7}$  torr for 72 hours prior to exposure to ethylene oxide. Tests and assays from June through August of 1970 were performed on pieces inoculated and subjected to vacuum one week before exposure to the test conditions. These pieces were inoculated with  $1 \times 10^7$  spores each. Therefore, tests were performed on pieces which had been exposed to vacuum and held under ambient conditions for as much as 9 months prior to ETO exposure and as little as 2 days.



under ambient conditions for as much as 9 months prior to ETO exposure and as little as 2 days.

The number of viable spores remaining after prolonged storage ranged from  $10^1$  to  $10^6$  spores per test piece.

Actual exposure of test pieces was initiated on June 8, 1970, after many weeks of false starts and aborted runs due to chamber, control, instruments and mechanical failures. The problems encountered were due, in part, to the complexity and new design of the system (see Fig. 1-1 and photographs 1-1a, 1-1b, 1-1c, and 1-1d).

Twenty-five complete trials were performed between June 8, 1970 and completion of the final working phase of the contract.

Controls, consisting of stainless steel strips and glass tubes with Morton caps, inoculated with  $1 \times 10^7$  spores and subjected to the  $10^{-7}$  torr vacuum, as previously stated, showed counts ranging from  $1 \times 10^5$  to  $1.5 \times 10^6$  spores when exposed, under dynamic conditions, to a conditioning cycle of humidity and temperature only. Lower counts, before exposure to ETO, were obtained using a conditioning cycle of 50% R.H. and  $50^\circ\text{C}$ , compared to those obtained with a cycle of 40% R.H. and  $40^\circ\text{C}$ .

Table 1-3 indicates that the two most difficult test pieces to decontaminate were capped tubes and capillary tubing but that the number of survivors was reduced by over 4 logs.

Table 1-4 reveals that increasing ETO exposure time to 24 hours, while maintaining the other parameters constant, did not appreciably increase kill rate over the "Best Cycle," which appears in Fig. 1-2.

Table 1-5 indicates the effectiveness of decontaminating plastic materials using the dynamic cycle. Even the poorest results revealed a reduction in viable spores of between 4 and 5 logs.

#### 1.2.2.1 Pertinent Data

- 1) Chamber cost forced the use of manual controls for many operations but the stated parameters of relative humidity, gas concentration, temperature and time were automatically controlled.

Cost also prevented incorporation of certain instruments which would have permitted physical measurement of the gas flow during exposure periods.

- 2) Antimicrobial studies associated with ethylene oxide were terminated during the second quarter of FY '71.
- 3) Ethylene oxide, material compatibility studies were terminated during the first quarter of FY '69.
- 4) Time required to complete contractual requirements, except for the final report was two years.
- 5) Final Technical Report due approximately 15 February 1971.

#### 1.2.2.2 Conclusions

- 1) Stainless steel strips were easiest to decontaminate (Table 1-3).
- 2) Storage at ambient - for extended periods especially after vacuum reduces the number of viable spores and assists decontamination (Fig. 1-3).
- 3) Apparently the dynamic cycle works as well without preconditioning as with it. This part of the cycle could be deleted. Heated humidified gas could be used from the start of the cycle. This was not tried due to lack of funds and time.
- 4) The chamber as designed and fabricated by Blickman leaves much to be desired as far as disposing of the ETO after cycle completion. Apparently the water trap is not large enough to absorb the volume of ETO being vented.
- 5) Based on two static runs, using plastic strips as test pieces, it appears that the dynamic cycle is more efficient in destroying spores than the static cycle under the stated test conditions (Fig. 1-4). The same chamber was used for both static and dynamic cycles. Preconditioning was carried out under 600 torr vacuum. It appears that preconditioning under vacuum while

maintaining dynamic conditions may increase kill potential over the dynamic cycle without vacuum conditioning. Not enough data were generated to make an absolute statement.

- 6) All results and figures presented may be biased in favor of the decontamination cycles by the apparent inefficiency of the sonicators used in the assay procedure.
- 7) At this time it appears that the dynamic ethylene oxide cycle can meet and maintain the conditions required by spacecraft materials and design while reducing the bio-burden to a level consistent with a less stringent dry heat terminal sterilization cycle.
- 8) The dynamic chamber, as fabricated, can be used to determine the biocidal efficiency and physical reactions of all nonexplosive gases under various conditions of temperature, humidity, pressure and vacuum while maintaining static or dynamic conditions.

### 1.2.3 Mechanical Cleaning

The biological effectiveness of low pressure vacuum cleaning was tested on the Mariner '71 proof test model (PTM) after return from the environmental test lab. The assay methods prescribed for the biological monitoring of spacecraft operations\* were conducted before and after cleaning. The following areas were chosen from the surfaces approved for bio-assy:

- 1) Portions of the solar panel back structure
- 2) Portions of the solar panel outriggers
- 3) The top of the canopus sensor box
- 4) The mast of the low gain antenna

Tests were also conducted on sample pieces of aluminized Armalon material used as a meteoroid shield on the Mariner '71 spacecraft, which was exposed to the spacecraft assembly facility environment for a period of two weeks, and on a rope stand near the spacecraft.

---

\*JPL PD610-18, 29 June 1970.

The equipment tested consisted of a conventional cleanroom type vacuum cleaner and various brush attachments commonly used to clean the spacecraft. Brushes and hard-nozzle attachments, with and without an underlying screen, were tested on the Armalon sample material, and on the rope stand.

Some of the problems encountered and important observations made were as follows:

- 1) None of the existing vacuum brushes and nozzles could be used on thin monolayer thermal shielding materials without the risk of tearing or badly creasing the material. Unless very taut, the material was pulled into the nozzle, thus interrupting the vacuum flow.
- 2) On heavier canvas type blanket materials such as the meteoroid shield, inward bulging due to vacuum pressure differential did not seem to harm the material but it did greatly hamper the movement of the cleaning device on the surface, except where the contact area was less than  $1/4 \text{ in}^2$ .
- 3) Best results on the heavy canvas type material were obtained with a  $1/4 \times 1 \ 3/4$  inch nozzle having a rounded lip. This configuration permitted the formation of a large number of small orifices between the nozzle lip and the rippled surface of the blanket material, which in turn, resulted in maximum flow velocity near the surface. The velocity was limited only by the amount of vacuum available. Removal efficiency of up to 90% was observed on samples treated with this type of nozzle.
- 4) The vacuum brushes tested were of the circular type ( $1/2$ , 1 and 2 inch diameter) with nylon and sable bristles installed. Efficiencies up to 86% were measured with nylon brushes. Sable brushes seemed to be slightly better and showed efficiencies up

to 92%. It appeared that not all of the particulates removed from the sample surface were transported into the vacuum system. Apparently a large number were swept aside by the brush. Smoke tests indicated that the radial inward flow travels primarily through the bristles near the brush body and not at the surface where it was needed to reentrain particles loosened from the surface by the brush.

- 5) The primary problem with all brushes tested was the bristles, which were not sufficiently stiff to support pressure against the surface being sampled without excessive buckling and bending. On the large, 2-inch diameter, sable brush, the bristles tended to turn inward and block the air flow (Fig. 1-5). Under these conditions the brush would usually be converted into an unusable ball of hair.
- 6) Prior to each test the brushes were carefully cleaned and wiped with isopropyl alcohol. They became visibly contaminated after a short period of time and particles lodged between the bristles near the root had to be removed by means of a small vacuum nozzle. Under tightly scheduled operational conditions this time-consuming cleaning process would undoubtedly introduce a scheduling problem.
- 7) It was discovered that the bulging of soft surface materials into the vacuum nozzle due to pressure differentials could, in most cases, be avoided by placing a piece of screening material between the surface being sampled and the vacuum nozzle. The use of such a screen seemed also to be advantageous on hard surfaces. When a screen was used, the orifice between the nozzle lip and the surface was positively controlled. Constantly high flow velocities near the surface and a high degree of turbulence were also maintained. Removal efficiency of up to 96% was observed with this method of cleaning on certain hard surfaced facility items, e. g., a chromed rope stand used to rope off the work area.
- 8) The capability of the vacuum cleaners used (although identical and from the same manufacturer) varied quite noticeably. From flow measurements obtained and from literature data on

particle aerodynamics and adhesion, it was calculated that most of the vacuum devices used would have had the capability of removing 20 to 30 micron size or larger particles by flow alone if the proper nozzle design had been employed. For smaller particle sizes, mechanical force, such as brushing has to be applied in order to break the adhesive bond and to entrain particles into the flow.

As a result of these observations, it was decided to redesign the brushes. Major changes include (see Fig. 1-6): Shorter and stiffer bristles, individual bundles of bristles with spaces between to permit easier cleaning and to increase flow and turbulence and additionally, a sharp edged radial flow inlet to reduce the effective orifice. This design forces the flow closer to the surface. The new brushes are presently being used in spacecraft operations to test their practical use. The cleaning efficiency of these brushes has not yet been established.

1.2.3.1 Mechanical Cleaning Problem Areas. The contamination level present on some of the selected spacecraft surfaces was below the sensitivity threshold of the applied assay method. On other surfaces such as the meteoroid shield and on the sampled facility item previously discussed, the contamination level was relatively high, but very nonuniform. Additionally, the surface areas available for sampling were relatively small ( $1/10$  to  $1/4$  ft<sup>2</sup>), therefore, the results obtained, could not be considered conclusive enough to accurately determine or to compare cleaning efficiencies, or to decide on the one most efficient mechanical cleaning method.

1.2.3.2 Mechanical Cleaning, Future Activities. Plans for the remaining six month period are to establish the capability of removing particulates from a smooth level surface by means of vacuum flow, and to determine the correlation between factors affecting this capability. Standard glass slides seeded with 1.1, 7 and 30 micron size test particles and with common dust will be used. Typical nozzle shapes that produce sub-critical, critical and supersonic velocities, and the generation of high surface turbulence by means of an underlying screen between the surface and the nozzle tip will be tested.

The test setup planned is schematically shown in Fig. 1-7. Typical flow conditions existing underneath the tip of a vacuum nozzle can be simulated with this setup in a way that allows a variation of the main parameters under simultaneous observation of the test surface through a microscope.

The data to be obtained are the effect of vacuum, and the number of passes of the nozzle over the surface, in terms of percent removal per particle size. Indirect information such as flow velocities, boundary layer conditions near surface velocity gradients, particle drag and surface adhesion, will be obtained from flow calibration runs with the test setup, and from theoretical evaluations based on particle physics and established aerodynamic relationships.

Upon completion of the above, the task will be directed toward evaluation of the bio-burden reduction efficiency of the following prospective cleaning methods:

- 1) The Lunar Receiving Laboratory (LRL) cleaning process which utilizes a benzene-methanol mixture for the removal of organics.
- 2) A vacuum bake-out procedure such as presently used to clean the interior tracts of mass spectrometers.
- 3) Cold plasma cleaning, utilizing oxygen, carbon dioxide or hydrogen. This procedure has been successfully used to remove organic matter and oily films from optical lenses and from thermal surfaces in order to restore their original properties. It appears, at this time, that the period of exposure required to achieve microbial kill with cold plasma will be relatively short, thereby reducing materials compatibility problems to a minimum.

Table 1-1. Properties of some liquid cleaning and biocidal compounds

Liquid cleaning and biocidal compounds evaluated	Physical <sup>a)</sup> cleaning effectivity	Biocidal efficiency <sup>a)</sup> bacteria, yeasts, molds		Material <sup>a)</sup> compatibility
		Vegetative	Spores	
Methyl Ethyl Ketone	+++	+	--	++
Isopropyl Alcohol	++	+++	+	++
Ethyl Alcohol	+	+++	+	+
Trichloro-Ethylene	+++	--	--	+
Alphatic Naptha	+	--	--	++
Formaldehyde Alcohol	++	+++	+++	--
Alcohol-Iodine	++	+++	++	--
Iodine-Detergent (Aqueous)	++	+++	+	--
Peracetic Acid	+	+++	+++	+
Hexane	+	--	--	+
Dichlorodifluoromethane	+++	--	--	+
Toluene	++	+++	--	+
Acetone	++	+++	--	+
Trichlorotrifluorethane	+++	--	--	+
Benzalkonium Chloride	+	+++	--	+
Synthetic Phenolic	+	+++	+	+

a) Legend:

Cleaning Effectivity: None = --, Slight = +, Moderate = ++, Good = +++

Biocidal Efficiency: Same as above

Compatibility: Incompatible = -, Compatible in isolated cases only = +, Compatibility Limited = ++, Completely compatible in all cases = +++



Table 1-2. Spore assessment of inoculated JPL test pieces during storage

Test piece	Viable spore concentration/test piece						
	January, 1969 Inoculated test pieces			November, 1969 Inoculated test pieces <sup>a/</sup>			
	Initial	After 3 mos.	After 6 mos.	Initial	After Vacuum	After 6 mos.	
Capillary Tubing	$1.1 \times 10^5$	$9.2 \times 10^4$	$1.73 \times 10^2$	-	$3.26 \times 10^5$	$3.2 \times 10^5$	
Glass Tubing	$9.4 \times 10^5$	$8.7 \times 10^5$	-	$6.7 \times 10^5$	$4.41 \times 10^5$	$1.5 \times 10^1$	
Morton Tubes	$1.1 \times 10^6$	$1.1 \times 10^6$	$1.39 \times 10^4$	$1.3 \times 10^6$	$3.16 \times 10^6$	$1.35 \times 10^3$	
Glass Strip	$1.0 \times 10^6$	$1.0 \times 10^6$	-	$8.4 \times 10^5$	$2.84 \times 10^5$	$3.65 \times 10^3$	
Plastic Strip	$1.2 \times 10^6$	$1.1 \times 10^6$	-	$8.2 \times 10^5$	$2.5 \times 10^5$	$1.76 \times 10^3$	
Stainless Steel Strip	$1.2 \times 10^6$	$1.0 \times 10^6$	$8.1 \times 10^4$	$1.1 \times 10^5$	$1.06 \times 10^5$	$1.73 \times 10^4$	

<sup>a/</sup> Replicate sampling showed great variance and inconsistency.

Table 1-3. Mean number of survivors per test piece, based on type of test piece and all dynamic cycles after inoculation with  $1 \times 10^7$  spores 1 week prior to exposure

Test piece	Mean number survivors
Stainless Steel Strips	8.9
Plastic Strips	66.6
Glass Strips	20.4
Glass Tubing	30.0
Morton Capped Tubes	580.5
Capillary Tubing	768.8

Table 1-4. Comparison of dynamic 24 hour cycles-varying temperature relative humidity and ETO concentration

All types of test items included. Each test piece inoculated with  $1 \times 10^7$  B. subtilis var. niger spores one week prior to exposure.

Test conditions*				Mean percent survivors
Temp. °C	R. H.	ETO Conc.	Time (hrs)	
30	30	600	24	$2.9 \times 10^{-2}$
40	40	600	24	$9.5 \times 10^{-3}$
50	50	800	24	$5.1 \times 10^{-4}$

\*Time constraints did not permit variation of one parameter at a time while maintaining the others constant.

Table 1-5. Effect of variation in parameters using plastic strips inoculated with  $1 \times 10^7$  spores inoculated 1 week prior to exposure (dynamic conditions)

Temp, °C	R. H.	ETO Conc, Mg/l	Time (hrs)	Survivors	
				Mean number	Mean percent
30	30	600	24	164.0	$1.6 \times 10^{-3}$
40	40	600	24	157.0	$1.6 \times 10^{-3}$
40	40	800	16	0.6	$6.0 \times 10^{-6}$
40	40	800	24	4.0	$4.0 \times 10^{-5}$
50	30	800	4	10.0	$1.0 \times 10^{-4}$
50	40	800	4	0.6	$6.0 \times 10^{-6}$
50	50	800	16	0.6	$6.0 \times 10^{-6}$
50	50	800	24	3.0	$3.0 \times 10^{-5}$

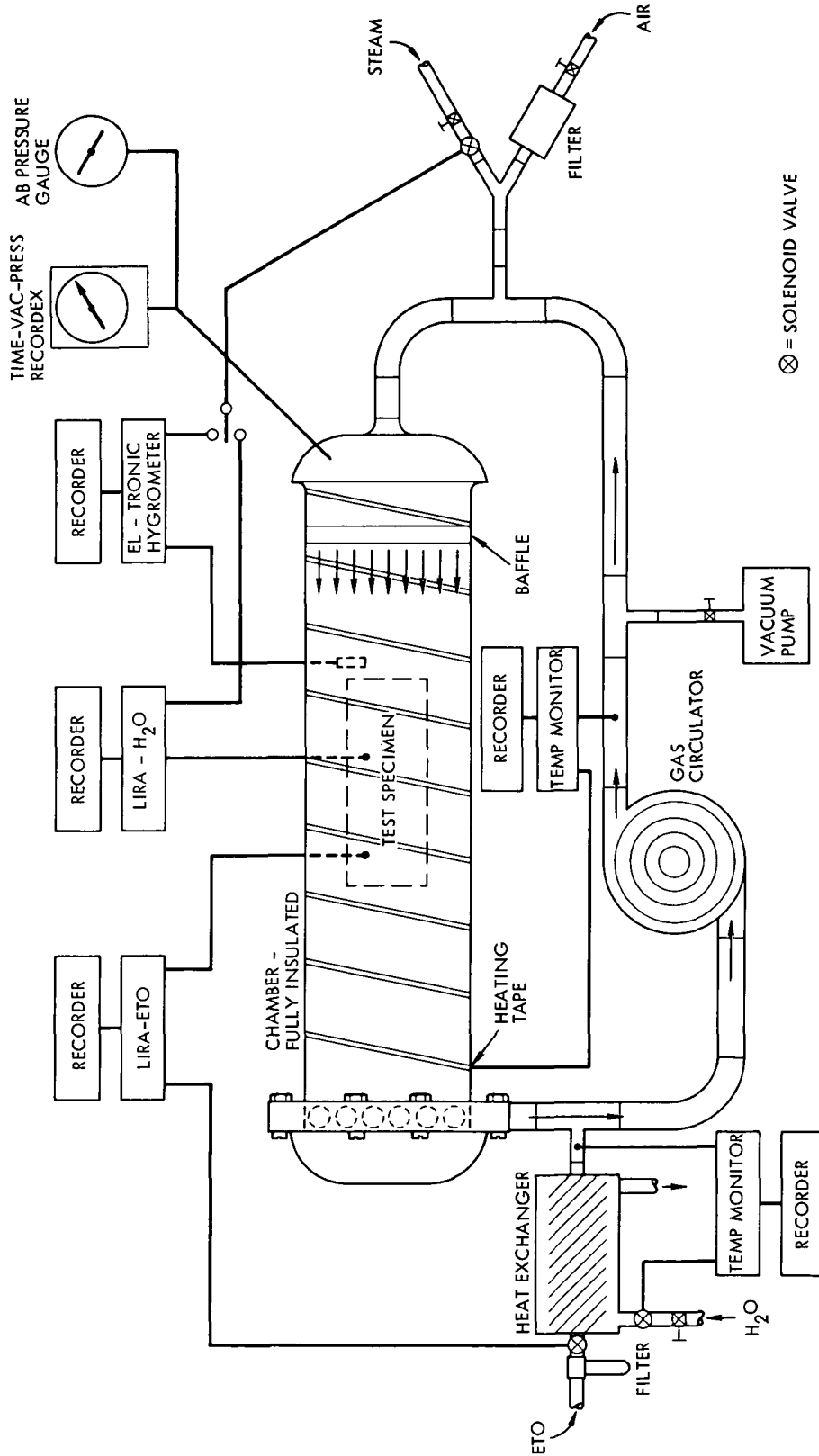


Fig. 1-1. ETO chamber (line drawing)

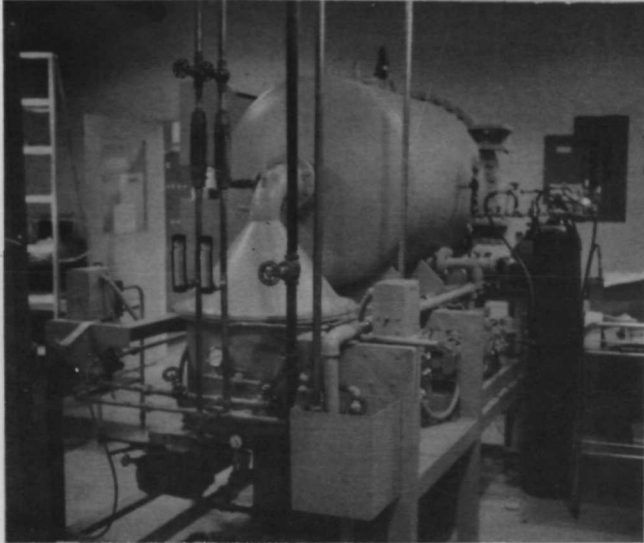


Fig. 1-1a

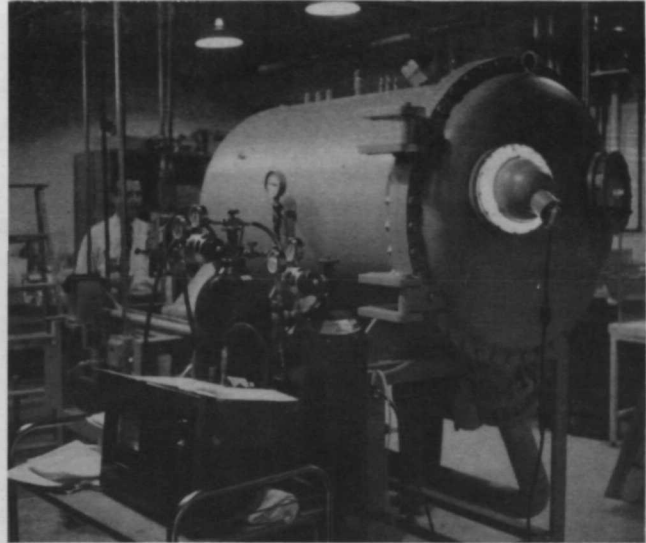


Fig. 1-1b

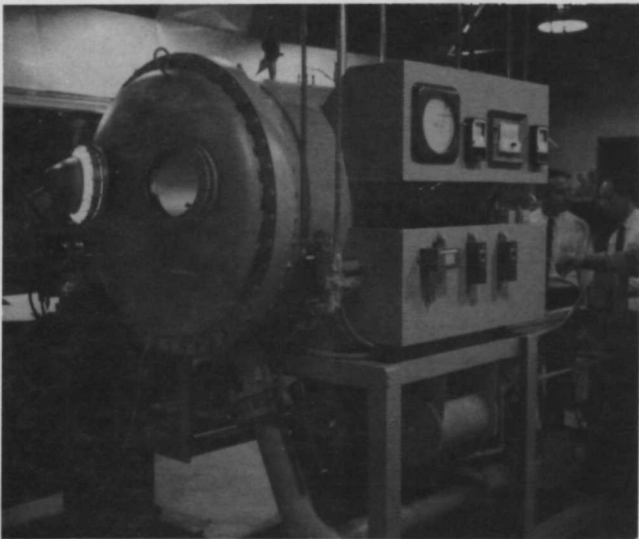


Fig. 1-1c

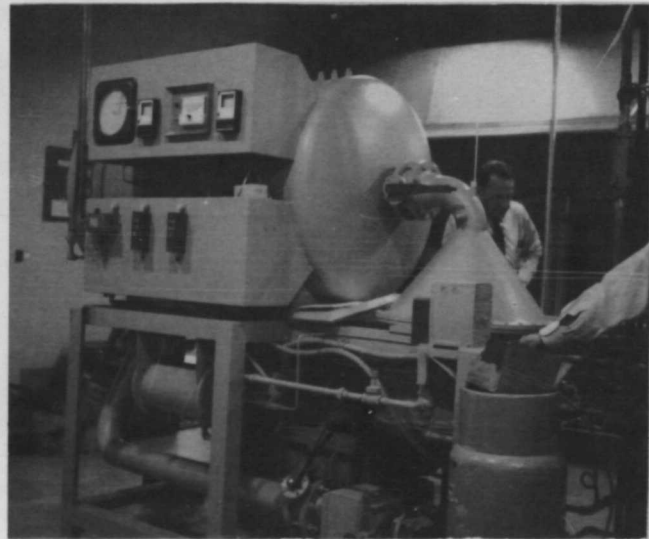


Fig. 1-1d

Fig. 1-1a thru 1-1d. Views of ETO chamber in operation

<u>BEST CYCLE CONSIDERING ALL TEST PIECES</u>	
50°C - 50% R.H. - 800 Mg/l ETO - 16 HOURS EXPOSURE	
<u>RESULTS USING THIS CYCLE</u>	
MEAN NUMBER OF SURVIVORS PER TEST PIECE	4.65
MEAN PERCENT SURVIVORS PER TEST PIECE	$4.6 \times 10^{-4}$

Fig. 1-2. Standard dynamic cycles

MEAN NUMBER OF SURVIVORS - ALL TEST PIECES - ALL CYCLES = 245.6

MEAN PERCENT SURVIVORS =  $2.5 \times 10^{-3}$

STAINLESS STEEL STRIPS INOCULATED WITH  $1 \times 10^6$  SPORES AND EXPOSED TO  
VACUUM OF  $1 \times 10^{-6}$  FOR TWO WEEKS AND STORED AT AMBIENT OVER  
SIX MONTHS

MEAN NUMBER SURVIVORS 3.1 OR  $3.1 \times 10^{-4}\%$

STAINLESS STEEL STRIPS - NON-VACUUM EXPOSED - STORED AT AMBIENT  
OVER SIX MONTHS.

MEAN NUMBER SURVIVORS 52.2 OR  $5.1 \times 10^{-3}\%$

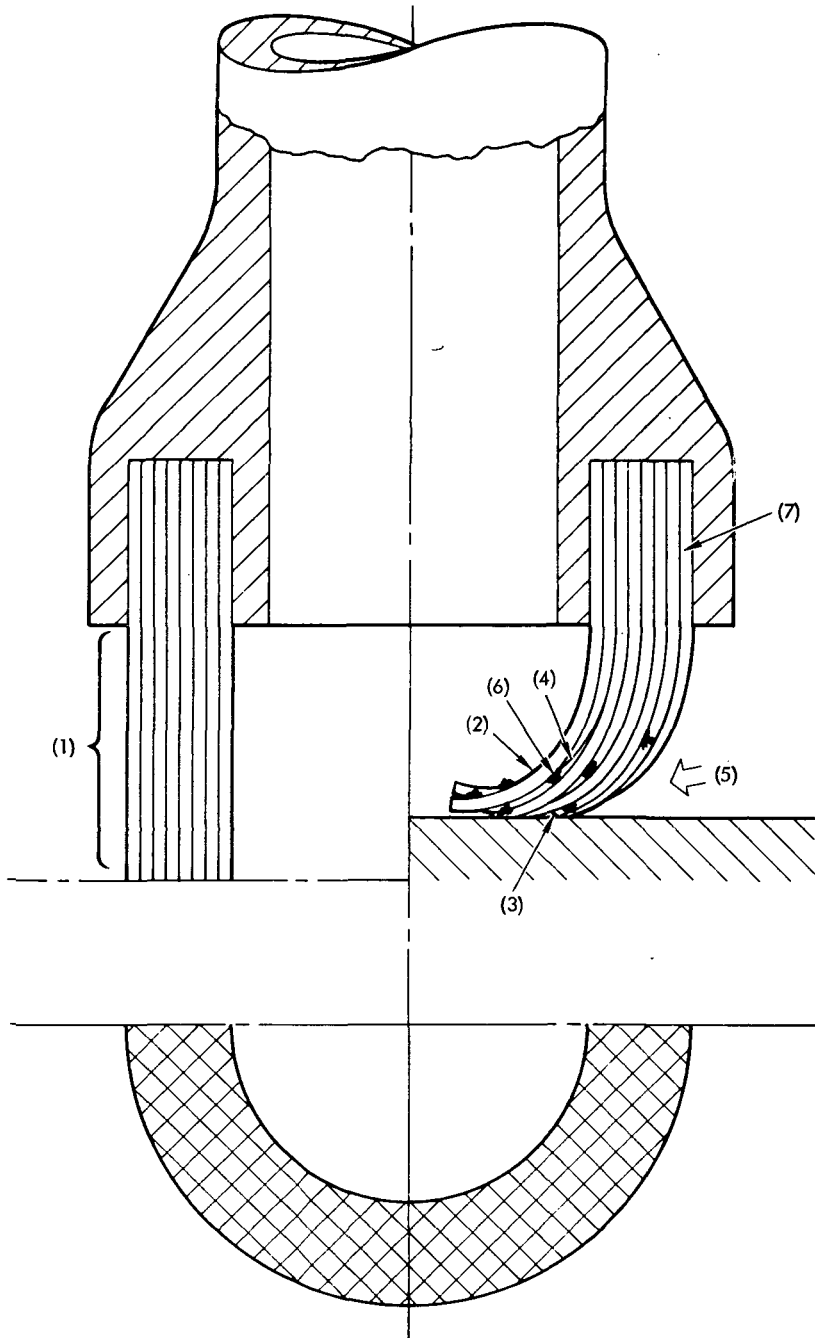
Fig. 1-3. Storage at ambient

TEST PIECES - PLASTIC STRIPS INOCULATED WITH  $1 \times 10^7$  SPORES  
ONE WEEK PRIOR TO EXPOSURE.

<u>CYCLE PARAMETERS:</u>	TEMP.	R.H.	ETO CONC.	TIME
	50°C	50%	400 Mg/L	2 HRS
<u>MEAN PERCENT SURVIVORS</u>				
STATIC CONDITIONS			$7.5 \times 10^{-5}$	
DYNAMIC CONDITIONS			$2.5 \times 10^{-5}$	

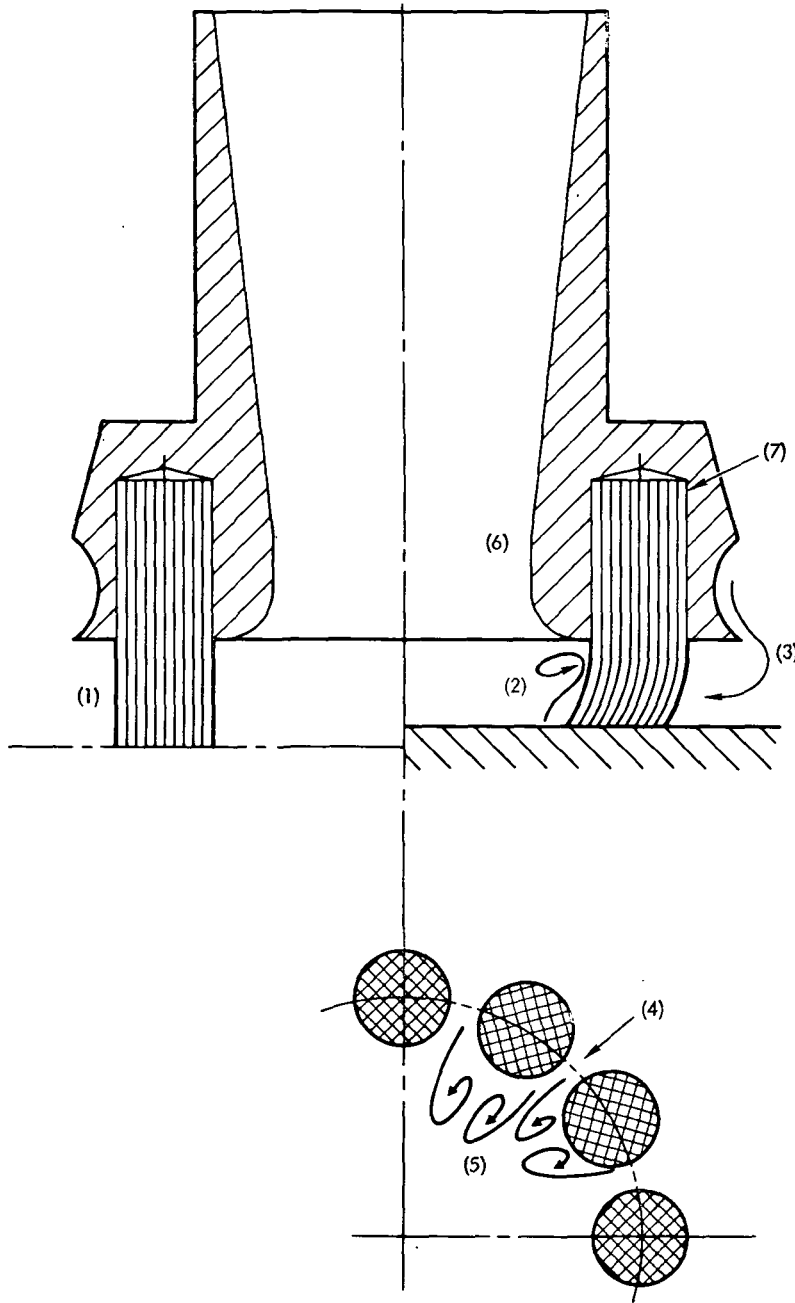
Fig. 1-4. Comparison of static and dynamic cycles with preconditioning under 600 torr vacuum using same chamber





BRISTLES TOO LONG (1) BUCKLE AND BEND INWARD (2) DUE TO PRESSURE AND FLOW. WHISKERS RUB SIDWAYS (3), ENTANGLE (4) AND BLOCK FLOW NEAR SURFACE (5) PARTICLE ENTRAPMENT (6), HARD TO CLEAN. POOR BOND (7), WHISKERS COME LOOSE DURING USE

Fig. 1-5. Deficiencies of old circular vacuum brushes



SHORT BRISTLES (1) LARGER BEARING AREA. NO EXCESSIVE BUCKLING AND BENDING (2) DUE TO PRESSURE AND LOAD. USE OF EDGE EFFECT (3) TO FORCE FLOW CLOSER TO SURFACE. GAPS BETWEEN BRUSHES (4) ALLOW PART OF FLOW TO PASS FREELY AND TO MAINTAIN HIGH FLOW VELOCITIES AND TURBULENCE (5) INSIDE OF BRUSH CIRCLE. STREAM-LINED INTERIOR TRACT (6) STRONGER BOND WITH BRUSH BODY (7)

Fig. 1-6. Design features of improved vacuum brush

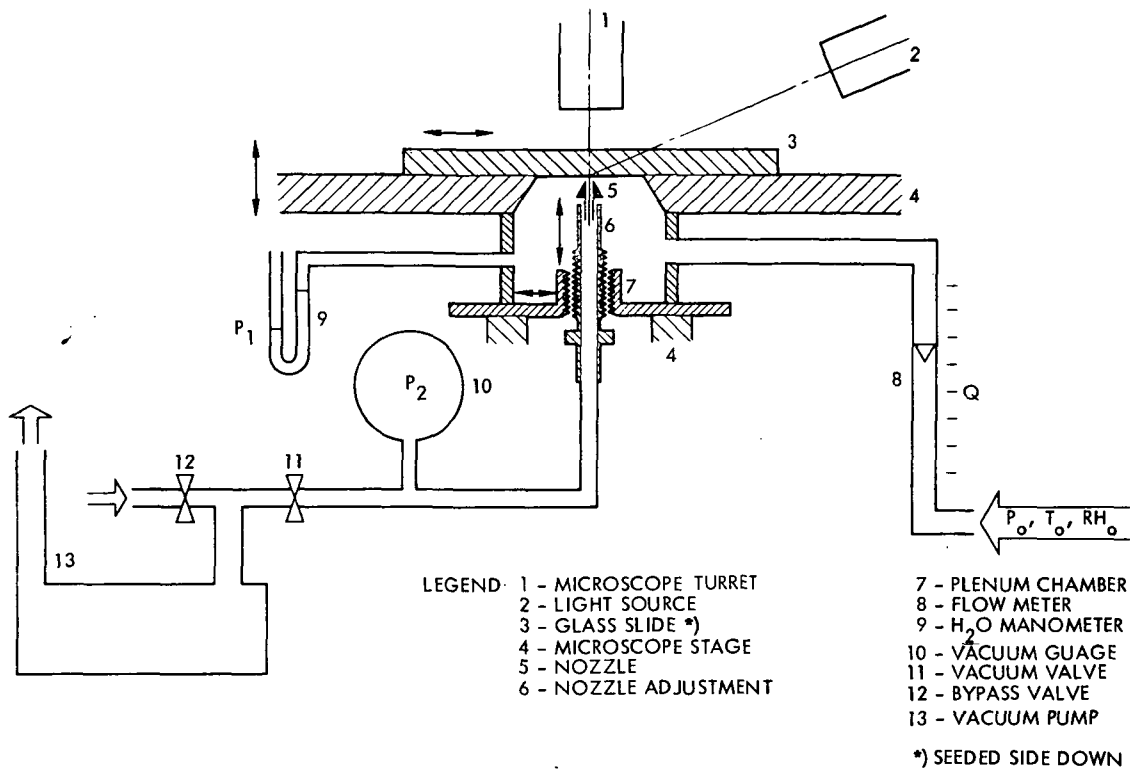


Fig. 1-7. Vacuum flow test, schematic of test set up

900-484

SECTION II  
STUDIES OF SPACECRAFT STERILIZATION PARAMETERS

## SECTION II

## STUDIES OF SPACECRAFT STERILIZATION PARAMETERS

NASA No. 191-58-61-06-55

Cognizance: M. D. Wardle

Associated Personnel: C. Hagen (AVCO), G. Simko (AVCO),  
H. Loo (AVCO), R. MacKay (AVCO), T. Laue

## 2.1 INTRODUCTION

The primary objective of this task area is to acquire the necessary parametric information to define optimum flight acceptance and sterilization processes for space hardware. In line with this goal, the dry heat resistances of microorganisms found on spacecraft surfaces are characterized. In addition, studies are performed to estimate the dry heat resistance of microorganisms between surfaces mated at pressure levels representative of those on flight hardware.

## 2.2 SIGNIFICANT ACCOMPLISHMENTS

## 2.2.1 Tasks and Tests Conducted

2.2.1.1 Thermal Resistance of Microbial Populations Occurring in Hardware Assembly Areas. Results from the dry heat testing of Mariner '69 bacterial spore isolates and environmental populations were compiled in a final report and submitted for publication in the open literature. In addition, dry heat testing of spore isolates recovered from the Mariner '71 spacecraft were started.

At present, twelve spore isolates from Mariner '71 have been dry heat tested and show a  $D_{125^{\circ}\text{C}}$  value range from 13 to 106 minutes (Table 2-1). These initial results appear similar to the range of dry heat resistances detected in populations from Mariner '69.

In conjunction with this task, a cooperative effort has been established between JPL and USPHS (Phoenix) personnel to investigate the heat resistance of naturally occurring microbial populations. Preliminary discussions have been involved with test protocols and the possible relationships existing between

the heat resistance of artificially sporulated Mariner '71 isolates and naturally occurring microbial populations in soil and collected upon stainless steel fallout strips located in spacecraft assembly areas. A test program has been initiated to collect microbial populations in assembly areas at Cape Kennedy and to characterize their dry heat resistances.

2.2.1.2 Study of Surface Mating Pressures and  $D_{125^{\circ}\text{C}}$  Values. Tests were performed to determine the dry heat resistance of Bacillus subtilis var. niger spores placed between stainless steel, aluminum and magnesium surfaces mated with applied pressures of 0, 1,000, 5,000 and 10,000 psig. Experiments were conducted in ambient, nitrogen and helium environments. A final report on this task has been submitted for publication in the open literature.

For experiments conducted with mated stainless steel surfaces in different gaseous environments, it was observed that dry heat resistance in ambient atmosphere was significantly greater than in nitrogen and helium (Table 2-2). Nitrogen and helium appeared equivalent in their effect on heat resistance. Although a pressure effect was evidenced between 0 and 5,000 psig applied pressure in ambient atmosphere, none was noted in nitrogen or helium. An analysis of variance indicated both pressure and gas to be significant sources of variation (Table 2-3). A comparison of Al mated to Mg, with stainless steel to stainless steel, indicated that the Al-Mg system produced a significantly greater heat resistance (Table 2-4). This difference was attributable to a material effect on heat resistance (Table 2-5).

2.2.1.3 Quartz Crystal Microbalance. Tests were conducted to study the various parameters affecting the sensitivity of quartz crystal microbalance mass measurements, i. e., temperature, spore deposition procedures and relative humidity.

Testing revealed a hysteresis phenomenon that occurred when spores were inoculated onto crystal surfaces using a micropipette, and then subjected to a heating and cooling cycle. This source of error was believed to be related to the spore deposition procedure. In an effort to alleviate this problem a technique of crystal seeding using monodisperse aerosols was developed.

Experimentation was also performed to better define the influence of relative humidity on crystal operation. Frequency changes as great as  $10^2$  Hz were found attributable to fluctuating relative humidities (Table 2-6). Measurements of spore masses (and subsequent conversion to numbers of spores) in a vacuum at constant temperature and relative humidity showed the quartz crystal microbalance to be highly efficient when compared to other methods of spore enumeration (Table 2-7).

### 2.2.2 Relevance to Planetary Quarantine

This task area will provide the NASA Planetary Program with necessary parametric information for flight acceptance guidelines and terminal sterilization process calculations. The study of the thermal resistance of assembly area microbial populations points to the urgency of a reconsideration of the dry heat resistance parameter for populations naturally occurring in such areas. In particular, efforts must be made to come to a majority opinion on the natural heat resistance of these populations. The mated surface study has indicated that the dry heat resistance of Bacillus subtilis var. niger does not exceed the guidelines stipulated by NASA (Planetary quarantine provisions for unmanned planetary missions, NHB 8020.12) for sterilization of unmanned spacecraft. However, this parameter should be validated with a study of isolates from populations found on flight spacecraft. The quartz crystal microbalance has proved a unique tool that with further research would aid in the elucidation of the mechanics of dry heat kill.

## 2.3 FUTURE ACTIVITIES

### 2.3.1 Thermal Resistance of Microbial Populations Occurring in Hardware Assembly Areas

Additional isolates will be acquired during the Mariner-Mars 1971 microbiological monitoring program, and a  $D_{125^{\circ}\text{C}}$  value will be determined for all isolates in both ambient and nitrogen atmospheres. A study will be initiated to investigate the effect of long heat ramps (as would be used for real time spacecraft sterilization procedures) on the dry heat resistance of spores equilibrated to a range of relative humidities. The program will also include experiments to estimate the dry heat resistance of noncultured, naturally

occurring microbial populations to be collected at Cape Kennedy and relate them to D values of cultured isolates.

2.3.2 Study of Mating Pressures and  $D_{125^{\circ}\text{C}}$  Values

No future activities planned.

2.3.3 Quartz Crystal Microbalance

No future activities planned.

2.4 PUBLICATIONS

- 1) Wardle, M. D., Brewer, W. A., and Peterson, M. L., 1971. Dry Heat Resistance of Bacterial Spores Recovered from Mariner-Mars 1969 Spacecraft. To appear in Applied Microbiology, May 1971.
- 2) Simko, G. J., Devlin, J. D., and Wardle, M. D., 1971. Dry Heat Resistance of Bacillus subtilis var. niger spores on Mated Surfaces. Applied Microbiology (Submitted).
- 3) Laue, T. and Wardle, M. D., 1971. A Quartz Crystal Microbalance for Mass Measurements of Bacterial Spores. JPL document (in preparation).



Table 2-1. Dry heat resistance of Mariner '71 aerobic spore isolates cultured in a liquid synthetic sporulation medium

Isolate number	$D_{125^{\circ}\text{C}}$	95% Confidence limits	R(sq)	Remarks
1	24.25	22.64 - 26.11	0.939	PTM isolate pre-solar simulation
2	26.66	24.56 - 29.15	0.959	PTM isolate pre-solar simulation
3	24.32	20.94 - 29.00	0.823	PTM isolate pre-solar simulation
4	12.75	11.21 - 14.79	0.900	PTM isolate pre-solar simulation
5	19.59	16.82 - 23.45	0.862	PTM isolate pre-solar simulation
6	27.23	25.59 - 29.10	0.967	PTM isolate post-solar simulation
7	19.78	18.07 - 21.84	0.932	PTM isolate post-solar simulation
8	18.59	17.17 - 20.28	0.961	PTM isolate post-solar simulation
9	106.37	99.23 - 114.68	0.927	PTM isolate post-solar simulation
10	75.98	70.41 - 82.51	0.913	PTM isolate post-solar simulation
11	66.33	61.35 - 72.19	0.909	PTM isolate post-solar simulation
12	72.81	68.08 - 78.25	0.931	PTM isolate post-solar simulation

Table 2-2.  $D_{125^{\circ}\text{C}}$  values (min) for Bacillus subtilis var. niger spores on stainless steel in selected atmospheres<sup>a, b</sup>

Atmosphere	Applied pressure (psi)				
	0	1,000	5,000	10,000	Average
Air	27.98 <sub>bc</sub>	30.27 <sub>ab</sub>	39.65 <sub>a</sub>	40.67 <sub>a</sub>	34.64 <sub>d</sub>
Nitrogen	17.05 <sub>c</sub>	19.58 <sub>bc</sub>	28.36 <sub>bc</sub>	25.97 <sub>bc</sub>	22.74 <sub>e</sub>
Helium	18.73 <sub>bc</sub>	17.34 <sub>c</sub>	20.77 <sub>bc</sub>	24.30 <sub>bc</sub>	20.29 <sub>e</sub>
Average	21.02 <sub>f</sub>	22.40 <sub>f</sub>	29.59 <sub>g</sub>	30.31 <sub>g</sub>	

<sup>a</sup>D values are averages of three determinations.

<sup>b</sup>Mean  $D_{125^{\circ}\text{C}}$  values subscripted with any identical letter(s) are not significantly different ( $P < 0.01$ ).

Table 2-3. Analysis of variance for stainless steel system in selected atmospheres<sup>a</sup>

Source of variation	F-ratio
Replication	0.184
Gas (G)	34.98*
Pressure (P)	10.00*
G x P	0.824

<sup>a</sup>F-ratios followed by an asterisk are significant ( $P < 0.01$ )

Table 2-4. Comparison of  $D_{125^{\circ}\text{C}}$  values (min) for Bacillus subtilis var. niger spores on Al-Mg and stainless steel - stainless steel mated surfaces in nitrogen<sup>a, b</sup>

Materials	Applied pressure (psi)				Average
	0	1,000	5,000	10,000	
Aluminum mated to magnesium	44.26 <sub>abc</sub>	37.02 <sub>bcd</sub>	51.42 <sub>ab</sub>	56.92 <sub>a</sub>	47.41 <sub>f</sub>
Stainless steel mated to stainless steel	17.05 <sub>e</sub>	19.58 <sub>e</sub>	28.36 <sub>cde</sub>	25.97 <sub>de</sub>	22.74 <sub>g</sub>
Average	30.66 <sub>h</sub>	28.30 <sub>h</sub>	39.89 <sub>i</sub>	41.45 <sub>i</sub>	

<sup>a</sup>D values are averages of three determinations.

<sup>b</sup>Mean  $D_{125^{\circ}\text{C}}$  values subscripted with any identical letter(s) are not significantly different ( $P < 0.01$ ).

Table 2-5. Analysis of variance for Al-Mg vs stainless steel - stainless steel systems in nitrogen<sup>a</sup>

Source of variation	F-ratio
Replication	0.617
Material (M)	88.29*
Pressure (P)	6.97*
M x P	1.22

<sup>a</sup>F-ratios followed by an asterisk are significant ( $P < 0.01$ ).

Table 2-6. Effect of Dry Nitrogen, 62% relative humidity (RH) cycles on crystal frequency (F)

Crystal number	$\Delta F$ (Hz)	
	(GN <sub>2</sub> to 62% RH)	(62% RH to GN <sub>2</sub> )
1	103.3	78.4
2	112.9	100.4
3	112.3	96.7
4	76.0	87.5
5	65.7	30.6
6	78.0	65.3
7	151.1	70.0
8	76.0	69.9

Table 2-7. Bacterial spore masses as measured using the eight quartz crystal microbalance and independent methods

Test number	Mean number of spores detected <sup>a</sup> (95% confidence limits)				Counting chamber
	Quartz crystal microbalance <sup>b</sup>	Test crystal plate count	Control crystal plate count	Control crystal plate count	
1	5.32 x 10 <sup>6</sup> (4.81 - 5.80 x 10 <sup>6</sup> )	1.11 x 10 <sup>7</sup> (0.915 - 1.305 x 10 <sup>7</sup> )	1.45 x 10 <sup>7</sup> (1.000 - 1.090 x 10 <sup>7</sup> )	2.40 x 10 <sup>7</sup> (2.192 - 2.608 x 10 <sup>7</sup> )	
2	5.45 x 10 <sup>6</sup> (4.85 - 6.05 x 10 <sup>6</sup> )	1.14 x 10 <sup>7</sup> (1.034 - 1.246 x 10 <sup>7</sup> )	1.080 x 10 <sup>7</sup> (0.686 - 1.474 x 10 <sup>7</sup> )	2.34 x 10 <sup>7</sup> (1.944 x 2.736 x 10 <sup>7</sup> )	
3	7.05 x 10 <sup>6</sup> <sup>c</sup> (6.35 - 7.14 x 10 <sup>6</sup> )	1.18 x 10 <sup>7</sup> (1.046 - 1.314 x 10 <sup>7</sup> )	1.16 x 10 <sup>7</sup> (0.528 - 1.792 x 10 <sup>7</sup> )	2.86 x 10 <sup>7</sup> (2.057 - 3.115 x 10 <sup>7</sup> )	
4	5.40 x 10 <sup>6</sup> (4.66 - 6.13 x 10 <sup>6</sup> )	1.22 x 10 <sup>7</sup> (1.047 - 1.393 x 10 <sup>7</sup> )	1.22 x 10 <sup>7</sup> (1.068 - 1.742 x 10 <sup>7</sup> )	2.86 x 10 <sup>7</sup> (2.031 - 3.041 x 10 <sup>7</sup> )	

<sup>a</sup> Each test consisted of six replications.

<sup>b</sup> Mass detected was converted to numbers of spores.

<sup>c</sup> Air conditioner breakdown leading to fluctuating temperature.

SECTION III  
NATURAL SPACE ENVIRONMENTAL STUDIES

## SECTION III

## NATURAL SPACE ENVIRONMENTAL STUDIES

NASA No. 191-58-62-04-55

Cognizance: D. M. Taylor - M. Knittel

Associated Personnel: C. Hagen (AVCO), R. L. Olsen (BOEING)

## 3.1 INTRODUCTION

The natural Space Environment Studies seeks to determine the probability of survival of microorganisms during exposure to such environments of space as: launch vacuum profile, vacuum and heat, and irradiation. Further, the work is directed toward the understanding of the probability of release from interiors of solids by simulated spacecraft impact and aeolian erosion and, if released, the probability of growth of the microorganisms in the environment of a particular planet.

## 3.2 SIGNIFICANT ACCOMPLISHMENTS

## 3.2.1 Effect of Launch Pressure Profile on Survival

The test matrix for the launch vacuum studies is near completion. A total of 24 bacterial cultures isolated from the MM'71 spacecraft during routine monitoring, have been subjected to a change in pressure from 760 torr to  $1 \times 10^{-5}$  torr in a 12 minute period (see fig. 3-1). These 24 cultures consist of 6 gram positive cocci and 18 sporeforming rods. The sporeforming rods were isolated from the heat shocked and nonheat shocked plating procedures and are used as spore preparations.

The results thus far show that the above pressure change can cause up to a 10 percent reduction in viable numbers of spores and up to a 50 percent reduction in numbers of surviving nonsporeforming bacteria.

## 3.2.2 Effect of Ultra-High Vacuum and Heat on Survival of Bacteria

The study has included not only the effect of vacuum on survival of bacteria but also the effect of temperature by placing the culture holders in a thermal gradient bar which causes a gradient in temperature from -105C to 59C.

Cultures are dried on the holders and placed into the bar and this assembly placed into the vacuum chamber. The chamber is pumped to a pressure of  $10^{-10}$  torr. The cultures have been left in the chamber for 14 days and some up to 28 days.

The results show that spores of Bacillus subtilis var. niger survive well in vacuum when the temperature is below 59C. Ninety two percent of the initial population are recovered after 14 days at 28C (see Fig. 3-2). When the temperature is 59C only 31 percent survive the temperature and vacuum.

Nonsporeforming bacterial cells are more effected by the vacuum (Fig. 3-2) and temperature than bacterial spores. When cells of Staphylococcus epidermidis were exposed to vacuum ( $10^{-11}$  torr) and a temperature of 60C for 14 days, a 99 percent reduction in numbers of viable cells was observed. Temperatures less than 60C resulted in greater survival after 14 days exposure; for example, at 30C an 89 percent reduction was observed, while at -105C the lethality was increased to 80 percent of the initial population. A similar survival profile of a Micrococcus sp. was observed under the same conditions.

### 3.2.3 Effect of Space Radiation on Survival of Microorganisms

The objective of this study is to determine the lethality of radiation, in the natural space environment, on microorganisms associated with an unsterilized spacecraft. The radiation sources that will be considered are from the space environment, trapped belts surrounding planets, and radioisotope thermal generators (RTG) proposed for advanced outer planet missions.

The accomplishment to date has been to define the study. This has included the development of the philosophy and approach, scope of the study and an analysis of the type and quantity of radiation from the sources that are of major concern to planetary quarantine (PQ).

3.2.3.1 Philosophy and Approach. To maximize the amount of information for use in PQ Analysis, the following philosophy and approach was developed. First, the information needed for PQ Analysis is "what is the probability that a viable organism on the surface or within a spacecraft will survive irradiation in the space environment from all radiation sources?" This question could be answered by exposing spacecraft contaminants to all the radiation present on a



proposed mission to some planet. This direct approach has many disadvantages. The disadvantages are:

- 1) Irradiation levels are defined only within limits and actual levels are unknown.
- 2) Types and levels surrounding a planet are trajectory dependent.
- 3) Not all surfaces of a spacecraft will have the same irradiation exposure.
- 4) The total energy and flux of each type of radiation in combination would have to be studied.

Without the first three disadvantages, the fourth requirement would be almost impossible to simulate.

Therefore, the philosophy developed for this study is as follows: "The information needed for PQ Analysis is the effect of the total radiation dose acquired from the space environment and the method by which this effect can be calculated (within limits) for any proposed mission and spacecraft surface." Answers to the following questions are required:

- 1) Is the survival of microorganisms the same if they are irradiated with different types of radiation at the same level of exposure?
- 2) Is the survival of microorganisms the same if they are irradiated with different energies of the same particle when total exposure and rate are the same?
- 3) What is the survival of microorganisms at different levels of exposure?
- 4) What is the effect of dose rate on survival?
- 5) What is the frequency distribution of radiation resistance of spacecraft contaminants?

The approach developed as the result of the above philosophy requires conducting the following series of tests.

- 1) Conduct a series of tests, with each type of radiation with different particle energies where rate and total exposure are held constant.

- 2) Conduct a series of tests with each type of radiation with the same particle energy and rate but different total exposures.
- 3) Conduct a series of tests with each type of radiation with the same particle energy and total exposure but at different rates (fluxes).

Thus, with each type of radiation, the effect of varying particle energy, rate and total exposure will be evaluated.

3.2.3.2 Scope of Study. The present study is being limited to an evaluation of the radiation belt surrounding Jupiter, solar winds, and the proposed RTG energy source. The study will include the effect of electrons, protons, neutrons, and gamma radiation. An evaluation of the 3 Kev protons in the natural space environment is also included in the task. This energy of protons is considered to be a major constituent in the solar winds.

The microorganisms to be tested are isolates from the Mariner '71 spacecraft. A random selection of three nonsporeformer and nine spore isolates will be used. A sporeformer (B. subtilis var. niger) and nonsporeformer (Staphylococcus epidermidis) will serve as control cultures. The test isolates will be selected from those isolates showing the highest percent survival from the "Survival of Microorganism During Simulated Launch Profile Study." The organisms will not be exposed to irradiation in simulated space vacuum but the vacuum will be limited to a range of  $10^{-6}$  torr due to the limitations of proton sources. The organisms will be exposed to two temperatures. Low temperature exposure of -20C will be included since the survival of microorganism in vacuum is greater at low temperatures (space vacuum studies) and a temperature of 20C will be included to determine if the effect of irradiation on survival is temperature dependent.

3.2.3.3 Analysis of Space and Planetary Radiation. The analysis of the types and quantity of radiation in space and planetary environments were conducted with the support of the Natural Space Environmental Group, Section 294 at JPL. The models for the Jupiter trapped radiation belts were taken from the draft of NASA Space Vehicle Design Criteria Monograph, "The Planet Jupiter (1970)" to be published as a NASA SP-80XX. The predicted time that a flyby spacecraft would be in the Jupiter belt is based on mission strategies used by TOPS.

The models for the predicted electrons and protons in the Jupiter radiation belt are presented in Table 3-1 and 3-2 with the corresponding dosage rates based on absorption in carbon. As shown in Table 3-2, there is not a minimum model for protons. This is due to the lack of direct evidence for the existence of protons in the belt.

The time a spacecraft would be exposed to the radiation belts for two typical outer planet missions is given in Table 3-3 for electrons and Table 3-4 for protons. As can be seen from the data the amount of irradiation exposure is a function of the distance the spacecraft is from the planet.

The total dosage from each radiation source based on the models both for the amount and distribution from the two typical flyby missions are given in Tables 3-5 and 3-6. No calculations have been made at this time for Jupiter orbiters or probe missions but, as can be seen from the data, total dose would be much higher.

3.2.3.4 Radiation Test Vacuum Equipment. The chamber, formed by a combination of attached T's and constructed from 304 stainless steel with an inside diameter of 6.08 in. is shown in Fig. 3-3. The face plates, or flanges, were constructed from 6061 T6 aluminum, Fig. 3-4. The test fixtures, made from 1/4 in aluminum, were mounted to the flanges. The thermal electric coolers, placed between the test fixture and flange, controlled differential temperatures across the test fixtures so that one fixture was maintained at +20°C while the other fixture was maintained at -20°C. The temperatures were monitored with nine copper constantan thermocouples for each flange. The aluminum platforms that contained the suspensions of bacteria were placed into the test fixtures and were secured by means of allen set screws.

The chamber operation utilized a mechanical roughing pump to evacuate the chamber to the 10-40 micron pressure range after which the oil diffusion pump (200 liters/sec capacity) was started. A liquid nitrogen trap and a tube baffle system minimized the backstreaming of oil. The temperature controllers were activated simultaneously with the chamber evacuation. Within 15 min the chamber pressure was in the  $10^{-6}$  torr range and the +20°C and -20°C temperatures were established. At the conclusion of an experiment the chamber was back filled to ambient pressure (760 torr) with dry nitrogen.

### 3.2.4 Release of Microorganisms from Solid Materials

A current contract (JPL Contract No. 952916) is being conducted to obtain information on specific planetary quarantine events that were identified during the previous contract, "Release of Microorganisms from Solids After Simulated Hard Landings," (JPL Contract No. 952511). The previous contract furnished information on the percentage of spores released from the interiors of methyl methacrylate and epoxy (Eccobond) pellets after hard impact onto stainless steel. Impact of methyl methacrylate into sand was also investigated. The methyl methacrylate data showed the percentage of spore release to be less than 1 percent at the four impact velocities tested. An exception to this release percentage was observed in the epoxy results. The current contract was undertaken to investigate the observed percentage release difference in the two materials and to study the effects of aeolian erosion on viable microbial release from solids. The current contract is divided into three phases.

3.2.4.1 Results of Current Contract. Phase I of the current contract was initiated to determine the efficiency of a grinding technique for releasing viable microorganisms from the interiors of inoculated Eccobond pellets. Microbial release data was obtained by dissolving and grinding inoculated methyl methacrylate and comparing these data with release data obtained from grinding inoculated Eccobond. This comparison technique provided required information from which an efficiency factor for grinding could be calculated. This phase has been completed and a preliminary data analysis has been made.

Phase II was conducted to determine the number of bacterial spores released from inoculated Eccobond after hard impact into sand. The data from this phase was required to supplement the hard impact release data obtained on the previous contract with respect to material effects. This phase has been completed and a preliminary analysis of the data has been made.

Phase III has been started to study the effects of aeolian erosion on the release of microorganisms from solid materials. Inoculated methyl methacrylate and Eccobond are being eroded with sand accelerated at three velocities. Data will be available for use in determining the probability of microbial release due to this erosion process.

3.2.4.2 Examination of Contract Work. A preliminary estimate of the grinding efficiency factor (Phase I) has been made at 1.3 logs. This means that 1.3 logs more viable microorganisms are present in Eccobond pellets than the previous assay method showed. This factor will provide a means for adjusting microbial impact release data obtained on this and the previous contract. It also appears that a closer examination of the data will provide information on particle size with respect to release. This latter examination will be made at the end of the contract during final data analysis.

A preliminary examination of the Phase II results show release of microorganisms from Eccobond impacted on sand to be:

0.27 percent at 550 ft/sec  
6.1 percent at 1500 ft/sec  
4.7 percent at 3100 ft/sec  
6.9 percent at 5000 ft/sec

These data are comparable to the methyl methacrylate data previously obtained in that, generally, a lower percentage of viable microbial release is obtained on sand impact than on stainless steel. These data have not as yet been adjusted using the grinding efficiency factor obtained during Phase I.

Material differences appear to be present when all impact data are compared. These preliminary observations remains to be confirmed during final data analysis at the end of the contract.

Sufficient data are not available in Phase III, aeolian erosion, to draw any conclusions. This work is in progress.

### 3.2.5 Probability of Growth

Each planet in our solar system has a unique environmental makeup with all of the factors of this environment which, integrated together, could limit the growth of a microorganism that might reach one of their surfaces. Until now the approach has been to simulate these environments and expose microorganisms in these simulated environments and determine if they could survive or grow. Experiments of this type are planet specific and very difficult, with many variables to control. In addition, as more information becomes

available on a planet, the parameters often change invalidating the earlier work. To circumvent this problem, an analytical task has been initiated to develop a parametric approach to determine the probability of survival and growth.

The test plan for this task has been formulated during this reporting period. The important parameters of the planets; such as temperature, amount of water, and atmospheric pressure, will be used to determine minimum and maximum values for growth of microorganisms. Then, by using the numbers of microorganisms that grow at each value of the parameter between the minimum and maximum values, it will be possible to construct distribution curves for each of the parameters. These distribution curves can then be applied to the values that are known about the particular planet in question to determine if the environment is such to support the growth of microorganisms.

### 3.3 PROBLEMS

There were only minor problems that occurred during this reporting period.

### 3.4 FUTURE ACTIVITIES

Launch vacuum profile test matrix will be completed in the next few weeks and an evaluation of the data will be performed. A few additional vacuum profile determinations will be made beyond the test matrix to confirm the data or to include other test organisms.

#### 3.4.1 Survival of Microorganisms

Survival of Microorganisms in ultra-vacuum will start the task of exposing selected survivors of the launch vacuum test to be a long term exposure; up to 6 months to ultra-high vacuum. The purpose is to learn if long term exposure to vacuum and temperature has any added effect on reduction in numbers of survivors beyond what has been found during the 28 day exposure.

#### 3.4.2 Exposure of Microorganisms

The exposure of microorganisms to deep space irradiation will begin during the next six months. The same test organisms used during the launch profile and irradiation tests will be used in this study.

### 3.4.3 Probability of Growth

The probability of growth of microorganisms in other planet environments study will concentrate on gathering together the available published data about the maximum and minimum limits of growth for the important planet environmental parameters. The completion of this task will be followed by the construction of distribution curves for the numbers of microorganisms capable of growing within these limits.

### 3.5 PUBLICATIONS

An abstract has been approved and accepted for presentation at the annual meeting of the American Society for Microbiology.

Knittel, M. D., Godfrey, J. F., Hagen, C. A., and Taylor, D. M.; "Survival of Spores and Nonsporeforming Bacteria During Simulation of a Launch Vacuum Profile".

Knittel, M. D., Favero, M. F., and Green, R. H., "Microbiological Examination of Electrical Cable from Surveyor III". Paper presented before Second Annual Lunar Conference, Houston, Texas, January 1971. Published in proceedings.

Green, R. H., Biologische Schutzmassnahmen in der Raumfahrt der USA, Arch. fur Hygiene and Bakteriologie 154 3 (1970) 286-298

Green, R. H., Biologische Schutzmassnahmen in der Raumfahrt der USA Prophylaxe 9 Jahrgang - 1970. Heft 7-Juli. (condensed version of above).

Green, R. H., Taylor, D. M., Gustan, E. A., Fraser, S. T., and Olson, R. L., "Survival of Microorganisms in a Simulated Martian Environment," Space Life Sciences 11 (1970) 111-222. D. Reidel Publishing Company, Dordrecht - Holland.

Table 3-1. Electron flux models for Jupiter trapped radiation belt

E(Mev) Interval	Maximum model		Nominal model		Minimum model	
	Flux (e/cm <sup>2</sup> sec)	Dose rate (rad (c)/hr)	Flux (e/cm <sup>2</sup> sec)	Dose rate (rad (c)/hr)	Flux (e/cm <sup>2</sup> sec)	Dose rate (rad (c)/hr)
1-3	5.5 x 10 <sup>5</sup>	5.1 x 10 <sup>1</sup>	1.4 x 10 <sup>6</sup>	1.4 x 10 <sup>2</sup>	2.2 x 10 <sup>6</sup>	2.2 x 10 <sup>2</sup>
3-10	4.9 x 10 <sup>6</sup>	5.7 x 10 <sup>2</sup>	7.4 x 10 <sup>6</sup>	8.7 x 10 <sup>2</sup>	2.9 x 10 <sup>6</sup>	3.4 x 10 <sup>2</sup>
10-30	2.2 x 10 <sup>7</sup>	3.1 x 10 <sup>3</sup>	9.0 x 10 <sup>6</sup>	1.3 x 10 <sup>3</sup>	1.9 x 10 <sup>5</sup>	2.7 x 10 <sup>1</sup>
30-100	3.2 x 10 <sup>7</sup>	7.8 x 10 <sup>3</sup>	8.7 x 10 <sup>5</sup>	2.1 x 10 <sup>2</sup>	---	---
100-300	3.5 x 10 <sup>6</sup>	1.4 x 10 <sup>3</sup>	---	---	---	---

Table 3-2. Proton flux models for Jupiter trapped radiation belt

E (Mev)	Maximum		Nominal	
	Flux (e/cm <sup>2</sup> sec)	Dose (rad (c)/hr)	Flux (e/cm <sup>2</sup> sec)	Dose (rad (c)/hr)
1-3	2.8 x 10 <sup>6</sup>	1.8 x 10 <sup>4</sup>	5.4 x 10 <sup>3</sup>	3.5 x 10 <sup>1</sup>
3-10	1.2 x 10 <sup>7</sup>	4.2 x 10 <sup>4</sup>	9.6 x 10 <sup>4</sup>	3.3 x 10 <sup>2</sup>
10-30	4.4 x 10 <sup>6</sup>	5.2 x 10 <sup>3</sup>	8.8 x 10 <sup>5</sup>	1.2 x 10 <sup>3</sup>
30-100	1.8 x 10 <sup>4</sup>	1.1 x 10 <sup>1</sup>	3.7 x 10 <sup>6</sup>	1.8 x 10 <sup>3</sup>
100-300	---	---	1.5 x 10 <sup>6</sup>	3.1 x 10 <sup>2</sup>



Table 3-3. Duration in electron radiation belt for Jupiter flyby missions

Mission	Periapsis (Rj)	Duration, hr		
		Maximum	Nominal	Minimum
1977 JSP	4.2	2.5	$8.0 \times 10^{-2}$	$5.6 \times 10^{-2}$
1979 JUN	10.3	1.0	$7.0 \times 10^{-3}$	$8.3 \times 10^{-4}$

Table 3-4. Duration in proton radiation belt for Jupiter flyby missions

Mission	Periapsis (Rj)	Duration, hr		
		Maximum	Nominal	Minimum
1977 JSP	4.2	19.0	$8.0 \times 10^{-2}$	$1.2 \times 10^{-2}$
1979 JUN	10.3	19.0	$7.0 \times 10^{-3}$	0

Table 3-5. Electron doses for Jupiter flyby missions

Mission	1-3 Mev			3-10 Mev			10-30 Mev			> 30 Mev		
	Max	Nom	Min	Max	Nom	Min	Max	Nom	Min	Max	Nom	Min
1977 JSP 4.2 Rj												
Max	13.75*	350.00	550.00	1425.00	2175.00	850.00	7750.00	3250.00	6.75	23000.00	525.00	---
Nom	0.44	11.20	17.60	45.60	69.60	27.20	248.00	104.00	0.22	736.00	16.80	---
Min	0.31	7.48	12.32	31.92	48.72	19.04	173.60	72.80	0.15	515.20	11.76	---
Average	4.83	123.01 (107.60)	193.33	500.84	764.44 (521.34)	298.75	2723.87	1142.27 (1289.50)	2.37	8083.73 (4134.12)	184.52	---
1979 JUN 10.3 Rj												
Max	5.50	140.00	220.00	570.00	870.00	340.00	3100.00	1300.00	2.70	9200.00	210.00	---
Nom	0.03	0.98	1.54	3.99	6.09	2.38	21.70	9.10	0.02	64.40	1.47	---
Min	<0.01	0.12	0.18	0.47	0.72	0.28	2.57	1.08	<0.01	7.64	0.17	---
Average	1.84	47.03 (41.48)	74.57	191.49	292.27 (199.33)	114.22	1041.25	436.27 (492.87)	0.91	3090.68	70.55 (1580.61)	---
*Rad (c)												

Table 3-6. Proton doses for Jupiter flyby missions

Mission	1-3 Mev		4-10 Mev		10-30 Mev		>30 Mev	
	Max	Nom	Max	Nom	Max	Nom	Max	Nom
1977 JSP								
4.2 Rj								
Max	342000.00*	66.50	798000.00	6270.00	98000.00	22800.00	20.90	40090.00
Nom	1440.00	0.28	3360.00	26.40	416.00	96.00	0.09	168.80
Min	216.00	0.04	504.00	3.96	62.40	14.40	0.01	25.32
Average	114552.00 (57287.13)	22.27	267288.00 (134694.10)	2100.21	32826.13 (20231.46)	7636.80	7.00	13428.04 (6717.52)
1979 JUN								
10.3 Rj								
Max	342000.00	66.50	798000.00	6270.00	98000.00	22800.00	20.90	40090.00
Nom	126.00	0.02	294.00	2.31	36.40	8.40	<0.01	14.77
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average	114042.00 (57032.08)	22.17	266098.00 (134094.38)	2090.77	32678.80 (20140.80)	7602.80	6.97	13368.26 (6687.61)
*Rad (c)								

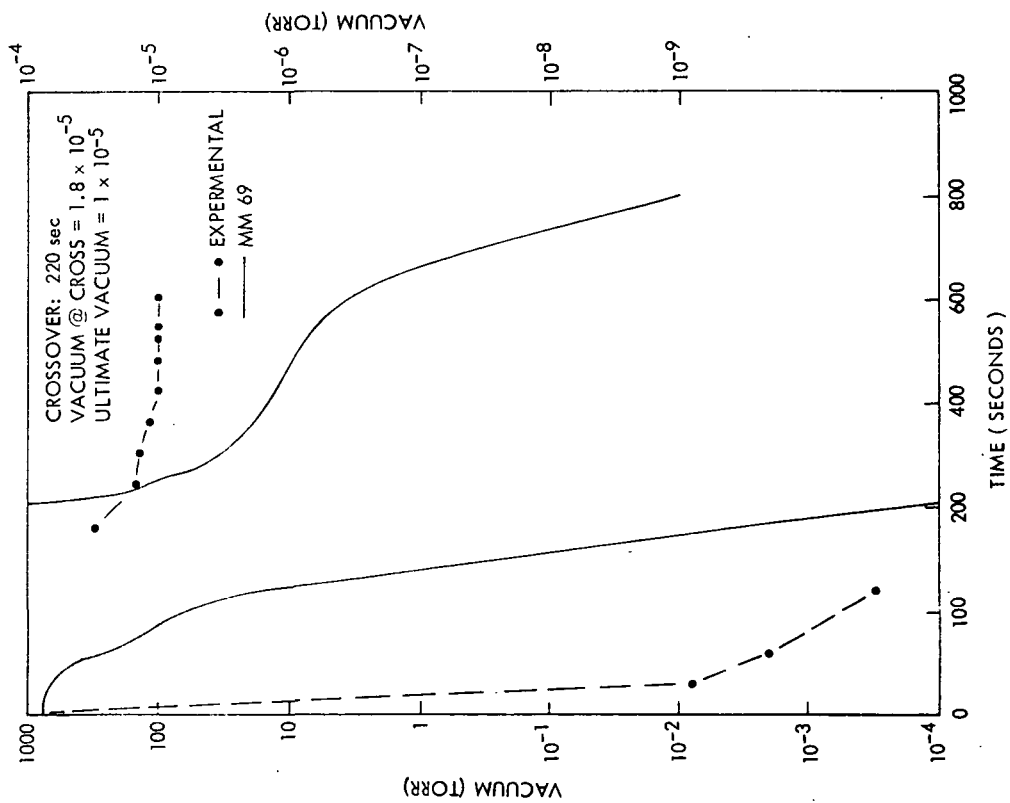


Fig. 3-1. Launch pressure profile

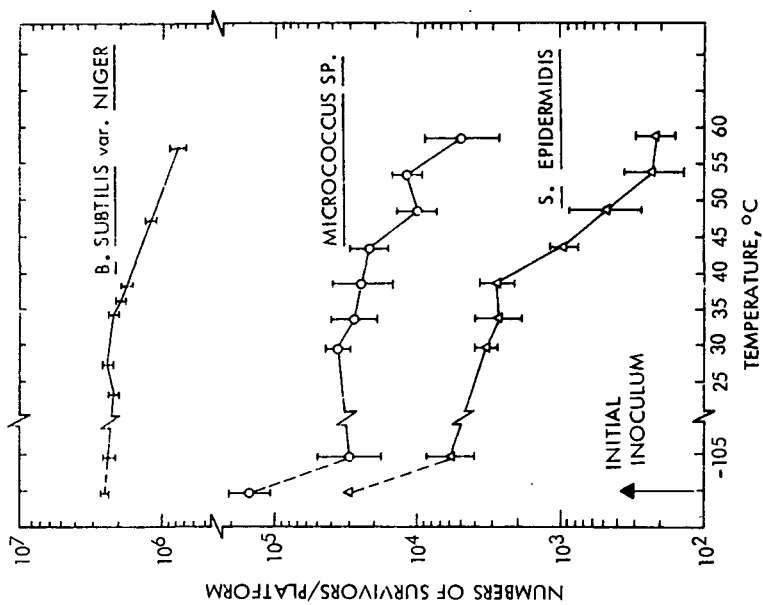


Fig. 3-2. Survival of bacteria exposed to different temperatures in ultrahigh vacuum for 14 days

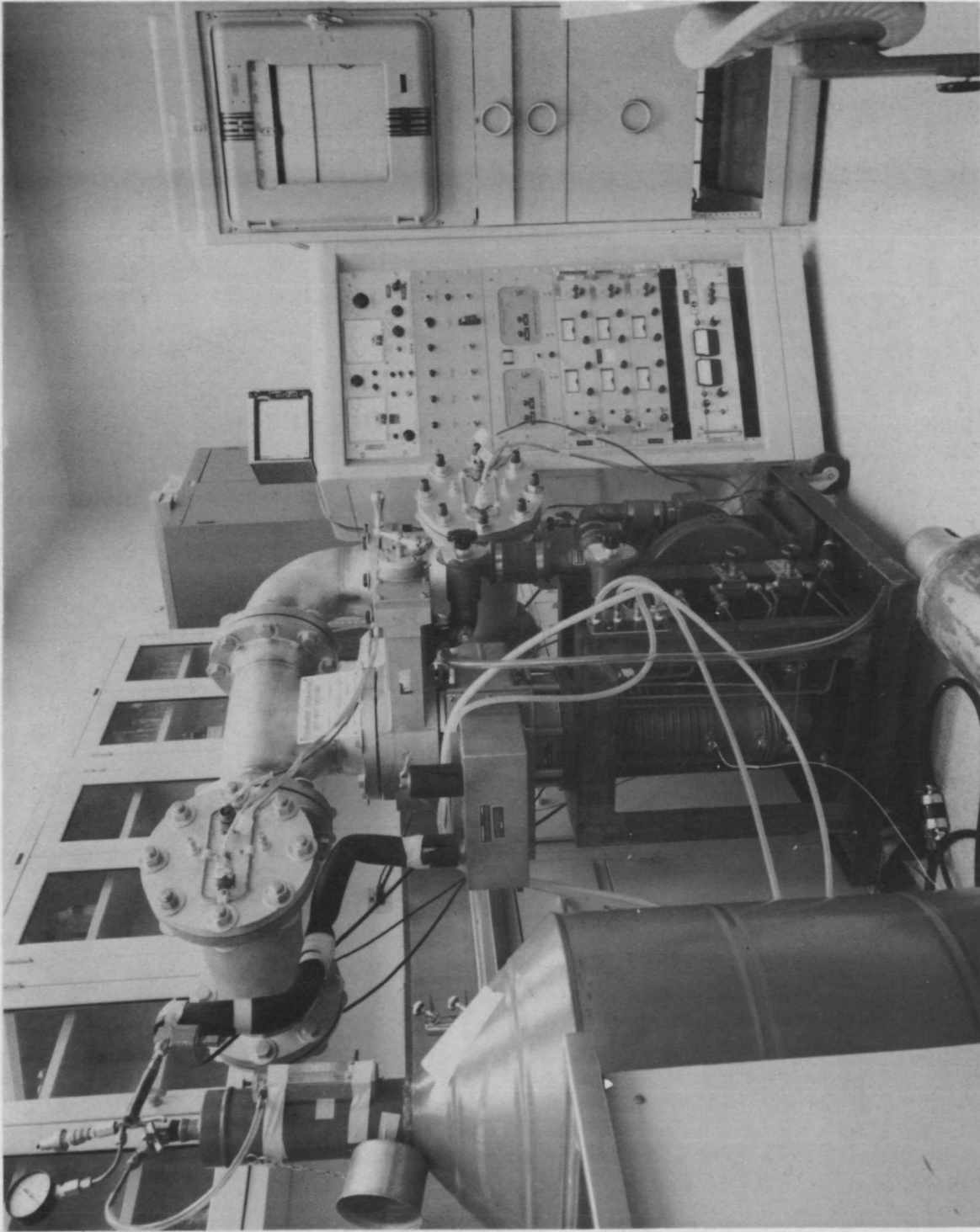


Fig. 3-3. Irradiation study vacuum test equipment

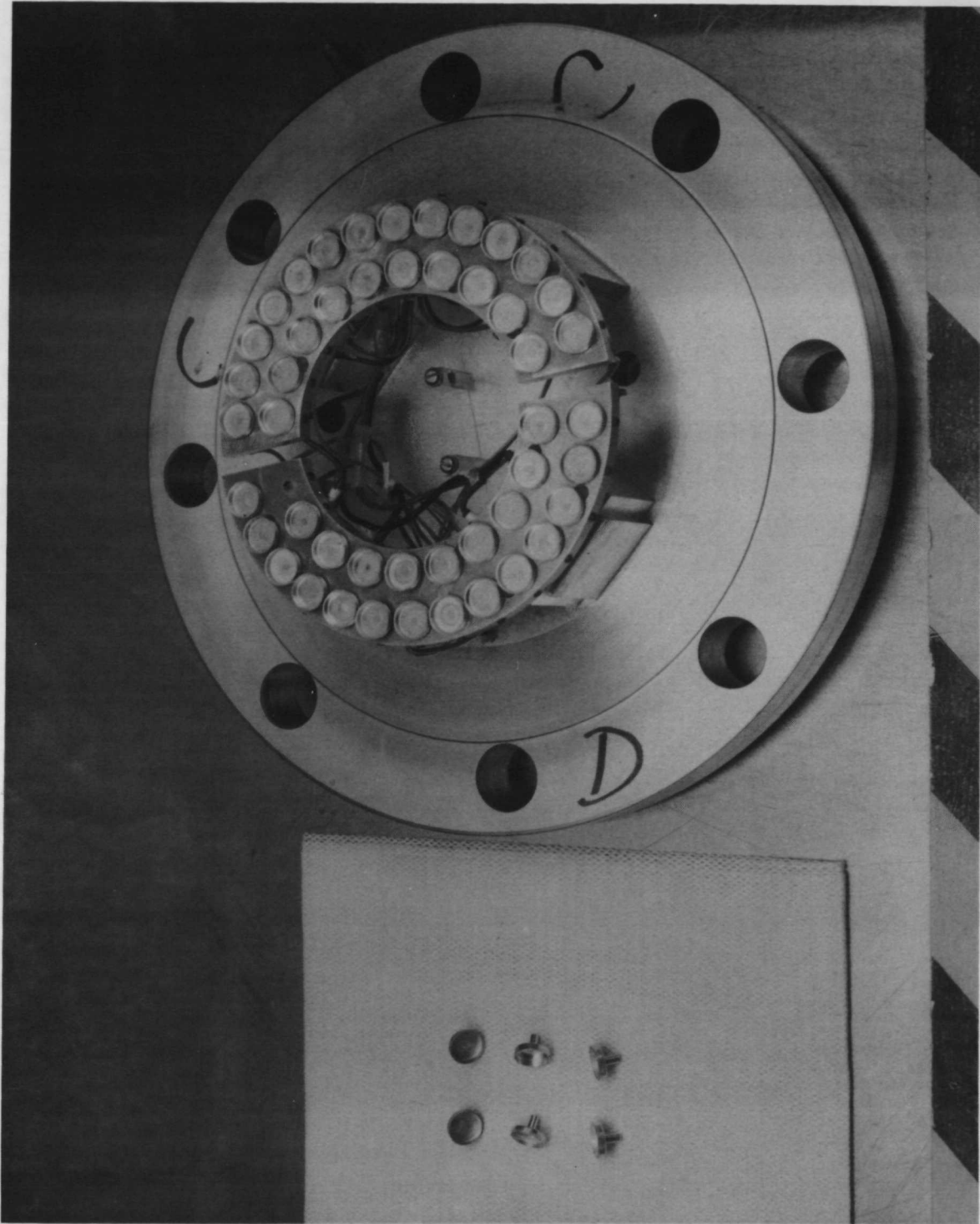


Fig. 3-4. Irradiation study test fixture

SECTION IV  
PLANETARY QUARANTINE SUPPORTING ACTIVITIES

## SECTION IV

## PLANETARY QUARANTINE SUPPORTING ACTIVITIES

NASA No. 191-58-28-02-55

Cognizance: R. H. Green, D. M. Taylor

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## 4.1 INTRODUCTION

Planetary Quarantine Support Activities include the technical assistance for all Space Research and Technology (SR&T) tasks and the operation and maintenance of the microbiological laboratories at JPL. This is accomplished through a contract with AVCO Corp., which at the present time, employs individuals constituting a multidisciplinary group of microbiologists, contamination control engineers, physicist, statistician-computer scientist, and associated support personnel.

## 4.2 SIGNIFICANT ACCOMPLISHMENTS

In addition to the technical support provided to other SR&T programs, personnel of the Planetary Quarantine Laboratory were involved with the following tasks:

- 1) The isolation, with partial classification, of bacteria recovered from MM'71 PTM spacecraft hardware for future use in studies involved with determining bacterial resistance to heat, vacuum, and various forms of radiation.
- 2) The evaluation of a possible relationship existing between nonviable particle size and bioburden.
- 3) Environmental monitoring for fungi (molds) in spacecraft assembly and test areas.
- 4) The evaluation of possible approaches to a direct microbiological assay procedure.



#### 4.2.1 General Support

Some of the tasks, although reported elsewhere in this document are listed in this section since the personnel are in virtual full time assignment.

- 1) Contamination Control Engineer and Two Microbiologists: Microbiological Monitoring of Spacecraft Assembly Operations (NASA Task No. 191-58-23-03-55) which are involved with the refinement of techniques and procedures necessary to estimate the microbiological burden on spacecraft; the bioassay storage and data retrieval system; and the documentation and certification procedures for verification of environmental parameters in laminar flow and nonlaminar flow facilities.
- 2) Three microbiologists: Review of Heat Specifications (NASA Task No. 191-58-21-06-55) which are involved with studies to determine the dry heat resistance of microbes in spacecraft assembly areas and Planetary Quarantine Analyses (NASA Task No. 191-58-22-04-55) which are involved with studies to determine the effect of launch profile, space radiation, and vacuum on survival of bacteria.
- 3) Physicist: Post Launch Recontamination Studies (NASA Task No. 191-58-63-11-55) which involves an examination into the effect of flight environments on the possible redistribution of viable particles.
- 4) Statistician-Computer Scientist: Microbial Burden Prediction Model (NASA Task No. 191-68-63-06-55) which involves the development of a computer code to predict microbial burden on the spacecraft during system assembly and test procedure.

#### 4.2.2 Isolation of Bacteria From MM'71 PTM Spacecraft

Bacterial isolates have been collected, and retained, from four stage burden microbiological assays:

- 1) Prior to space simulation tests.
- 2) Immediately after space simulation tests.

- 3) Three days after space simulation tests with the spacecraft exposed to the environmental conditions of the Spacecraft Assembly Facility (SAF).
- 4) During the post environmental disassembly and inspection stage.

Attention was directed to the occurrence of sporulating bacteria recovered from the nonheat shocked portion of the sample. The isolates were collected and classified in the following manner. After the enumeration of bacteria from a particular spacecraft microbiological stage burden, or assay, the bacterial clones were picked from these primary plates and streaked directly onto Trypticase Soy Agar (TSA) and incubated at 37°C for 24 hours after which the colonial morphology was noted and a Gram stain was done. At least 25 percent of the bacterial clones from a particular spacecraft area were restreaked for classification. Bacillus cultures not sporulating within 24 hr were reincubated for an additional six days. They were then classified as nonsporulating bacillus if sporulation had not occurred within this time. The shortcoming of this method was recognized since sporulation may be related to the temperature of incubation as well as the type of medium.

Table 4-1 classifies the isolates as sporulating bacillus, nonsporulating bacillus, coccus, and other types that include streptomyces and yeast. There are four points of interest:

- 1) The high incidence of sporulating bacteria at all assays except the post space simulation assay.
- 2) The large decrease in numbers of bacteria during the space simulation tests.
- 3) The rapid reestablishment of the bioburden within 3 days following the space simulation tests with cocci as the predominating type which reflects the personnel activity.
- 4) The increase, or reestablishment, of the sporulating bacilli during the four months following the space simulation tests which reflects, more probably, the nonpersonnel environment.

#### 4.2.3 Relationships Between Nonviable Particles and Bioburden

Four Millipore membrane filter holders with 47 mm membrane filters were placed at each of 8 sites in the SAF high bay area (see Monitoring Task, Section V, for filter location). The filters were collected each week. Two of the filters were assayed to enumerate the numbers of microorganisms deposited upon the filters during the one week exposure period. Assay was done by placing a filter on hardened TSA prepared in petri plates and incubating for 24 hours at 32°C. The nonviable particulate material was counted for various size particles on the remaining two filters from each site in accordance with ASTM F25-63T procedures. The data were plotted to show the numbers of microorganisms as a function of the number of nonviable particles of a particular size range recovered from a site. This is shown in Fig. 4-1.

The data are not complete at this time but there appears to be a greater association of viable particles with nonviable particles of the smaller size range: 5-15 $\mu$  and 15-25 $\mu$ . There also appears to be a dependency on site. The complete data will be statistically analyzed and reported upon at a later date.

#### 4.2.4 Environmental Monitoring for Fungi (Molds)

Since the microbiological monitoring procedures for spacecraft hardware does not include enumeration of fungi, in particular molds, and since it has been reported in the literature that molds can be extremely resistant to desiccation, heat, ultraviolet radiation, and vacuum, a preliminary study was initiated to enumerate molds in spacecraft assembly and test environments on a weekly basis.

Stainless steel coupons, similar to those used to assay bacterial fallout, were used. The assay procedure was similar to that used for bacterial fallout (see para. 5.2.1.1 for site location) except that Sabouraud's Agar was used as the recovery medium and the incubation temperature was 25°C.

The weekly data appear in Fig. 4-2 which plots the weekly average of molds settling per square foot across the eight sites in addition to the high and low values during the same time period. The weekly low curve falling below the x-axis represents zero mold count at a particular site. The interruption of

the mold curves indicates no data for that week. The data are not complete but a trend appears to indicate that the numbers of molds settling out from the environment are greater than the numbers of bacterial spores.

#### 4.2.5 Direct Microbiological Assay Procedure

The detection and enumeration of microorganisms on surfaces of spacecraft hardware by a technique that avoids direct contact with the surfaces and provides real-time quantitative data would be an improvement over the conventional swab-rinse assay technique. Some of the undesirable features of the swab-rinse technique include the inefficient recovery of microorganisms, inability to assay certain areas of spacecraft hardware because of their fragility, deposition of water, or other leached material, onto the sampled surface, and the time involved with the assay to the availability of results.

Technological advances allow remote detection of agricultural and forest crops as well as marine populations. This same technology could perhaps be applied to microscopy to allow the detection of microorganisms on a surface. Such a technique would depend upon identifying a characteristic, or set of characteristics, unique to viable microorganisms.

Casida (1969. Appl. Microbiol. 18:1065) describes a procedure for visualizing soil microorganisms in situ. This technique utilized reflected light microscopy with a white light source and time-lapse photography. Differentiation of microorganisms from soil particles was accomplished by color discrimination with color photography. The diffraction colors of microorganisms corresponded to the green with 490 to 500 m $\mu$  wavelengths while the soil particles appeared either translucent, grey, brown, or black. The characteristic wavelengths were most prominent during periods of low metabolic activity.

Identification of additional characteristics such as size, shape, and response of microorganisms to monochromatic light may be necessary to differentiate between microorganisms and mineral particles on spacecraft surfaces. This would involve a method of data processing and analysis.

Kamentsky and Melamed (1969. Proc. IEEE. 57:2007) have demonstrated the feasibility of measuring multiple optical properties of individual

tissue cells for classification. Methods for automatic image analysis have been reported by Fisher (1966. Particle Size Analysis Conference) for use in metallurgical problems and by Lent and Nichols (1970. AIAA Earth Resources Observations and Information Systems Meeting. Paper No. 70-308) for the comparison of agricultural features by high altitude aerial photography from spacecraft. Related technology to microscopy have been reported by Prewitt and Mendelsohn (1965. Ann. N. Y. Acad. Sci. 128:1035) with their flying spot scanning microscope system for blood cell differentiation and by Soffen and Sloan (1966. American Astronaut Society Annual Meeting. AAS preprint 66-67) in their extraterrestrial life detection study that employed visual imaging microscopy.

A possible difficulty of the envisioned direct assay technique would be the detection of emissions by a microorganism which would be weak. An image intensifier may overcome this difficulty.

Discussions were held with Dr. Robert Colwell from the University of California at Berkley and with representatives of the Carl Zeiss company. Their comments were encouraging and helpful.

A possible imaging system is schematically shown in Fig. 4-3 which is a modification of the Quantimet 720 system marketed by Metals Research, Ltd.

#### 4.3 RELEVANCY TO PLANETARY QUARANTINE

The present activities benefit planetary quarantine programs in the following manner:

- 1) The establishment of a relationship existing between nonviable particles and bioburden would allow the standardization of a rapid method to determine spacecraft bioburden, or if the converse, no existing relationship, then the technology of direct microbiological assay becomes of great importance.
- 2) The enumeration of sporulating bacteria from nonheat shocked samples and the enumeration of fungi are directly related to planetary quarantine analyses that consider biocontamination allocations and time-temperature calculations.

#### 4.4 FUTURE ACTIVITIES

The continued effort of Planetary Quarantine Support Activities will be directed toward maintaining that required level of technical competency in the area of planetary quarantine.

In addition, the following activities will continue:

- 1) Collection of data to establish any possible relationship between nonviable particles and bioburden up to the time of PTM encapsulation.
- 2) The enumeration of sporulating bacteria from nonheat shocked samples taken from the microbiological assay of PTM spacecraft.
- 3) The enumeration of molds settling out in spacecraft assembly and test areas up to the time of PTM encapsulation.
- 4) The evaluation of possible components for a direct assay system. The evaluation will also include the identification of microbial characteristics for possible use.

Table 4-1. Classification of MM'71 bacterial isolates

Assembly stage	Sporeformer	Nonsporeformer		Other <sup>1</sup>	Total
		Bacillus	Coccus		
Pre-Space Simulation	99	16	37	3	155
Post-Space Simulation	1	0	6	0	7
Post-Space Simulation Plus 3 days SAF	12	6	41	0	59
Post Environment Disassemble and Inspection	33	9	32	3	77

<sup>1</sup>Grouping includes streptomyces and yeast.

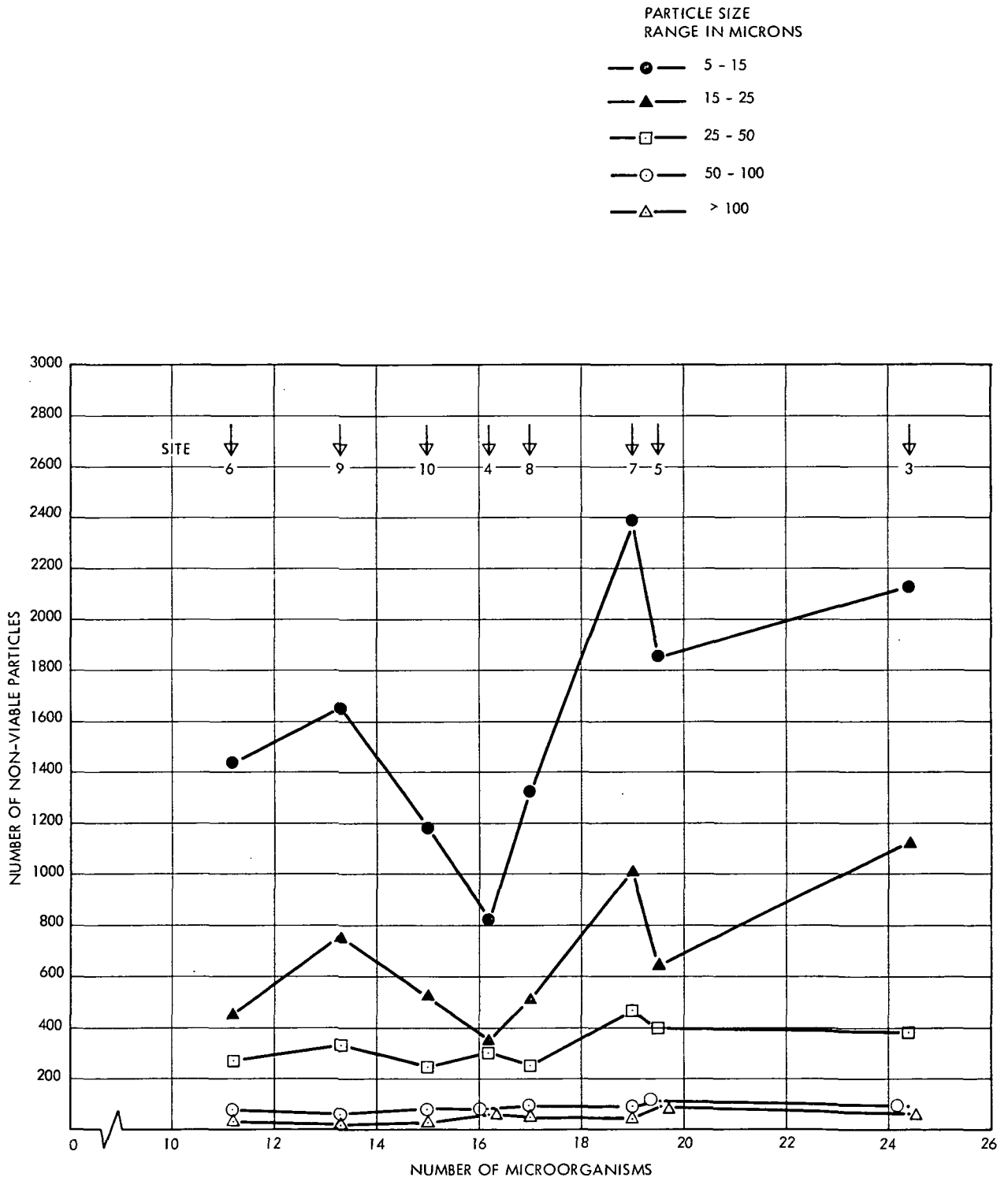


Fig. 4-1. Relationship between non-viable particles and bioburden



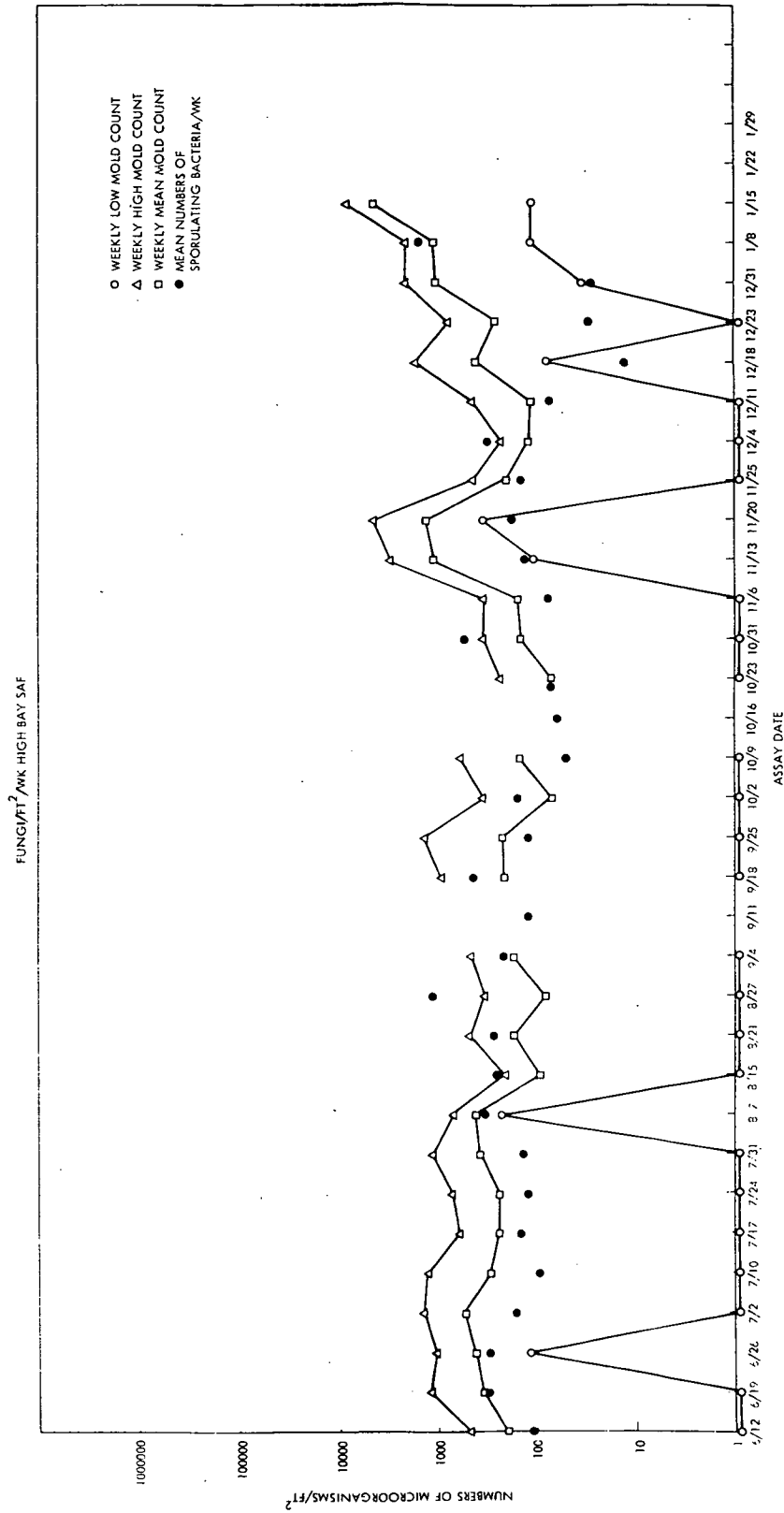


Fig. 4-2. Environmental monitoring for molds

A SPECIMEN OR SPACECRAFT



IS IMAGED BY A REFLECTED LIGHT MICROSCOPE WITH AUTOMATIC FOCUSING, LIGHT SOURCE AND ACCESSORIES WHICH PROJECTS THE IMAGE ONTO



VIDICON OR PLUMBICON IMAGE SCANNER WHOSE OUTPUT IS PASSED TO



A DETECTOR WHICH SELECTS THE FEATURES TO BE ANALYSED AND PASSES PULSES FROM THESE TO



AN AMENDER WHICH ALLOWS MODIFICATION OR AMENDMENT OF DETECTED SIGNALS BEFORE THEY ARE PASSED TO



A COMPUTER WHICH MEASURES THE SIZE, SHAPE, WAVELENGTH OF EMITTED SIGNALS, AND PASSES THESE ON TO A



DISPLAY WHICH CAN BE MONITORED OR READ OUT ACCUMULATING DIGITAL DISPLAYS OF MEASURED PARAMETERS



THE ENTIRE PROCESS CAN BE AUTOMATICALLY CONTROLLED BY A PROGRAMMER, OR CAN BE MANUALLY CONTROLLED BY SWITCHES

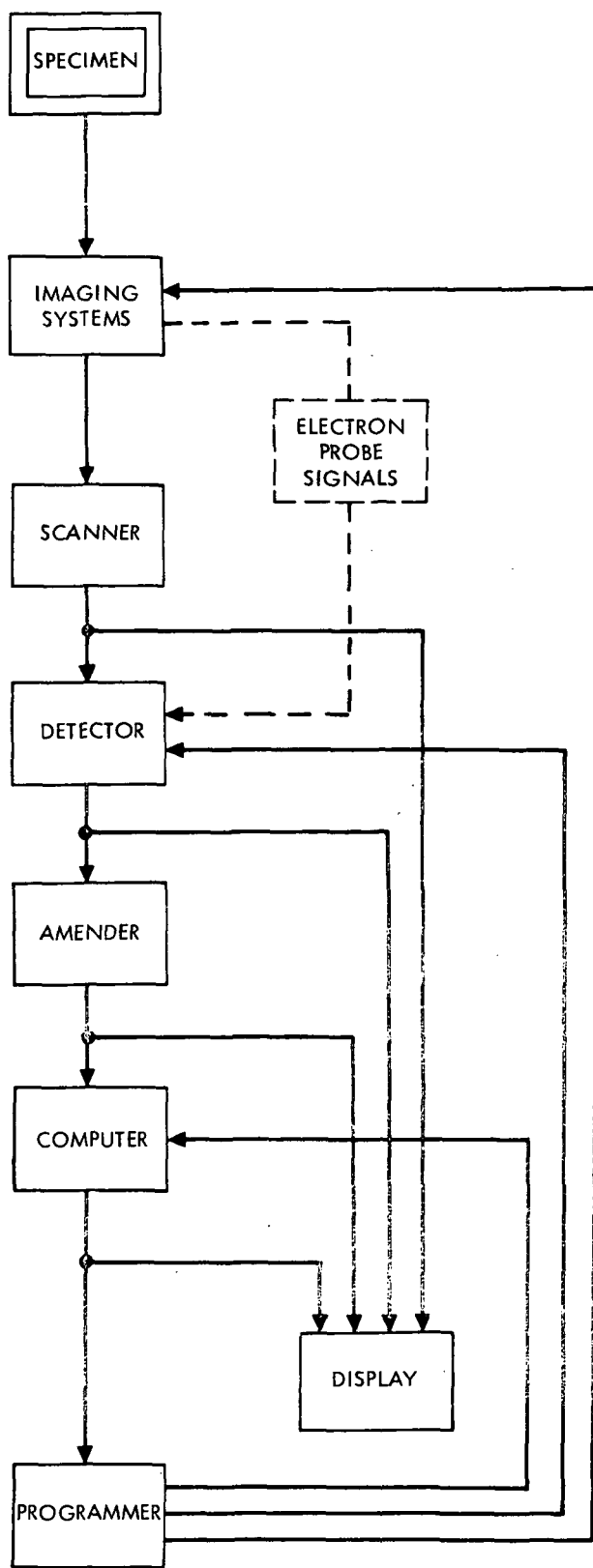


Fig. 4-3. Imaging system schematic

900-484

SECTION V

SPACECRAFT MONITORING METHOD AND PROCEDURES

## SECTION V

## SPACECRAFT MONITORING METHOD AND PROCEDURES

NASA No. 191-58-63-03-55

Cognizance: D.M. Taylor, R.C. Koukol

Associated Personnel: P. LaLime, G. Simko, C. Smith

## 5.1 INTRODUCTION

Continuity in this task was provided for improving techniques and procedures developed with Mariner '67 and '69 spacecraft hardware utilizing Mariner '71 spacecraft. Basically, the objectives are three-fold: (1) refine the techniques and procedures necessary for the direct biological estimation of bio-burden on an assembled spacecraft or subsystem; (2) provide data to update the input parameters for the microbial burden prediction model; (3) provide microbial isolates for other studies. Further, problems identified in the Planetary Quarantine (PQ) Advisory Committee reports were addressed to develop criteria for: (1) establishing the number of samples required for direct estimation of bio-burden on a surface; (2) determining where to sample a surface; (3) estimating the burden on a specific surface from individual samples; (4) methods of combining estimates from a number of surfaces. The MM'71 Proof Test Model (PTM) spacecraft was used for the conduct of the study areas selected. The approaches to meet these objectives and problems were as follows:

- a) To determine the relationship of environmental cleanliness and the spacecraft bioburden.
- b) The development of sampling procedures for problem areas, viz: cabling, thermal blankets, solar panels, and high gain antenna.
- c) The refinement of bioburden estimation consisting of number of samples taken, location of sample site and data extrapolation.

## 5.2 SIGNIFICANT ACCOMPLISHMENTS

### 5.2.1 Relationship of Environmental Cleanliness Level and Spacecraft Bioburden

This sub-task consisted of dual sub-set of monitoring and assays as follows:

- 1) Environmental monitoring for the collection of both viable and nonviable particulate fallout.
- 2) Stage monitoring of the MM'71 Proof Test Model (PTM) Spacecraft for bioburden.

5.2.1.1 Environmental Monitoring. In the environmental monitoring program, three methods are being employed:

- 1) Royco particulate sampling for nonviable particles.
- 2) Reynier air sampling for air borne viable organisms.
- 3) Stainless steel strips (1 x 2 in) for collection of settling organisms.

The environmental monitoring program consisted of 10 sites in the Spacecraft Assembly Facility (SAF); eight located in the 'High Bay Area' and two located in the 'laminar flow tent'. The frequency of data collection was twice per week from the Royco and Reynier samples and once per week from the settling strips. Parameters prescribed for the environmental monitoring methods are shown in the following text.

#### Royco - Light Scattering Photometric Particle Counter

	<u>Sampling Time</u>	<u>Size Range</u>	<u>Sampling Rate</u>
High Bay	10 min	0.5 - 5.0	1 cu ft/min
Laminar Flow Tent	30 min	0.5 - 5.0	1 cu ft/min

Reynier Sampler - Agar Media Impinger

	<u>Sampling Time</u>	<u>Size Range</u>	<u>Sampling Rate</u>
High Bay	1 hr	non-discriminate	1 cu ft/min
Laminar Flow Tent	1 hr	non-discriminate	1 cu ft/min

Settling Strips

	<u>Sampling Time</u>	<u>Size Range</u>	<u>Sampling Rate</u>
High Bay	7 days	non-discriminate	N/A
Laminar Flow Tent	7 days	non-discriminate	N/A

Data from the foregoing monitoring methods are shown in figures described below:

- 1) Figures 5-1 and 5-2 depict the mean particle levels from Royco sampling in the SAF High Bay and the SAF Tent Area, respectively.
- 2) Figures 5-3 and 5-4 depict the viable particle levels from Reynier Sampling in the SAF High Bay and the SAF Tent Area, respectively.
- 3) Figures 5-5 and 5-6 depict both the viable and heat-shocked particle levels from the Settling Strips in the SAF High Bay and the SAF Tent Area, respectively.

A visual observation of the particulate data indicates that the High Bay Area of SAF exceeded class 100,000 requirements for approximately two months during the summer, but the tent facilities were generally at an acceptable level. The viable count from the fallout data was correspondingly high in the High Bay Area during the same time period. The viable counts for the fallout data obtained by the settling strips in the Tent Area were consistently lower than the High Bay as expected.

5.2.1.2 MM'71 PTM Monitoring. The bioburden estimates developed for the Mariner Mars '71 PTM spacecraft were obtained by use of approved sampling methods and techniques contained in the MM'71 Monitoring Plan (PD 610-18, Part III). This consisted of collecting 250 random samples, each sample 4 inch<sup>2</sup>, from selected sampling areas. Supplementing the test data were 25 sterile control samples, also randomly obtained. To provide retrievability of the test data associated with the respective sample location, documentation consisted of: polaroid photography of the sample site; annotation of pictures with a log-book control number; compilation of data cross-referenced to the sample site location and log-book control number.

The monitoring program for the MM'71 PTM is designed in stages as follows:

- Stage I Initial Binder
- Stage II Pre-Solar Simulation
- Stage III Post-Solar Simulation
- Stage IV Weight and CG Test
- Stage V Post Vibration Test
- Stage VI Pre-Shipment AFETR
- Stage VII Pre-Encapsulation
- Stage VIII Decapsulation

The results of the bioburden assays (6 sampling modes) are shown in Fig. 5-7. Following bioburden assay number 5 (Post Vibration), the spacecraft was disassembled; components were cleaned and stored. Reassembly of the spacecraft and the concomitant bioburden buildup occurred approximately three weeks prior to the initiation of assay number 6, (Preshipment Assay), January 18, 1971.

An overall assessment of this data will be evaluated upon completion of the final stages (Stage VII, Pre-Encapsulation and Stage VIII, Decapsulation).

## 5.2.2 Development of Sampling Procedures for Problem Areas

The solar panels, high gain antenna, cabling and thermal blankets are components of spacecraft hardware in which difficulty of sampling has prevailed. The following are specific actions taken to date.

5.2.2.1 Solar Panels. The delicate wiring and solar cells necessitate cleaning and handling techniques which would not impair or degrade the hardware structure or functioning. In consonance with the flight cognizant engineer, the standard swab-rinse technique was adopted. The sampling procedure was to be conducted under the surveillance of the cognizant engineer.

5.2.2.2 High Gain Antenna. The surfaces of this ancillary equipment (front and rear) presented separate material and structural characteristics. The rear side consisted of a honey-combed skin, the perforations thereon presenting a problem of moisture collection which could impair the mission. The adopted procedure emphasized the use of the swab-rinse techniques with extreme care being observed to eliminate contact into a perforation. The front side was a rough-surfaced area that accommodated the same swab-rinse technique. Both sides were pressure-sensitive and required careful application to prevent impairment.

5.2.2.3 Cabling. Interconnecting cabling presented a major problem. Insufficient time was available to develop a satisfactory sampling technique; priority was given to method selection and data acquisition of the other principal items during the allowable time. This determination is deferred.

5.2.2.4 Thermal Blankets. The heat shielding materials for the propulsion module and scan platform had varying material characteristics. The swab-rinse technique was suitable for sampling all blankets except the propulsion module. For this item the dry swab technique was employed; the outer layer of the blanket has an extremely high absorbent quality. Surface cleaning of the propulsion module blanket therefore necessitated employment of an improved vacuum brush technique.

To observe the total effect on occluded bioburden within the laminar interior of the thermal blankets a detailed study was initiated. The respective



layers of a 1/2 inch square section sample were delaminated for biota assessment. This data is reported in Table 5-1. The bioburden, both surface and occluded areas, underwent a viability reduction as shown in Fig. 5-8. After 100 days, a 1.5 log reduction in the data was noted. These results seem to indicate that the incipient bioburden contained in the interior layers of the thermal blankets is reduced over a period of time to a comparatively insignificant number of organisms.

### 5.2.3 Refinement of Bioburden Estimation

In response to those problems identified in the Planetary Quarantine Advisory Committee (PQAC) reports noted in para. 5.1, the actions taken are respectively reported in the following paragraphs.

5.2.3.1 Number of Samples Required for Direct Estimation of the Bioburden on a Surface. A sequential statistical evaluation for determining the optimum number of random samples required is shown in Fig. 5-9 for the low-gain antenna and Fig. 5-10 for the Scan Platform Blanket. This evaluation was based on an initial sampling of 20 percent of the components surface area. Using random sampling tables, varying quantities were selected representing surface area percentages of 10, 5, 1 and 0.5.

Significantly, the results indicate that proportional sampling allocated per subsystem within the spacecraft total sampling (250), which falls in the area of less than 1 percent total area, provides a broad irregular range of data. As the percent of area sampled increases, the data becomes more regular; providing an increase in the confidence level.

5.2.3.2 Determining Where to Sample a Surface. This determination is being deferred until the total data collected for each planned milestone can be assessed. Factors of surface nodosity, component geometry, and environmental aerodynamics are considered to affect this study.

5.2.3.3 Data Extrapolation. This area of interest is likewise being deferred for the reason stated in para. 5.2.3.2.

### 5.3 FUTURE ACTIVITIES

Both the spacecraft bioburden and environmental monitoring will follow the spacecraft to Cape Kennedy, Florida for a continuance of post-encapsulation studies. Supplementary assays will be conducted to assess pre-shipment and post-shipment effects.

At the conclusion of the monitoring, statistical studies will be compiled to determine the relationships between microorganisms and specific types of hardware surfaces, determining the distribution of spore and non-spore isolates, as well as determining the effect on the total bioburden by statistically varying the number of samples taken on a given piece of hardware.

### 5.4 PUBLICATIONS

Presentation to the Semi-Annual NASA Sterilization Technology Seminar, December 1-2, 1970 at Williamsburg, Virginia; Dr. Dan M. Taylor.

Table 5-1. Distribution of initial bioburden of MM'71 thermal blankets

BLANKET	MICROORGANISMS PER 0.5 IN. <sup>2</sup> OF MATERIAL																																			
	LAYER																																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	TOTAL		
UPPER																																				
NONHEAT SHOCKED	5.2	0.6	0	4.2	0	1.0	0	0	0	0	0	0.4	0	0.2	0.6	0.6	0	0.4	0	0	0.2	0.6	0	0.2	0.2	0	0.4	0.8	0	1.0	0	0.8	0.2	16.4		
HEAT SHOCKED	0.6	0.2	0	0.2	0	0.2	0	0	0.2	0	0	0	3.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0	0	0.4	5.8		
OVERLAY	1.3	0	0.3	0	0.3	0.3	0.1	1.2	0.5	0.4	0.1	0.5	0.1	0.5	0.3	0.5	0.3	0	0.3	0.1	0.3	0.4	0.1	0.4	0.7	0.1	0.3	0.1	0.6	0.3	0.5	0.8	16.9			
SCAN PLATFORM																																				
NONHEAT SHOCKED	3.2	19.2	6.4	0	0	86.0	12.8	6.4	0	3.2	0	0	0	9.6	6.4	0	0	12.8																	166.0	
HEAT SHOCKED	3.2	1.6	0	0	0	3.2	0	0	0	6.4	0	0	0	0	0	0	0	2.0																	32.8	
OVERLAY	4.0	1.6	0	0	0	0	20.0	0	0.8	3.2	0	0	0	0.8	3.2	1.6	1.6	40.0																	76.8	

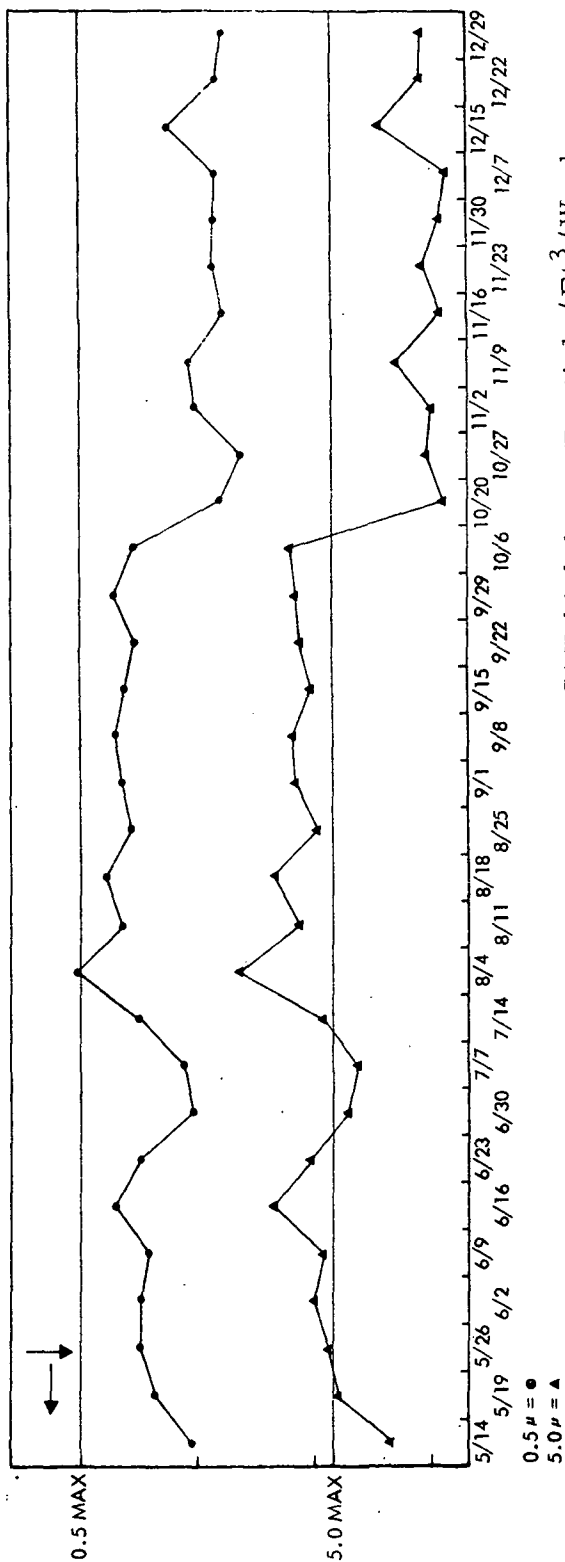


Fig. 5-1. Mean particle levels in SAF high bay. Particle/Ft<sup>3</sup>/Week

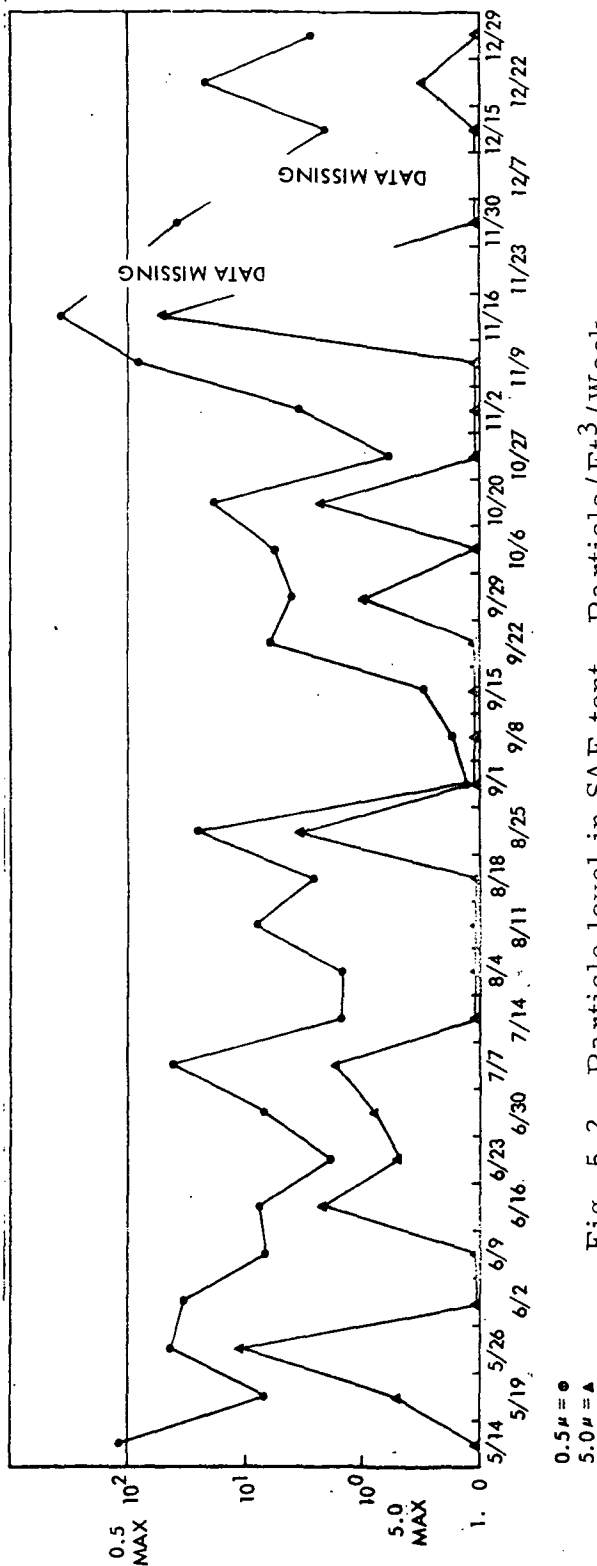


Fig. 5-2. Particle level in SAF tent. Particle/Ft<sup>3</sup>/Week

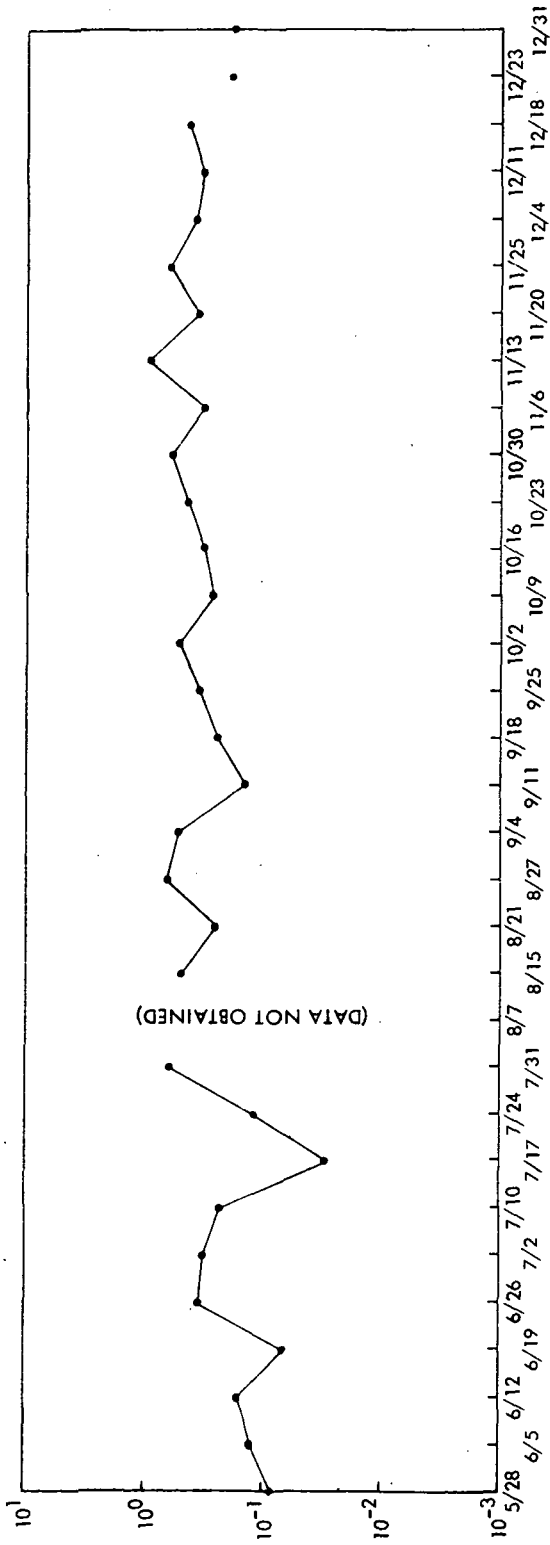


Fig. 5-3. Reynairs tent, high bay. Viable particles/Ft<sup>3</sup> of air/week

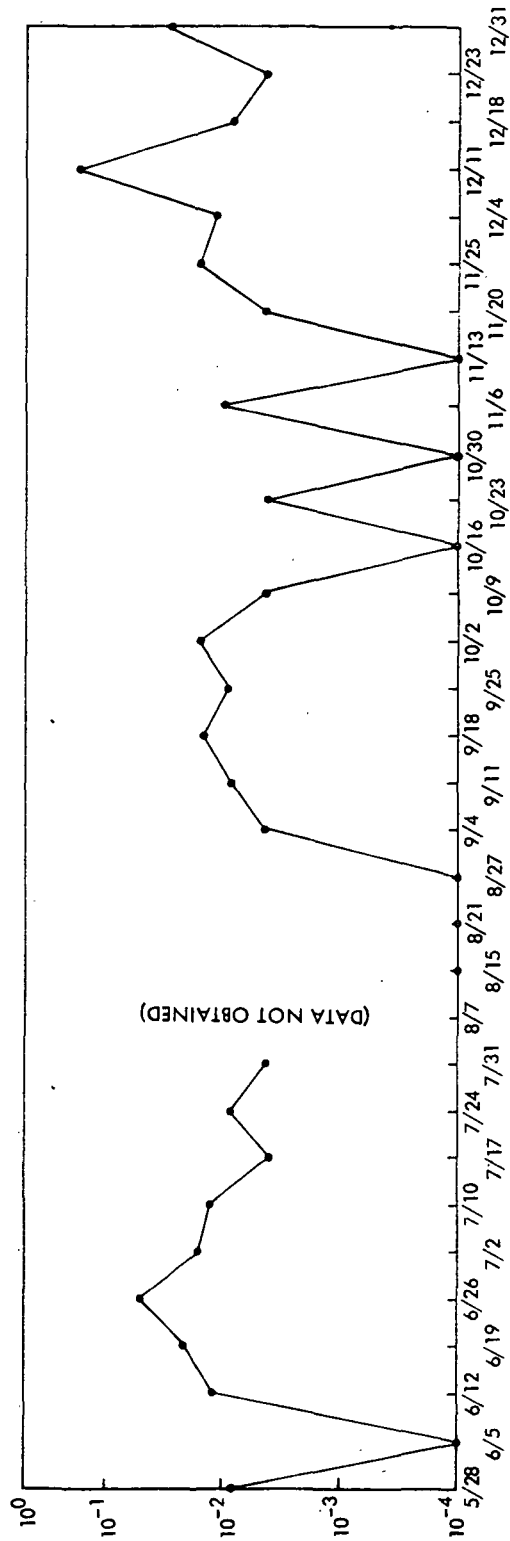


Fig. 5-4. Reynairs tent. Viable particles/Ft<sup>3</sup> of air/week

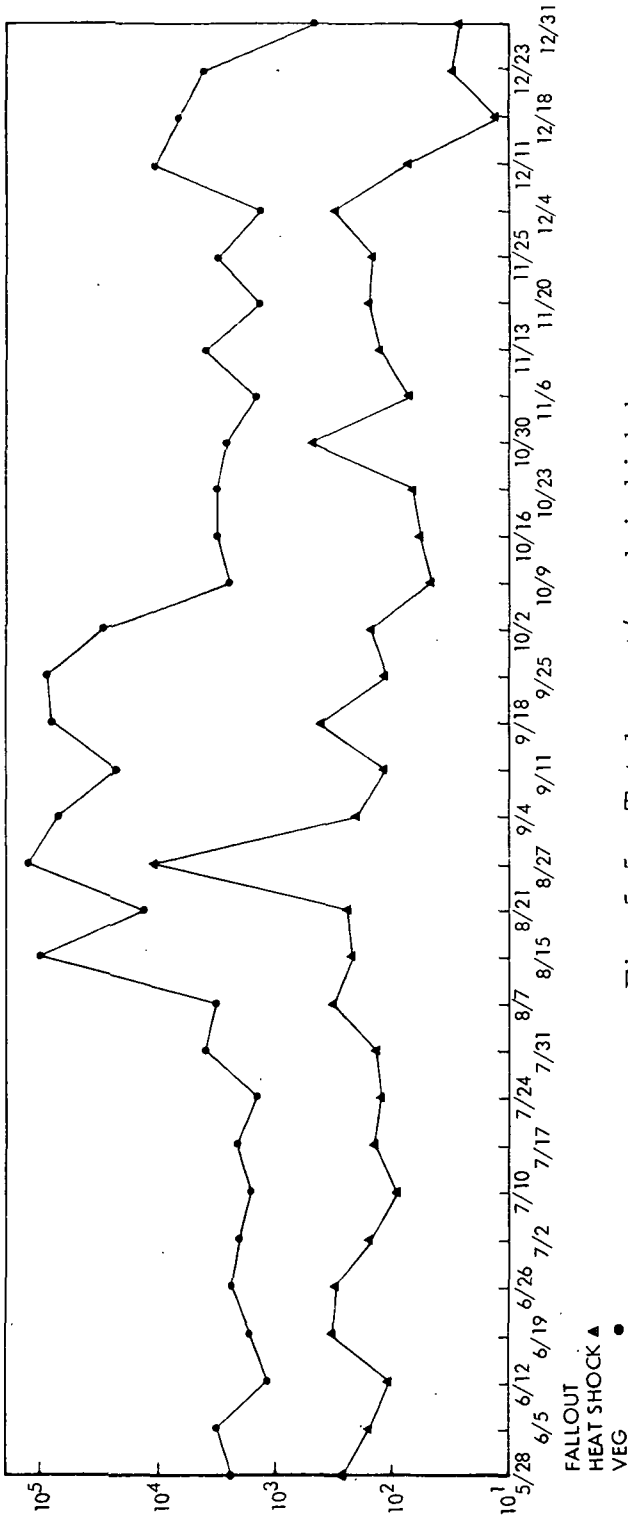


Fig. 5-5. Total count/week in high bay

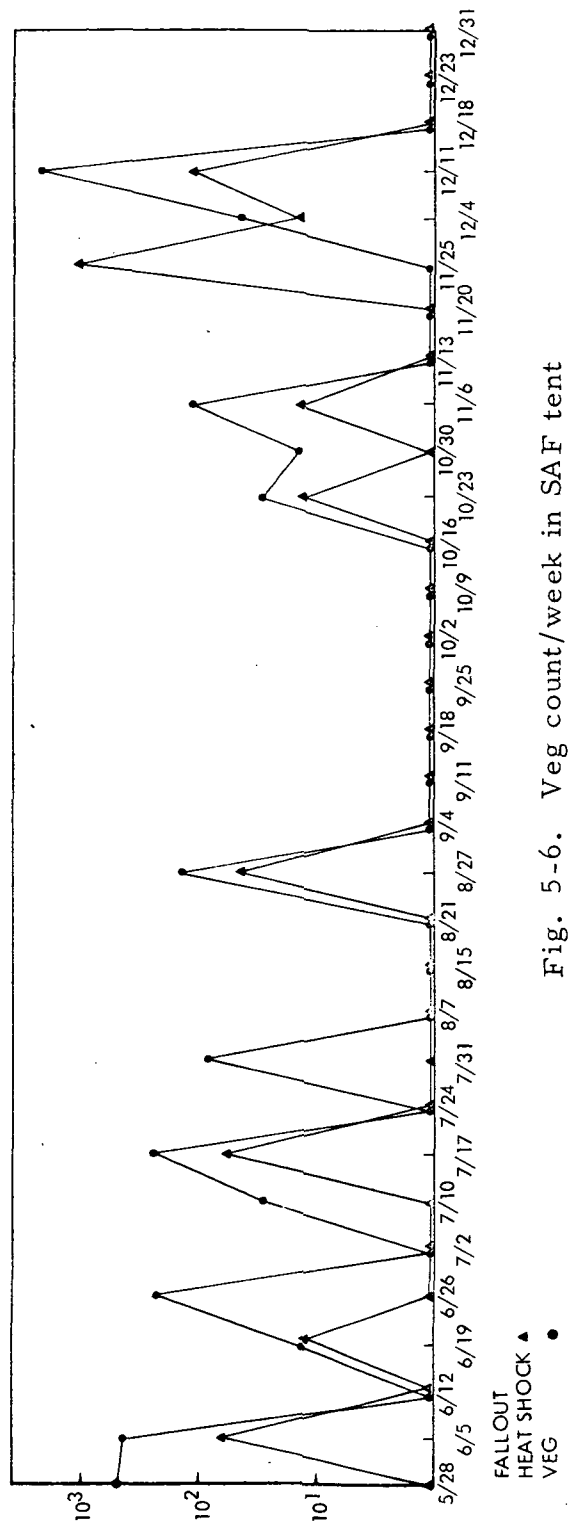


Fig. 5-6. Veg count/week in SAF tent

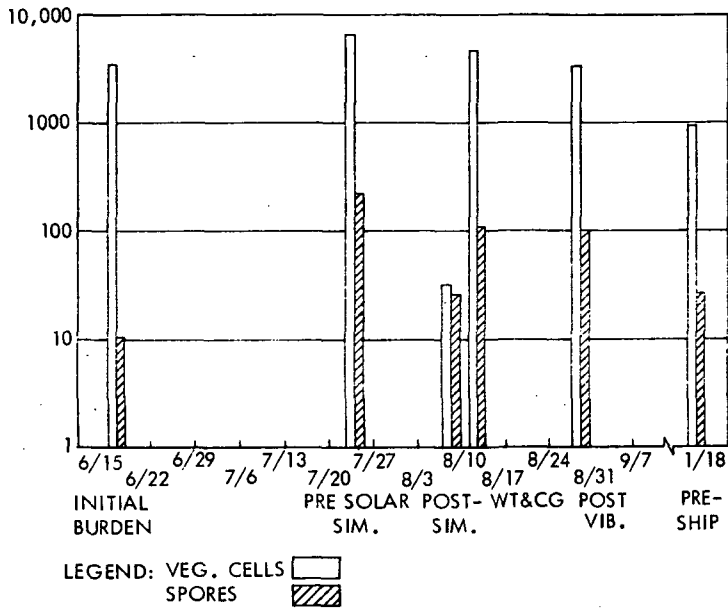


Fig. 5-7. Average microbial contamination/ft<sup>2</sup> for all spacecraft surfaces

Fig. 5-8. Bioburden dieoff within scan platform thermal blanket

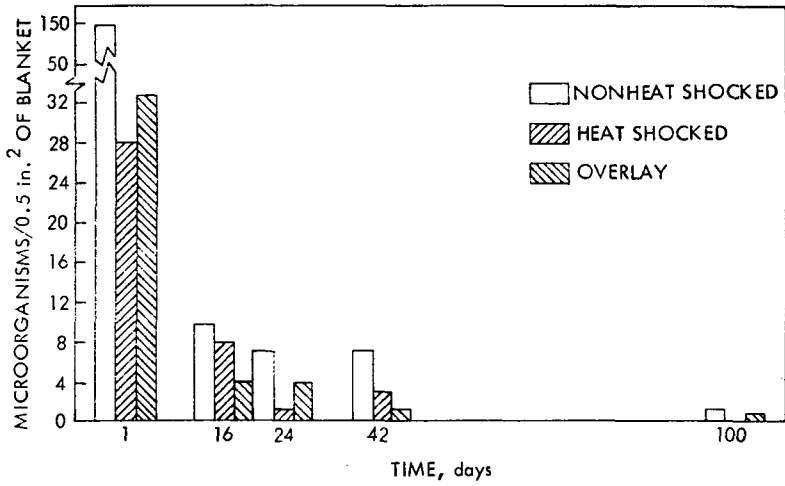


Fig. 5-9. Frequency distribution of burden estimation of low gain antenna

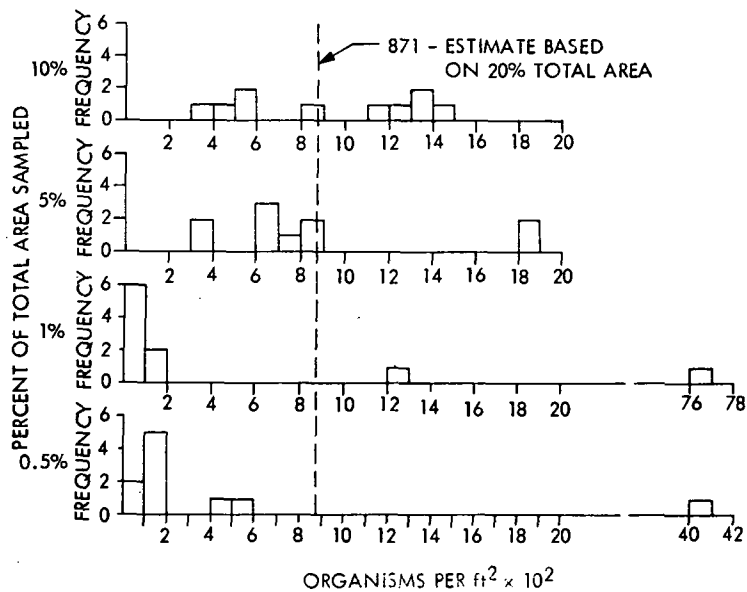
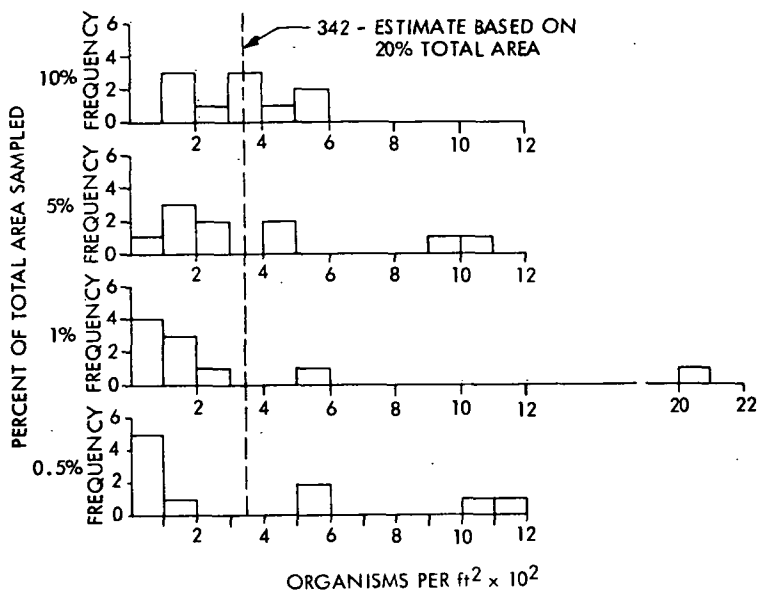


Fig. 5-10. Frequency distribution of burden of scan platform blanket



SECTION VI  
MICROBIAL BURDEN PREDICTION MODEL

## SECTION VI

## MICROBIAL BURDEN PREDICTION MODEL

NASA No. 191-58-63-06-55

Cognizance: A. R. Hoffman

Associated Personnel: D. Winterburn (AVCO), R. Koukol

## 6.1 INTRODUCTION

The Microbial Burden Prediction Model (MBPM) and its associated computer program have been developed as a tool for 1) supplementing the biological assays of a spacecraft by simulating the microbial accumulation during periods when assays are not taken, 2) reducing the number of biological assays that are required, and 3) predicting the microbial loading on the lander immediately prior to sterilization and the other non-lander spacecraft equipment prior to launch.

When this effort was begun over two years ago, a model was needed that would permit analysis of the manner in which a spacecraft was assembled before the build-up occurred so that biological monitoring could be planned and scheduled, and optimum times for sampling determined; and, just as importantly, so the assembly flow could be optimized so the microbial burden could be maintained at an acceptable level. During the actual assembly, the model can be used as a quality assurance control tool to ensure that the microbial burden is not becoming excessive on a given piece of hardware. Finally, a reasonable and meaningful estimate is needed at the time of encapsulation for an orbiter to be used in the post-launch planetary quarantine analysis. The prediction model, validated and verified on a continuing basis by direct assay methods, can provide such an estimate.

Early in the development of the Microbial Burden Prediction Model it was necessary to choose a method for dealing with several random variables in the model. With a desire to obtain a complete view of the distributions of resultant variables while using minimum computer run time, the decision was made to represent these variables as discrete probability density functions, or histograms. Since the details of histogram manipulation had not been fully developed, resulting difficulties and limitations were not completely understood (such as distributions concentrating in the highest valued histogram interval).

The Phase IX of the Math Model study contract with Martin Marietta refined the histogram method for combining random variables in order to obtain more realistic predictions of the microbial burden on spacecraft.

## 6.2 SIGNIFICANT ACCOMPLISHMENTS

During this reporting period, the Mariner '71 planned sequence emulation was completed. A limited number of sensitivity studies (abbreviated as studies) were performed to determine the effects of the environment on predicted burden levels. However, sensitivity studies was suspended until environmental microbiological data from Mariner '71-2 assembly and test is obtained and incorporated into the input histograms. In the meantime, the actual assembly of the Mariner '71-2 was emulated in near real-time, with the computer inputs being prepared and keypunched weekly.

Five studies have been completed on the Mariner '71 planned sequence. Selected input parameters to the model were increased by factors of 10 (i.e., an order of magnitude) and the predicted mean burdens for exposed surfaces and for all surfaces compared to the corresponding mean burdens of the reference run, or baseline (i.e., without changes to any input parameters). Table 6-1 gives the changes made, the corresponding mean burdens, and the baseline.

In only two studies did the predicted mean burdens indicate significant changes from the baseline. These studies reflected increases in the "average lifetime" of organisms at the Eastern Test Range (ETR) (Study 5) and in the ETR operational (environmental and personnel) fallout rate (Study 2). The increase in the "average lifetime" resulted in the greatest order of magnitude changes - 1.05 for the exposed surface and 0.48 for all surfaces - while the increase in the operational fallout rate resulted in changes of 0.86 and 0.45, respectively.

The two studies mentioned were also significant, at the predicted 95 percent burden level, when performed on the Mariner '67 assembly and test sequence. Table 6-2 gives a comparison of the Mariner '71 emulation at the predicted 95 percent burden level with that of the Mariner '67.

Figure 6-1 is a graph comparing the results of sensitivity studies 2 and 5 with that of the unaltered input data (baseline).

Figure 6-2 shows the performance of the program, before the Phase IX modification of the histogram combining method (herein referred to as the unmodified program), with the 5 percent and 95 percent probability burden levels plotted with the mean burden from day 200 to launch (day 276). Figure 6-3 shows similar results obtained from the modified program. Whereas the means of the two runs are much alike in value, the 5 percent and 95 percent levels of the modified program bound the mean much more closely.

For the unmodified program, the mean burden on all exposed surfaces, with the results of sensitivity studies 2 and 5 plotted for the ETR (after day 210), is given in Fig. 6-4. Figure 6-5 shows the results of the modified program for 5 percent, mean and 95 percent burden levels of the exposed surface.

During this time, in-house modifications were made to the computer program to increase the flexibility of the model and to minimize computer costs. Further investigation provided use of another output option, burden printout by biological zones, increasing the flexibility again.

Enumeration of the microorganisms on the surface of a spacecraft is necessary for sterilization process determination for planetary landers and for preparation of probability estimates for the planetary quarantine pre-launch analysis. The methods developed and results obtained show the extreme usefulness and the necessity of the model in predicting this microbial burden, and that from any microbial accretion process in general. The model thus lends itself to related work in water and air pollution, sewage treatment monitoring and control, and to work in similar fields.

### 6.3 PROBLEM AREAS

The environmental histograms used in the present model are based on data gathered from the Mariner '67 assembly and test sequence. This inaccuracy in present predictions will be rectified in the near future as new input histograms are formed, based on data from current biological assay data. These environmental histograms describe the fallout, or background contamination, consisting of spore and nonspore forming organisms in the different environments the spacecraft is subjected to during its assembly [JPL: Tent, High Bay, Vibration Area (Out of Tent), Simulator, Acoustic Lab; ETR: Hanger AO, Explosive Safe Facility (In Tent), Encapsulation].

One important (in-house) modification to the program was that permitting the suppression of the printout of unneeded output data, thus reducing computer run time and costs. As costs have been a limitation in determining the number and kinds of sensitivity studies performed, frequency of program updating is not definite. Tables 6-3 and 6-4 indicate the costs of past computer runs, and estimate costs of future runs based on past computer rates.

#### 6.4 FUTURE ACTIVITIES

Tasks proposed for the future include:

- 1) Comparison of predicted burdens with those of spacecraft direct assay estimates.
- 2) Comparison of results using both histograms based on Mariner '67 data and on current data.
- 3) Comparison of results of the old program to those of the new program (using current data).

Sensitivity studies similar to those performed on the Mariner '67 actual sequence and the Mariner '71 planned sequence should also be performed to provide data which will allow analyses and a better understanding of contamination and quarantine (decontamination) processes.

Table 6-1. Mariner '71 sensitivity studies

Study	Order of magnitude changes	Mean burden, exposed surface	Log increase	Mean burden, all surfaces	Log increase
1	Initial burden on solar panels	$8.38 \times 10^3$	None	$1.01 \times 10^5$	None
2	ETR operational fallout rate	$6.05 \times 10^4$	0.94	$2.88 \times 10^5$	0.45
3	Fallout and contact retention factors for harnesses and cables	$8.38 \times 10^3$	None	$1.01 \times 10^5$	None
4	Operational fallout rate on science instruments	$8.38 \times 10^3$	None	$1.01 \times 10^5$	None
5	"Average lifetime" of organisms	$9.32 \times 10^4$	1.05	$3.03 \times 10^5$	0.48
Baseline -- Mean burden on exposed surface: $8.38 \times 10^3$					
Baseline -- Mean burden on all surfaces: $1.01 \times 10^5$					

Table 6-2. Comparison of two sensitivity studies for the Mariner '67 and the Mariner '71

Order of magnitude change	Emulation	Pred. 95% burden level - exp. surface	Baseline	Log increase	Pred. 95% burden level - all surfaces	Baseline	Log increase
ETR operational fallout rate	MV '67	$4.88 \times 10^5$	$3.01 \times 10^5$	0.21	$6.00 \times 10^5$	$4.41 \times 10^5$	0.13
	M '71	$2.0 \times 10^5$	$2.3 \times 10^4$	0.94	$7.1 \times 10^5$	$2.5 \times 10^5$	0.45
"Average life-time" of organisms	MV '67	$5.97 \times 10^5$	$3.01 \times 10^5$	0.23	$7.45 \times 10^5$	$4.41 \times 10^5$	0.29
	M '71	$3.6 \times 10^5$	$2.3 \times 10^4$	1.19	$7.3 \times 10^5$	$2.5 \times 10^5$	0.47

Table 6-3. Costs of past computer runs

Run description	Cost, \$
Base Run (unmodified program)	333.44
Base Run (generate ITP Tape)	354.26
ITP Run	217.68
Sensitivity Study 1	269.86
Sensitivity Study 2	668.52
Sensitivity Study 3	692.96
Sensitivity Study 4	802.91
Sensitivity Study 5	596.51
Generate JPL Program Tape	30.31
Generate Martin Marietta Program Tape	32.87
Base Run (modified program)	414.81
Zone Printout-First Three Days	20.23

Table 6-4. Estimated costs of possible updating plans

Start Date - August 15, 1970, End Date - May 15, 1971

	Number of updates	Estimated CPU Time, sec	Estimated cost, \$	Total days tracked
1. Update program every week	40	19,600	12,700	5,736
2. Update program every two weeks	21	11,000	7,110	3,216
3. Update program monthly	10	5,560	3,600	1,626
4. Update program each month and each stage	22	13,000	8,480	3,806



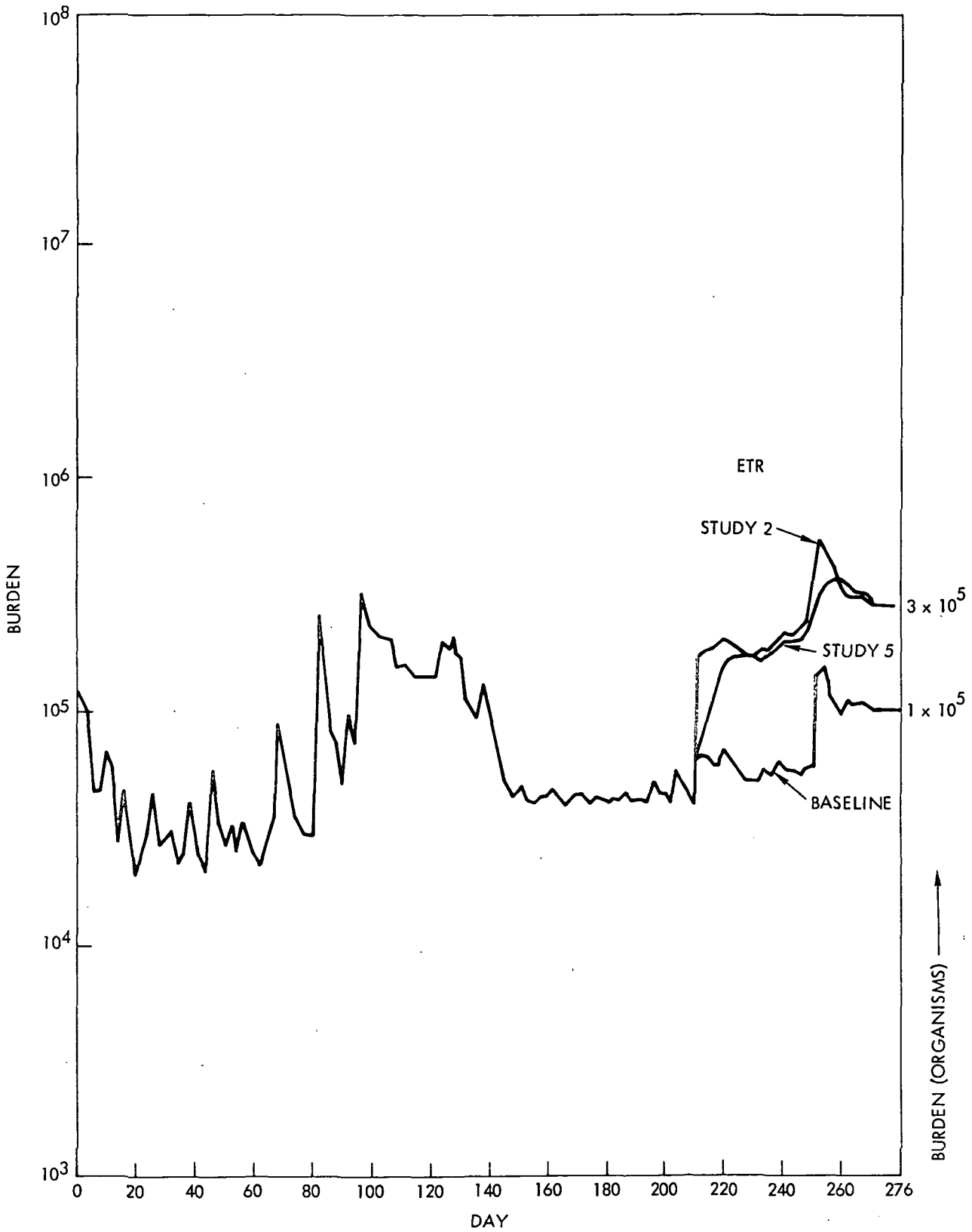


Fig. 6-1. Comparison of sensitivity studies 2 and 5 with baseline

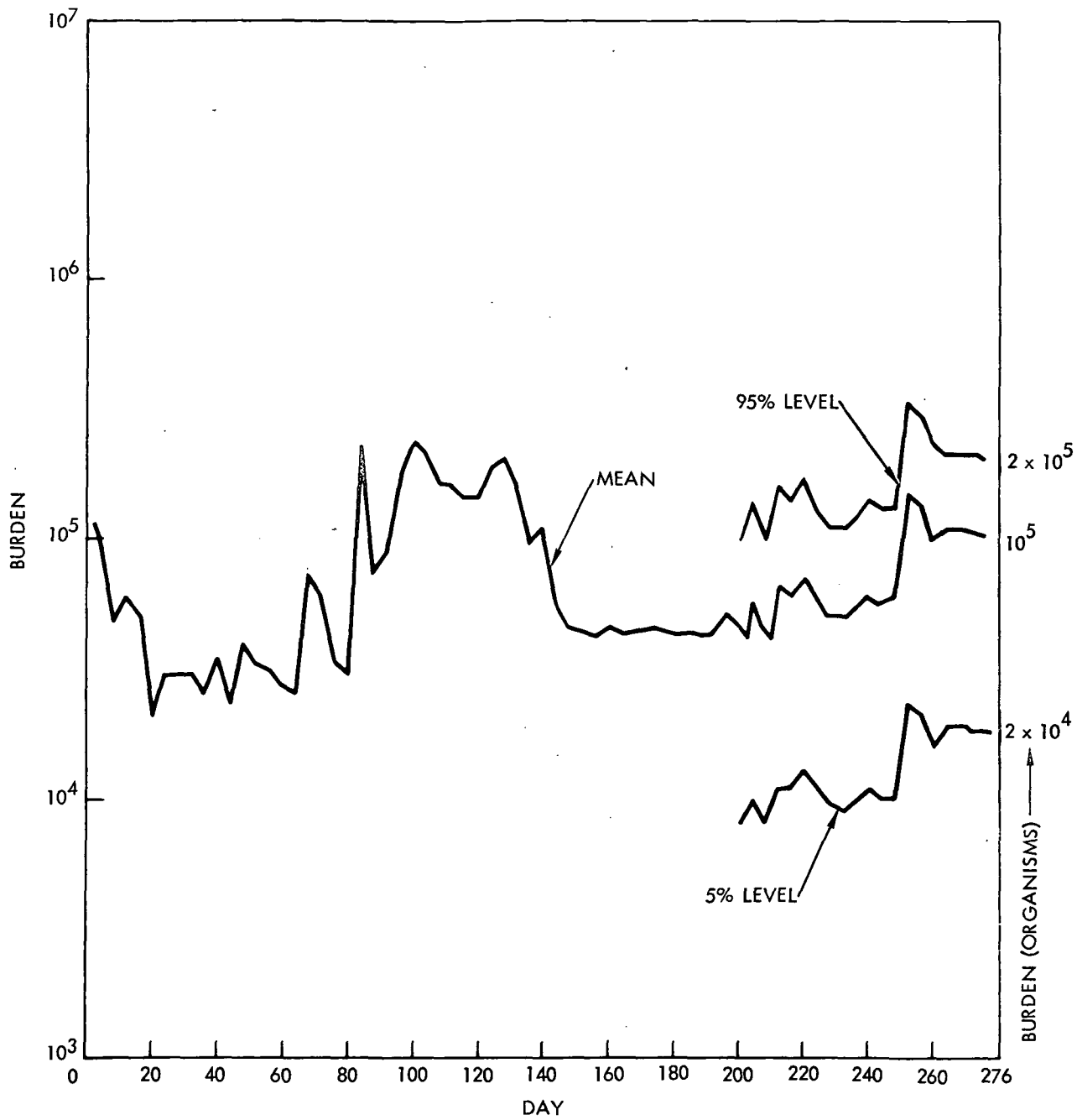


Fig. 6-2. M'71 predicted burden using unmodified program tape

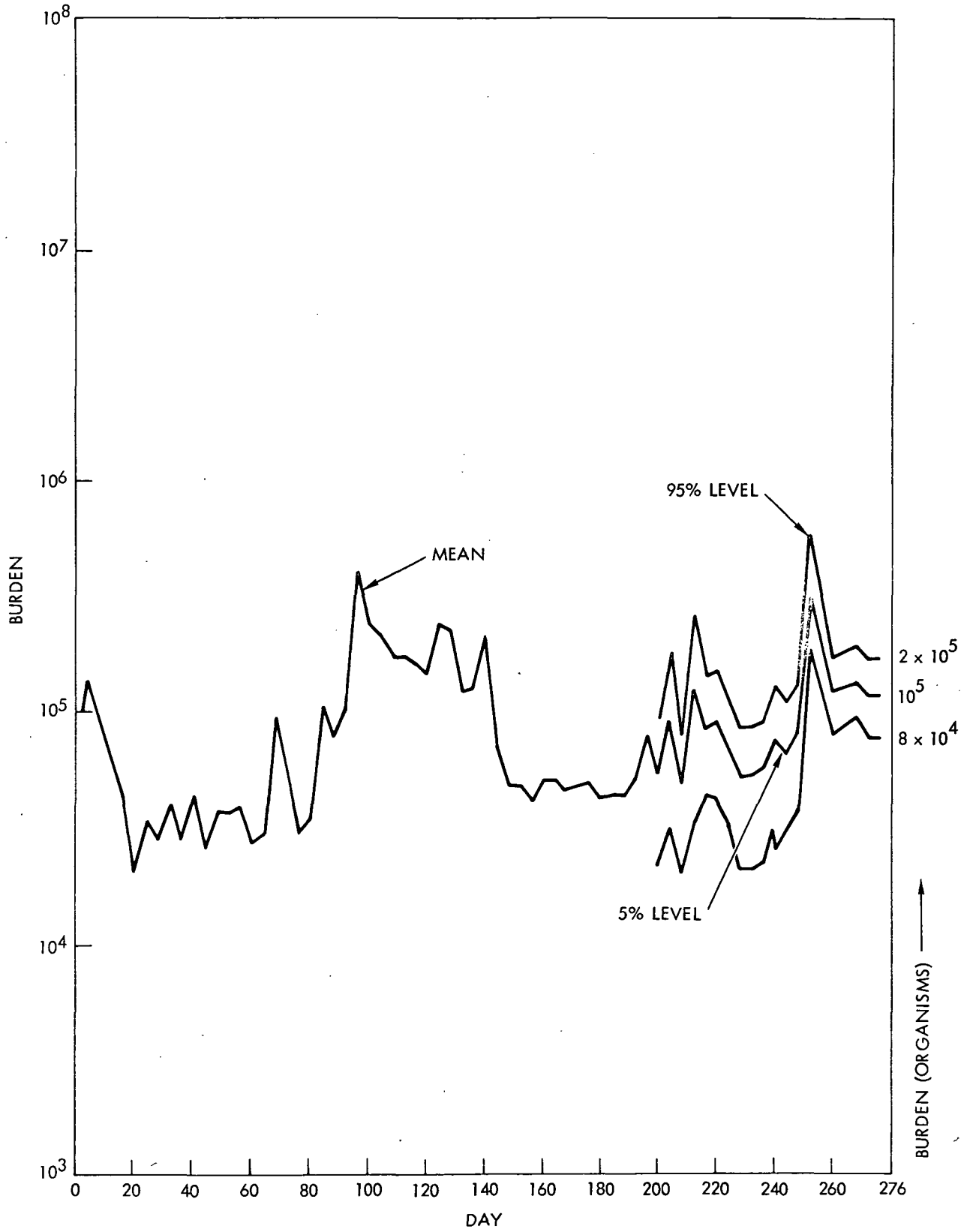


Fig. 6-3. M'71 predicted burden using modified program tape

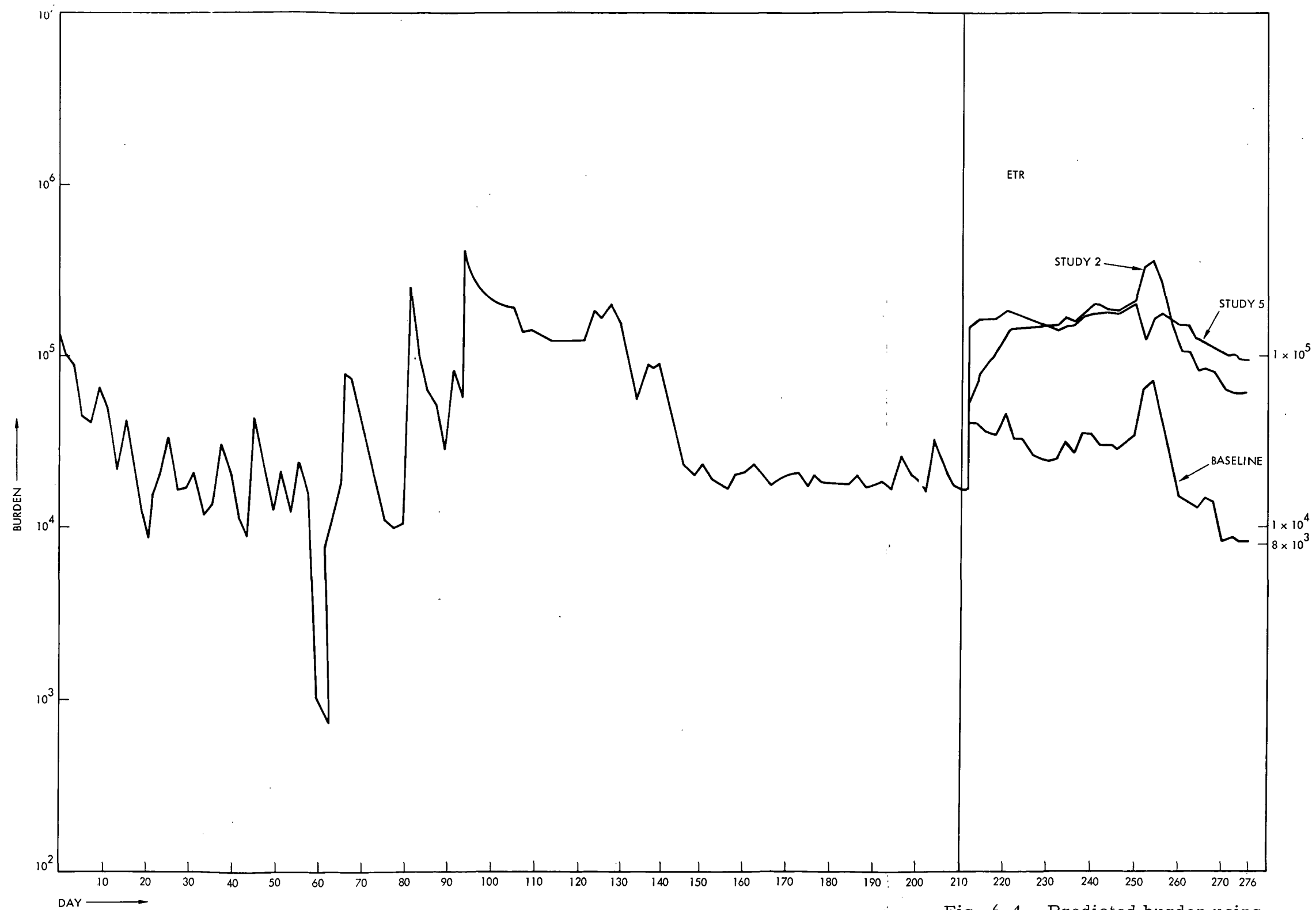


Fig. 6-4. Predicted burden using unmodified program tape - exposed surfaces, baseline, studies 2 and 5

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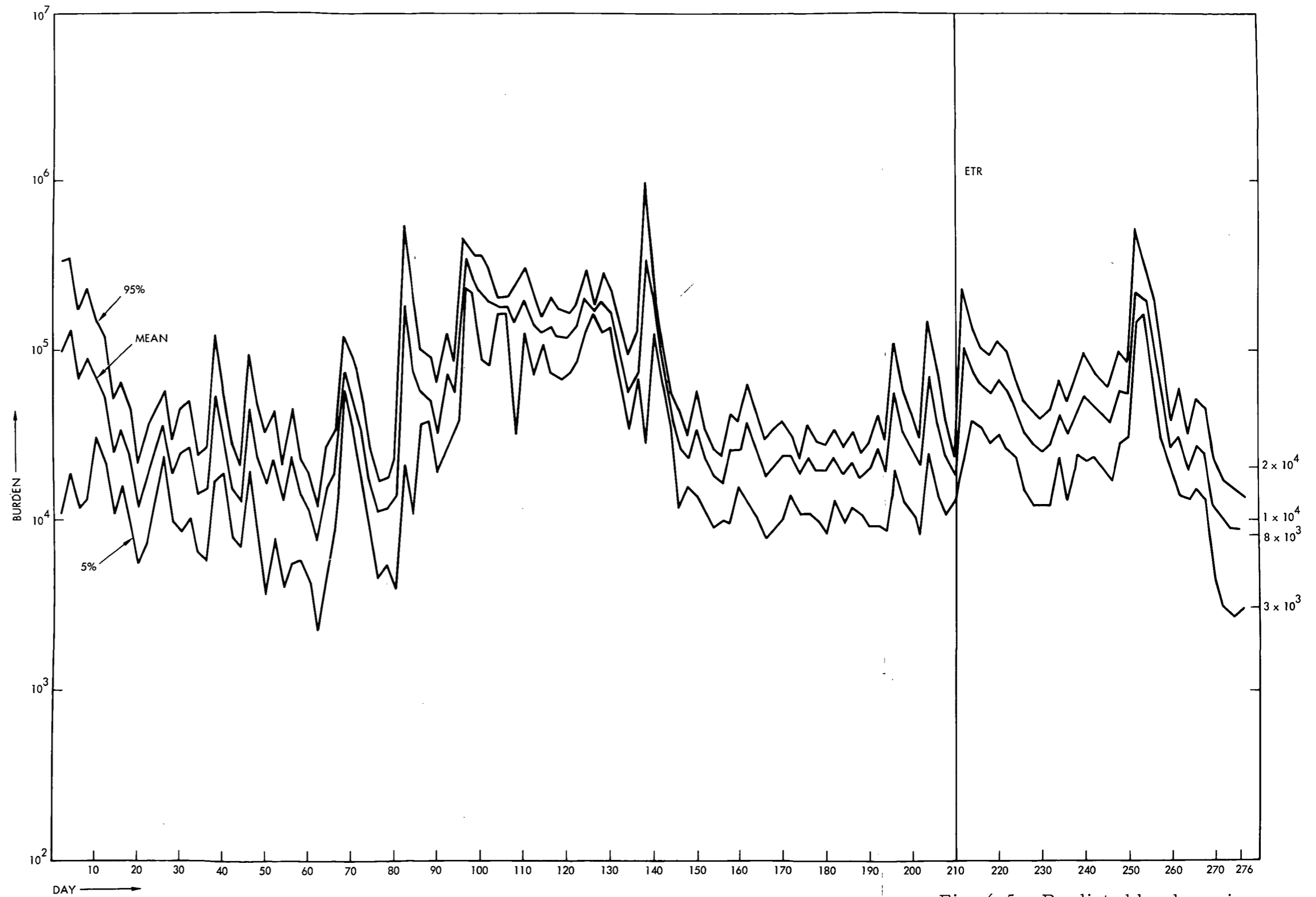


Fig. 6-5. Predicted burden using modified program tape - exposed surfaces, mean, 5% and 95% levels

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SECTION VII  
PLANETARY QUARANTINE CONSTRAINTS  
FOR ADVANCED MISSIONS

## SECTION VII

## PLANETARY QUARANTINE CONSTRAINTS FOR ADVANCED MISSIONS

NASA No. 191-58-63-10-55

Cognizance: C. C. Gonzalez

Associate Personnel: W. Stavro

## 7.1 INTRODUCTION

The objectives of this task are to perform analyses necessary to define planetary quarantine constraints, the parameters to which constraints are sensitive, determine mission strategies which will satisfy these constraints, and identify problem areas which will require further research.

Current models of the atmospheres of Jupiter and Saturn indicate the possible existence of regions with conditions favorable for growth of terrestrial microorganisms. To ensure that the environments of the outer planets are not altered biologically, a study was performed to identify planetary quarantine constraints and problem areas. Potential mission strategies compatible with both mission objective and planetary quarantine constraints were investigated.

Possible sources of contamination were identified and related to mission events, flight-path-control strategies, and interplanetary environments. Relevant parameters to which planetary quarantine analyses were considered most sensitive were selected and included in subsequent analyses. A preliminary allocation model was developed and analyses were performed to obtain probability of contamination values for the most significant sources. Potential problem areas in need of future research were identified.

## 7.2 SIGNIFICANT ACCOMPLISHMENTS

## 7.2.1 Tasks Conducted

The Planetary Quarantine Analyses for Advanced Missions involved the identification of contamination sources and the suballocation of probability of contamination among the various sources. A total allocation of  $7 \times 10^{-5}$  was assumed for each planet. Since the objective of the current analysis is not a detailed study, only major contributing sources were considered.



This report will present the results to date of the study to identify contamination sources and the relative importance of each. In order to determine whether a contamination source will result in microbiological contact with the planet in question, the initial steps involved trajectory considerations. The results of some base-line multiple planet mission studies are given along with results of related factors such as significant mission events, environmental parameters, sources of error and spacecraft reliability.

The main sources of contamination are considered to be large impactables such as the spacecraft and launch vehicle, and ejected debris.

A sequence of mission events was obtained from a Thermoelectric Outer Planet Spacecraft (TOPS) study in order to identify those which were potential contributors either to contamination by spacecraft impact or by ejected debris. In addition to identifying mission events, a list of parameters to which planetary quarantine analyses are sensitive was compiled. The parameters considered included the effect of planetary and interplanetary environment, launch vehicle characteristics, and trajectory and navigation parameters.

In performing a planetary quarantine analysis for large impactables, primary consideration must be given to trajectory and navigation analyses. The object of these analyses is to determine whether the mission would violate the quarantine constraint based on the allocation for spacecraft impact, and the relation of potential contamination sources to mission events. Flight-path-control and mission strategies which could be used to satisfy such constraints were investigated.

Two multi-planet gravity assist missions (Jupiter-Saturn-Pluto 1976 and 1977 opportunities) currently being considered by NASA were selected for analysis. Figure 7-1 shows the mission characteristics with the selected launch vehicle and launch period requirements. A spacecraft weight of 1450 lb was chosen based on current estimates for such a mission. Out of each opportunity a baseline trajectory was selected for quantitative analysis. The characteristics of these two trajectories, including launch and encounter dates, flyby altitudes, approach velocities and aim-points, are given in Fig. 7-2.

To perform the trajectory analyses, navigation errors associated with a typical mission were identified and are summarized in Fig. 7-3. Errors

in guidance hardware, gyro drift and accelerometer scale factor in all launch vehicle stages will be reflected in the injection of the spacecraft onto its interplanetary trajectory. A source of error, associated with the midcourse engine, is the magnitude and pointing capability of midcourse maneuvers. There are also the orbit determination errors associated with location of the spacecraft (radio tracking), and location of the planet (ephemeris uncertainty). For outer planet missions the ephemeris uncertainty is appreciable and thus there is a need for optical approach measurement instruments. Such an instrument is activated a few weeks before encounter to locate the exact position of the planet. Errors associated with such measurements are known as optical approach measurement errors. Finally, as shown in Fig. 7-3, there are the flyby errors, which are the magnification of arrival errors to departure errors in a planetary swingby due to uncertainties in the planet's gravitational attraction, oblateness and rotation, etc.

The presently adopted midcourse maneuver plan for a typical Jupiter-Saturn-Pluto mission is shown in Fig. 7-4. Injection plus a total of eight maneuvers are required. The time and purpose of each maneuver is listed in the illustration. Due to the above-mentioned navigational uncertainties, every time one of these nine maneuvers is performed, a certain probability of impact of the spacecraft into the encounter planet exists. This probability is a function of the direction (aiming) in which the maneuver is performed, as well as the errors in the maneuver. Trajectory and maneuver analyses were therefore performed to determine probabilities of impact. Trajectory analyses must also be performed to determine if ejected debris will impact the planet.

In addition to identifying sources of contamination and determining if they will impact the planet, the affect of environments encountered on the survival of organisms must also be considered. Planetary and interplanetary environmental parameters were identified in the mission sequence and values obtained. The environmental parameters also relate to other areas of PQ analysis such as the effect of meteoroid environments on particle release and in causing a catastrophic event such as spacecraft disintegration.

### 7.2.2 Results of Work

As a result of the investigation of mission events, the following mission phases were identified as potentially affecting planetary quarantine due to impact of spacecraft, a piece of hardware, or ejected debris.

- 1) Launch Phase; injection of spacecraft, deflection of launch/vehicle.
- 2) Attitude Stabilization
- 3) Cruise Phase; Pre-Maneuver and Post-Maneuver Phases
- 4) Mid-course Maneuver
- 5) Planetary Operations

Impact of the spacecraft, launch vehicle or hardware could result from: accidental aiming at the planet and subsequent loss of control, separation of hardware during operations such as scan platform unlatch.

Planetary environmental parameters for Jupiter, Saturn, and Pluto were provided. The planetary parameters for Jupiter and Saturn were taken from values provided in review copies of two NASA monographs being prepared at JPL. Very little information is available on Pluto, however, Pluto was included in order to do a complete Jupiter-Saturn-Pluto (J-S-P) analysis. Information was obtained from standard references. Interplanetary environmental parameters were also obtained from standard references.

The parameters of interest in terms of microbial survival included:

- 1) Planetary and interplanetary radiation environment, including charged particles.
- 2) Atmospheric structure - temperature, pressure, density, and composition which are required to understand the potential microbial growth and survival in the zones or regions of interest in the atmosphere; the analysis of the entry of a spacecraft or debris into the atmosphere and associated heating effects; and the analysis of orbital decay.

Parameters which affect ejected debris and catastrophic events include the asteroid and meteoroid environments and Saturn's rings.

The analyses needed to determine the probability of impact at Jupiter, due to injection errors, and the probability of impact at Saturn, due to Jupiter flyby errors, for both the '76 and '77 J-S-P missions were performed. The following assumptions and information were used in these calculations:

- 1) Lewis Research Center provided values of the injection errors for the TITAN IIIB/Centaur/Burner II launch vehicle for a mission that has a launch date of 1/1/70, an injection energy of  $22 \text{ km}^2 / \text{sec}^2$  (compared to approximately  $110 \text{ km}^2 / \text{sec}^2$  for a J-S-P), and a payload of 1450 lb. Since these were the best numbers available for the launch vehicle injection errors for the TITAN IIID/Centaur/Burner II (2300) for a typical J-S-P mission, they were used in this analysis.
- 2) In order to determine the Jupiter flyby errors, one must know the navigational errors just before Jupiter encounter. Assuming all maneuvers prior to Jupiter encounter were successfully executed, these resultant errors are the smaller of either the orbit determination errors or the optical approach measurement errors. Due to lack of data pertaining to orbit-determination errors for such a mission it was assumed that the final pre-Jupiter errors were those associated with the optical approach measurement.

In a multiple planet mission, the flyby geometry at the intermediate planets is fixed. This makes these missions unique when compared to previous single planet flyby missions where the encounter geometry is dictated by science and engineering desires as well as quarantine constraints.

These required maneuver aiming directions are usually demonstrated on the so-called "aim-plane" at the encounter planet. This is a plane which passes through the center of the target planet and is perpendicular to the incoming asymptote of the approach hyperbola. For multiple planet missions, therefore, there exists a specific point on the aim-planes of each intermediate planet which is the required final aim-point. In order to maximize the probability of total mission success and minimize the required fuel loading, it is

desired to aim at that required aim-point with all maneuvers prior to that encounter. This, however, may violate the planetary quarantine constraint on the encounter planet (see discussion in Section 7.2.1). For example, if the injection maneuver is aimed at the required final aim-point at Jupiter, errors in the injection maneuver, when mapped into encounter errors, may result in a probability of impact (assuming no midcourse corrections are able to be performed) that may violate the constraint allocated to that maneuver by the overall PQ constraint on Jupiter.

Using this procedure with the assumptions mentioned above, a computer program was written to determine the probability of impact of a specific aim-point in the aim-plane. The program also plotted contours of constant impact probability in that plane. Figure 7-5 shows the required aim-points, the 1- $\sigma$  ellipse of injection errors (in the case of Jupiter) and Jupiter flyby errors (in the case of Saturn), and the probability of planetary impact due to these errors. It is noticed immediately that the values of impact probability are several orders of magnitude larger than  $10^{-5}$ , where the allocated PQ constraint for that maneuver will probably lie if it is assumed that planetary impact by the spacecraft will cause contamination. The large ellipse in the aim-plane represents a contour of equal probability of impact of  $7 \times 10^{-5}$  due to injection errors and no correction maneuvers. All aim-points inside that contour, including the desired injection aim-point, have higher probabilities of impact.

### 7.2.3 Meaning of Results to Planetary Quarantine

The results of definition of the planetary and interplanetary parameters indicate that a spacecraft on an outer planets mission will encounter environments not encountered previously. Therefore, Planetary Quarantine analyses for these missions will cover new territory. Also, it becomes apparent when considering the models of atmospheres of Jupiter and Saturn that these planets appear to have habitats that may be suitable for the survival of terrestrial microorganisms.

The trajectory and navigation analyses indicate that the probability of impact of a spacecraft on an unbiased trajectory will exceed the allocation for large impactables.

This indicates both the importance of studying flight-path maneuver strategies to stay within prescribed planetary quarantine constraints for the outer planet missions and the possible sterilization effects due to the environment and entry heating.

### 7.3 PROBLEM AREAS

The main problem areas encountered so far is the lack of navigation and maneuver analysis data on multiple outer planet missions. Such data has been generated in this task for purposes of analysis.

### 7.4 FUTURE ACTIVITIES

#### 7.4.1 Work Planned for Next Six Months

Planetary Quarantine analyses will be performed with selected flight-path-control and mission strategies in order to identify optimal strategies. A more detailed planetary quarantine analyses will then be performed with optimal strategies to the limits which available information and time will allow. The probability of contamination due to both large impactables and ejecta debris will be determined for the Jupiter-Saturn-Pluto missions for each of the three planets. The analyses will use the environmental information obtained in the first subtask and a list of possible mission events obtained from the Thermoelectric Outer Planet Spacecraft (TOPS) Study, and studies being performed for outer planet missions. Preliminary allocations for launch vehicle, spacecraft and ejecta-efflux will be made based on a total planetary quarantine constraint for each planet of  $7 \times 10^{-5}$ .

Future required work will be identified as well as problem areas which need special attention.

#### 7.4.2 Additional Required Work

The following work is required to better understand the problem of planetary quarantine analyses for outer planets missions:

- 1) Study of entry heating of spacecraft or related debris into an outer planet atmosphere. The heating associated with entry may be sufficient to render a spacecraft or related debris both internally and externally sterile by the time it reaches the biologically interesting regions of the atmosphere. Previous studies have not paid sufficient attention to various types of shapes, sizes and materials of impacting bodies. Also, ablative characteristics were not considered in sufficient detail to understand effects of heat blockage.
- 2) Provide values of environmental parameters for Uranus, Neptune, and Pluto.
- 3) Preliminary Jupiter-Uranus-Neptune Mission PQ Analysis. Perform a Planetary Quarantine (PQ) analysis to identify problem areas significantly different from a J-S-P mission. For instance, the greater distances involved lead to larger navigation uncertainties than those currently anticipated for a J-S-P mission. Also, there is a greater amount of uncertainty in the state of knowledge of the outer two giant planets than for Jupiter and Saturn.
- 4) Preliminary Jupiter orbiter and/or entry probe mission PQ analysis. A PQ analysis similar to that currently being performed for a J-S-P mission. The fact that an orbiter will spend a longer time in the vicinity of the planet coupled with different modes of entry into the planetary atmosphere from a flyby, requires a separate analysis for such a mission. Even if an entry probe would be sterilized; an analyses would still be in order.
- 5) Analyze problem areas not considered in the current J-S-P PQ analysis. The analyses would be based upon and complement current (fiscal 1970) J-S-P analyses, with the use of selected optimal mission strategies. It would also use updated spacecraft, launch vehicle and mission parameters.

- a) Include PQ analysis for satellites most likely to have biological interest. A great deal of interest is being shown in selecting trajectories for a J-S-P mission which will bring the spacecraft close to the satellites of Jupiter and Saturn.
- b) Consider problem of satisfying conflicting PQ constraints (if any exist) - such as a planet and its satellites.
- c) Consider hazards of flying through the asteroid belt, perform an ejecta debris analysis.

## 7.5 PUBLICATIONS

Stavro, W. and Gonzalez, C., "Planetary Quarantine Considerations for Outer Planet Missions", an abstract of a paper submitted for presentation at the AAS 17th Annual Meeting, Seattle, Washington, June 28 - 30, 1971.

Stavro, W., and Gonzalez, C., "Flight Path and Mission Strategies to Satisfy Outer Planet Quarantine Constraints", an abstract of a paper submitted for presentation at the AAS/AIAA Astrodynamics Conference, Ft. Lauderdale, Florida, August 17 - 19, 1971.



## MISSION AND TRAJECTORY SELECTION

### MISSION CHARACTERISTICS

- 1977 J-S-P
  - LAUNCH VEHICLE, TITAN IIID (7 segment)/CENTAUR/BURNER II (2300)
  - LAUNCH PERIOD REQUIREMENT: 21 days (ONE LAUNCH)
  - SPACECRAFT WEIGHT: 1450 lb
  - MAXIMUM INJECTION ENERGY AVAILABLE:  $135 \text{ km}^2/\text{sec}^2$
  - MISSION DURATION: 7.58 years
  - LAUNCH DATES: Aug. 27, 1977 to Sept. 16, 1977
  
- 1976 J-S-P
  - LAUNCH VEHICLE: TITAN IIID (5 segment)/CENTAUR/BURNER II (2300)
  - LAUNCH PERIOD REQUIREMENT: 15 days (ONE LAUNCH)
  - SPACECRAFT WEIGHT: 1450 lb
  - MAXIMUM INJECTION ENERGY AVAILABLE:  $110 \text{ km}^2/\text{sec}^2$
  - MISSION DURATION: 9.1 years
  - LAUNCH DATES: July 23, 1976 to Aug. 6, 1976

Fig. 7-1. J-S-P missions selected for analyses

### MISSION AND TRAJECTORY SELECTION TRAJECTORY CHARACTERISTICS

- 1977 J-S-P TRAJECTORY:

LAUNCH DATE: 4 September 1977

LAUNCH  $C_3 = 126.4 \text{ km}^2/\text{sec}^2$

	<u>DATE</u>	<u>ALT AND CLOSEST APPROACH</u> (km)	<u>B</u> (km)	<u><math>\theta</math></u> (deg)	<u><math>V_\infty</math></u> (km/sec)	<u>BENDING ANGLE</u>
JUPITER ENCOUNTER	Dec 21, 78	152,094.5 (2.13 R)	593,170.3	3.4	13.7	97.4°
SATURN ENCOUNTER	Jun 8, 80	310,315.3 (5.14 R)	468,575.3	65.2	18.5	26.6°
PLUTO ENCOUNTER	Apr 3, 85	-----	-----	---	21.3	---

- 1976 J-S-P TRAJECTORY:

LAUNCH DATE: July 30, 1976

LAUNCH  $C_3 = 106.3 \text{ km}^2/\text{sec}^2$

	<u>DATE</u>	<u>ALT AND CLOSEST APPROACH</u> (km)	<u>B</u> (km)	<u><math>\theta</math></u> (deg)	<u><math>V_\infty</math></u> (km/sec)	<u>BENDING ANGLE</u>
JUPITER ENCOUNTER	Jan 1, 78	6,744 (0.10 R)	406,787	3.1	11.14	136.5°
SATURN ENCOUNTER	Feb 8, 80	365,095 (6.04 R)	560,186	55.9	15.6	31.1°
PLUTO ENCOUNTER	Sept 11, 85	-----	-----	---	18.55	---

Fig. 7-2. Trajectory particulars of two J-S-P missions

## **NAVIGATION ERRORS ASSOCIATED WITH A MULTIPLE PLANET MISSION**

- LAUNCH VEHICLE INJECTION ERRORS:

ERRORS IN GUIDANCE HARDWARE, GYRO DRIFT AND ACCELEROMETER SCALE  
FACTOR IN ALL LAUNCH VEHICLE STAGES

- EXECUTION ERRORS:

MIDCOURSE ENGINE MAGNITUDE AND POINTING ERRORS

- ORBIT DETERMINATION ERRORS:

1. RADIO TRACKING ERRORS
2. EPHEMERIS UNCERTAINTY

- OPTICAL APPROACH MEASUREMENT ERRORS:

APPROACH GUIDANCE INSTRUMENT ERRORS ASSOCIATED WITH 'TARGET CENTER  
FINDING' AND 'CELESTIAL DIRECTION MEASUREMENT' UNCERTAINTIES

- FLYBY ERRORS:

MAGNIFICATION OF ARRIVAL ERRORS TO DEPARTURE ERRORS IN A  
PLANETARY SWING-BY

Fig. 7-3. Typical mission errors used in trajectory analyses

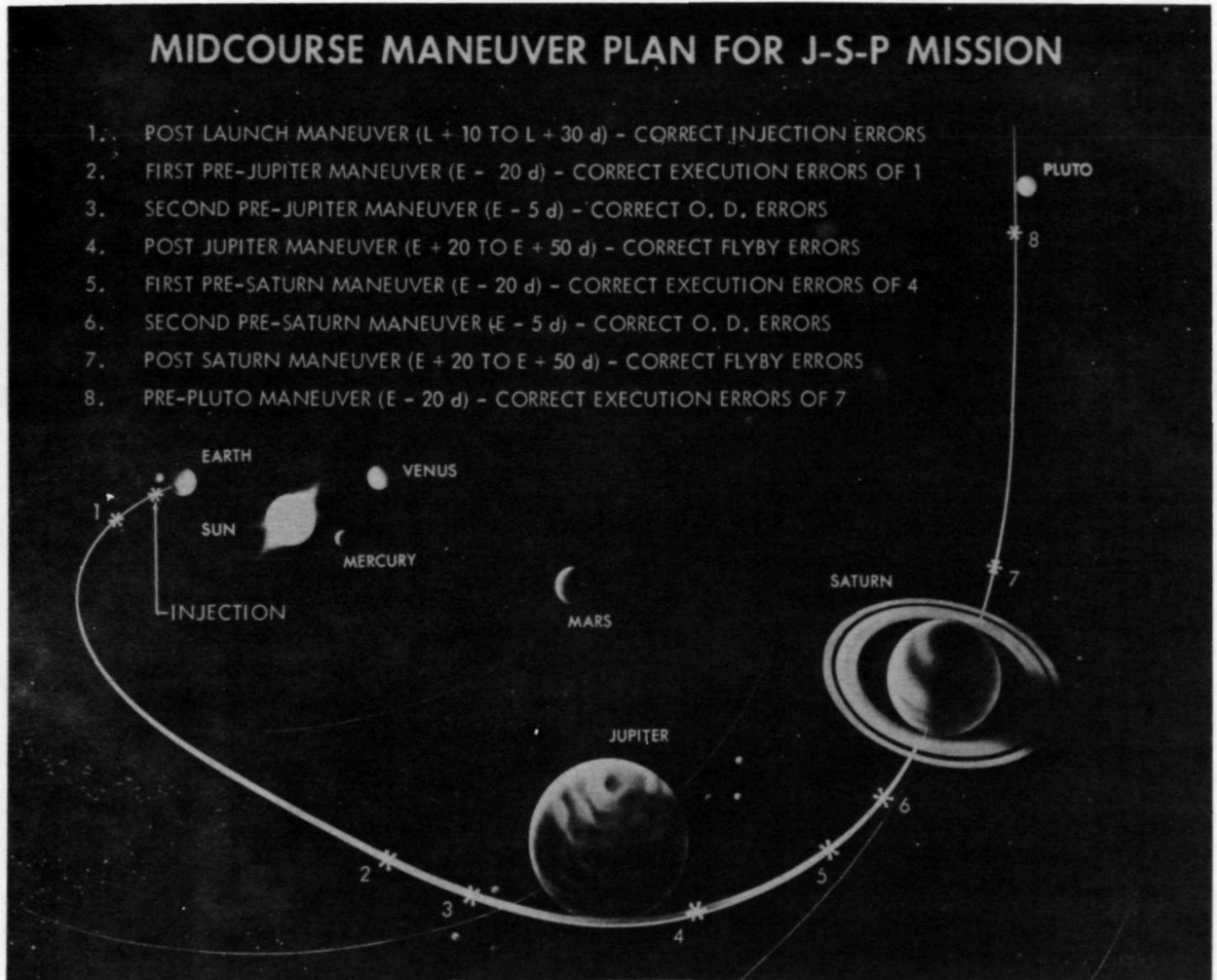


Fig. 7-4. Selected midcourse maneuver plan

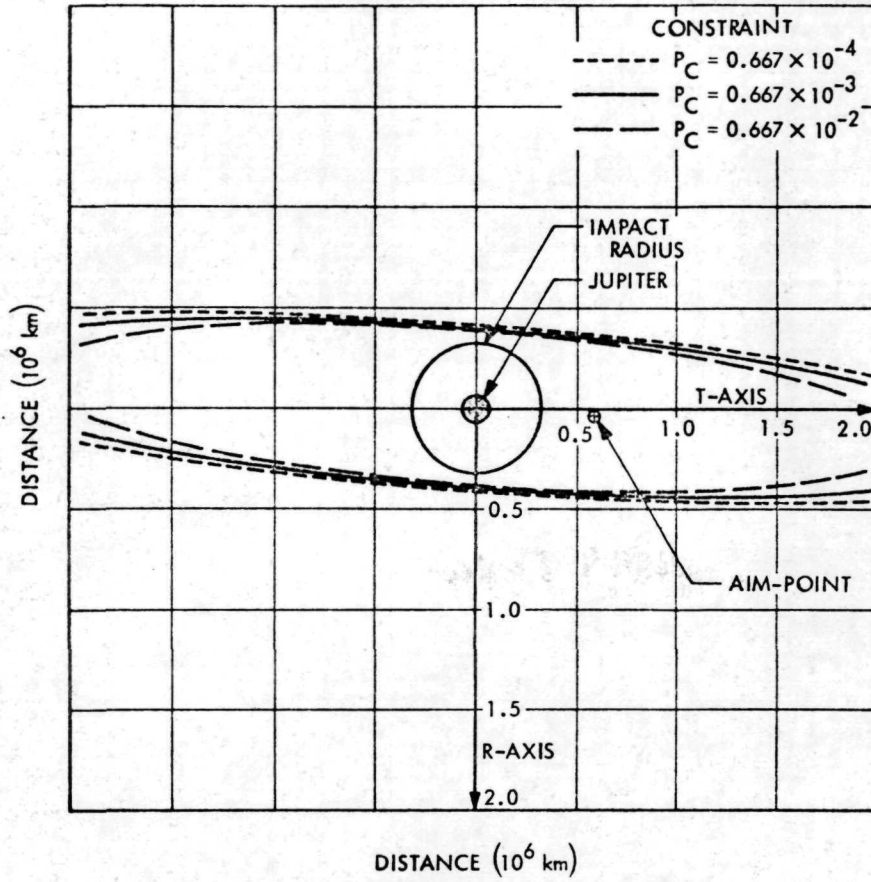


Fig. 7-5. Impact Probability Contours at Jupiter Aim-Plane for Injection Errors, 77 J-S-P

900-484

SECTION VIII  
POST LAUNCH RECONTAMINATION STUDIES

## SECTION VIII

## POST LAUNCH RECONTAMINATION STUDIES

(NASA 191-58-63-11-00-55)

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## 8.1 INTRODUCTION

During the launch phase and the spaceflight portions of a given mission, the spacecraft is exposed to a variety of environments. Such environments may cause the redistribution of viable particulate burden on the spacecraft by affecting the dislodgement, transport, and redeposition of particulates on various surfaces.

Two fundamental aspects are of interest when considering recontamination of a lander/orbiter type spacecraft, namely:

- 1) Particulate redistribution on the orbiter.
- 2) Recontamination of an initially sterile lander.

The subject study represents an effort to assess the effect of mission environments on viable particulate migration. Assessment of the various migration due to the various environments and quantifying such effects represent the core of the effort. Such mechanisms, together with an estimate of the various environment intensities for a typical mission, shall be integrated to provide a tool for obtaining quantitative estimates of particulate redistribution.

In this study the payload shroud internal surfaces are considered the most significant potential source of added contamination that may migrate to the spacecraft surfaces during the launch phase. The study assumes the redistributed burden on the spacecraft after launch as being the initial burden conditions for spaceflight particulate migration analysis.

The basic philosophy adopted in the task implementation is the concentration on the understanding of the fundamental physics behind various relevant particulate migration mechanisms, even though some of the mechanisms are, only at present, definable through qualitative statements. The approach also seeks quantization of various parameters employing rigorous physical arguments and/or experimental data whenever possible, with the

additional emphasis on formulating the nature of the approximation encountered with each type of analysis. The approach is also designed such that it may enable the analyst to "pin point" the areas where experimental data is mandatory for making quantitatively meaningful assessments, and to propose when needed a well defined experimental technique for acquisition of data relevant to the problem parameter.

## 8.2 TASK DEFINITION

### 8.2.1 Qualitative Analysis of Test Launch Recontamination

8.2.1.1 The Launch Phase. During the lift off, launch vehicle rocket motor burn induces an intense acoustic field in the vicinity of the vehicle. Such an environment induces random vibration in both the launch vehicle and the payload shroud. The vibration of the shroud may cause the release of viable particulates that may be initially attached to the shroud internal surfaces. In addition, the acoustic environment induced within the shroud, together with the structural dynamic coupling between the S/C and the launch vehicle, affects the excitation of the S/C into random vibration. Although the vibration levels acquired by the spacecraft is envisioned to be less than those imparted to the shroud, particle release from the spacecraft surfaces may still be possible.

Shortly after lift off, and due to the rapidly decreasing pressure in the vicinity of the shroud vent holes, the air within the payload cavity is rapidly discharged to the outside creating a convective aerodynamic environment within the cavity. Such a complex flow pattern may be envisioned to provide the predominant transport mechanism of dislodged particles. In addition to the above mentioned effect, however, nose cone aerodynamic heating as well as internal aerodynamic heating may bear relevance to the sterilization of microorganisms attached to the heated shroud internal surfaces and to an expected lesser extent on the S/C outside surfaces.

Early in the launch phase, the pressure within the payload cavity becomes reduced considerably and the internal air density becomes sufficiently small that the predominant transport mechanism becomes the static acceleration environment of the launch vehicle.



During the major portion of the launch phase the shroud and the spacecraft are exposed to a series of booster transients due to booster staging and explosive charge firings. Such events continually contribute to the particle dislodging from the various surfaces within the payload cavity.

When the external dynamic pressure becomes reduced sufficiently, the shroud is then jettisoned. Such an event induces the highest dynamic acceleration levels in the shroud structure. In fact, the separation is accomplished normally through the firing of a shaped charge that induces the cutting of the shroud skin along pre-designated contours. Some shroud designs employ rocket thrusters to assist the shroud separation in a fashion that would clear the spacecraft.

The debris and the dislodged particles released during the shroud separation have two transport mechanisms available to them. One being the aerodynamic effects now that the spacecraft is exposed to the external atmosphere, another being the launch vehicles static acceleration. In addition, the spacecraft is also exposed to significant aerodynamic heating in the period immediately following the shroud separation. Such heating effects may be relevant to the possible sterilization of viable organisms on a fraction of the spacecraft surfaces.

The last event of interest in the launch sequence is that of the spacecraft separation. The spacecraft separation is normally achieved through the firing of a pyro-device (V-band release for the Mariner type S/C). Such an event induces large acceleration levels in the vicinity of the explosive device and is envisioned to release significant amount of particle ejecta from the neighboring spacecraft surfaces. Post S/C separation the craft is then ready to assume the Heliocentric portion of the flight. At that time the bio-burden of the S/C could have been considerably altered from what existed prior to lift off.

8.2.1.2 The Heliocentric Flight. The envisioned principal mechanisms of particulate dislodgement from the various spacecraft surfaces during the Heliocentric flight may be through meteoroid impact as well as pyro-firing events aboard the spacecraft. Such pyro-firing events may correspond to pyro-value firings for engine burns, a science platform unlatch (as in the Mariner

type vehicles) and solar panel release and deployment. Other dynamic environments of milder amplitude may also occur depending on the particular mission and the associated spacecraft design. Most of such dynamic disturbances are localized and are propagated over a relatively small zone of influence. Assuming no surface lamination or fragmentation, particulates closer to the disturbance source may acquire sufficiently large ejection velocities to escape the S/C local force field. (Gravitational, Electrostatic, Magnetic... etc). In a region sufficiently remote from the disturbance, the propagated excitation may not be large enough to dislodge a significant percentage of the attached contaminants. A third region in between the two previously discussed zones may possess sufficient dynamic environment to dislodge particulates but with ejection velocities smaller than those needed for escape. Such a zone may yield dislodged contaminants that will tend to temporarily orbit the spacecraft. (Such particles have been detected by the Canopus tracker on board the MM'69).

Transport mechanisms of contaminants may be due to line of sight "straight" trajectories from the dislodgement site to a redeposition site, or due to the biasing of orbiting particulates through the exposure to other forces, mainly, solar electromagnetic (EM) radiation pressure. Such pressures are extremely small, nevertheless, due to the small size of the orbiting particles (space cloud of contaminants), the solar EM radiation pressure can be shown to affect the scavenging of such particles biasing their orbits around the spacecraft away from the sun. In addition to the above described mechanisms, spacecraft trajectory and attitude maneuvers can cause the alteration of the relative position of the spacecraft with respect to the orbiting contaminants and hence may yield redeposition of a portion of such particles.

The above mentioned mechanisms of particle ejection, transport and redeposition are continually available during the Heliocentric position of the mission.

8.2.1.3 The Aerocentric Flight. In the vicinity of the target planet, the bio-shield is ejected with its associated dynamic environment releasing particulates that may or may not contribute significantly to the already released and tandem traveling particulates.

Orbiting maneuvers, and the other types of transport mechanisms discussed for the heliocentric flight become of most significance after the bio-shield ejection. The detailed geometry of the S/C and the topological aspects of the near planet maneuvers become of importance.

In addition the orbiter/lander separation is also a pyro-event and, therefore, may dislodge additional contaminants from various surfaces.

The details of the method by which the separation and deorbit of the lander is achieved becomes of significance when the question of the probability of the lander intercepting, or being intercepted by ejecta and acquiring them is raised.

As for the orbiter and the associated ejecta in the aerocentric orbital flight, the particulate redistribution activities during both the launch phase and the Heliocentric portions of the flight may affect the burden sharing between the various spacecraft surfaces, and may therefore invalidate the assumptions currently made regarding the maintenance of the burden percentage sharing that existed prior to lift off. (This is the assumption that the S/C burden at encounter is a fraction of that prior to lift off with the same distribution sharing between the various surfaces.)

### 8.2.2 Task Structure

The first step in the task implementation was devoted to the detail task subdivision and scoping. The purpose of such an effort was to identify the specific task areas related to the various technical disciplines and to construct a task implementation plan for the current fiscal year.

A combined discipline approach is being employed in this study in an attempt to identify and quantify the parameters associated with particulate redistribution during relevant mission events. The subject investigation was subdivided into a study of:

#### Principal Subtask "A"

The adherence forces between particles and spacecraft surfaces and the intensity of the various types of flight environments necessary to dislodge such particles:

- 1) Literature search.
- 2) Construction of a mathematical model for adhesive forces.
- 3) Assessment of the Relevant Environment Intensities necessary to dislodge various surface particles.
- 4) Identification of further work needed to better determine the various parameters.

Principal Subtask "B"

Launch phase dynamic events and their associated aerodynamic, vibration, and acoustic environments.

- 1) Launch vibration levels of both the spacecraft and the shroud.
- 2) Launch acoustic levels internal to the shroud.
- 3) Launch vehicle transient vibration environments.
- 4) Launch phase aerodynamic environment.

Principal Subtask "C"

Effect of the launch phase on the migration of particulates from the spacecraft shroud to the Orbiter and/or Biobarrier:

- 1) Estimates of the payload cavity burden distribution.
- 2) Effect of the launch phase dynamic environments on particle dislodging within the payload cavity.
- 3) Particulate redistribution and the aerodynamic environments.

Principal Subtask "D"

Space flight environments and their intensities during various trajectory domains: Relevant spacecraft environments identified for a typical mission are listed below:

- 1) Meteoroid momentum and energy fluxes.
- 2) Solar wind electron and proton energy fluxes.

- 3) Radiation pressure and light intensities as function of frequency.
- 4) Magnetic fields intensity originating from spacecraft and intra-stellar space.
- 5) Electrostatic fields arising from the spacecraft.
- 6) Gravitational field arising from spacecraft.
- 7) Pyro-valve firing shock and vibration environments.
- 8) Trajectory maneuvers.

Principal Subtask "E"

Spaceflight phase particulate redistribution mechanisms:

- 1) Particle Dislodgement.
  - Meteoroid impact shock propagation
  - Vibration and shock environments
- 2) Particle Transport relative to the spacecraft.
  - Solar wind
  - Solar electromagnetic radiation
  - Magnetic fields
  - Gravitational fields
  - Trajectory maneuvers

Principal Subtask "F"

Spaceflight particulate redistribution model.

The subsequent sections summarize the task completed portions and delineates the corresponding results.

### 8.3 SIGNIFICANT ACCOMPLISHMENTS

The following presents the completed subtasks and the associated interim work results.

### 8.3.1 Particle Adhesive Force Model

Particle adhesive forces, in general, are dependent upon a large set of variables. Such variables may be separated into three main categories, namely:

- 1) Particle related variables such as particle size, shape, material and electrostatic charges on the particle.
- 2) Surface related variables such as surface roughness, material and electrostatic charges on the surface.
- 3) Surrounding environment related variables such as the medium; air, fluid, vacuum...etc. In air, for example, other environment variables such as relative humidity have been shown to bear strong relationship to particle forces.

Figure 8-1a delineates typical shapes of particles that have been observed on various surfaces. They tend to display a wide range of aspect ratio and indeed not all of such particles are near spherical in shape.

The scope of the effort on the definition of particle forces was limited to conditions relevant to those that may exist on spacecraft surfaces, i. e., only particles in air, and of materials typical of those that may be found on a S/C surface were considered.

The literature review on the subject of particle adhesive forces has shown that most of the experimental work was biased towards the questions relevant to the problem of surface cleaning, a fact that caused the experimenters to seek and report upper bound type information on particle forces.

In addition, the data available from various sources introduce rather significant contradictions in the claimed findings; and most of such data was not applicable to the particle force under typical conditions relevant to S/C type surfaces. For example, one author's test was made to obtain particle forces for glass spherical particles on optically flat quartz surfaces (Ref. 2 and 7). The analytical treatment on particle forces, however, employed idealized spherical shaped particles and yielded a significant comparative relationships between the various particle forces.

Figure 8-1a depicts the four most significant particle forces that may exist in a gaseous environment (Air). These forces have contributions that vary in magnitude with respect to the total particle adhesive force. The most significant contribution appears to be due to the existence of surface tension forces between the particle and a film of water that binds the particle to the surface. Such a film is a consequence of local deposition of water due to the humidity of the surrounding air. In fact, experimental data have shown an increase in particle force with the increase in the relative humidity of the surrounding environment.

The second adhesive force of significance is the force due to molecular attraction between the particle molecules in the vicinity of the surface. Here again experimental data in the literature indicates that a particle in a dry atmosphere retains 30 to 40 percent of its adhesive force at 100 percent RH.

Electrical forces due to coulomb attraction between typical charged particles on a spacecraft surface may be the third in magnitude with the magnetic forces being the least significant (Ref. 1). Order of magnitude type analysis on a charged particle have shown that (Fig. 8-1b) the electrical forces are of the order of  $2.3 \times 10^{-7}$  dynes for particle sizes in the range from  $10\mu$  to  $100\mu$  in diameter. Typical particle charge intensities were obtained from experimental results reported on the measurement of particle charges on various size particles. The data indicated that the charge is almost linearly proportional to the particle diameter in the subject range with approximately 1000 electron charges on a  $10\mu$  diameter particle.

In comparison to the experimental particle forces measured on a  $100\mu$  particle, which is in the order of 1 to 3 dynes at 100 percent relative humidity, it appears that surface tension and molecular forces are the major contributors to particle adhesive forces in an atmospheric environment.

An empirical formula was constructed to provide a best curve fit relation for the basic particle adhesive force as a function of; particle diameter ( $D_p$ ), relative humidity (RH) and surface roughness (S). (Equation 1).

$$F = k D_p (\alpha + \beta RH) (-1.7S) \quad (1)$$

$$10\mu \leq D_p \leq 100\mu$$

$$0\% \leq RH \leq 100\%$$

$k, \alpha, \beta, \gamma$  are constants empirically determined

$D_p$  = Particle Diameter

RH = Relative Humidity

S = Surface Roughness

The formula covers the range from  $10\mu$  to  $100\mu$  particle size, 0 to 100 percent of relative humidity and the surface roughness range from  $2100\text{\AA}$  to  $4800\text{\AA}$ .

Further examination of the formula shows that particle force appears to be linear with both the particle size and the relative humidity, and bears a logarithmic relationship to the surface roughness. The range of surface roughness, however, in which the data was available (Ref. 1 and 7), is small and even at  $S = 4800\text{\AA}$  is still within a surface roughness that is less than the wave length of green light. Therefore, the explicit effect of the surface roughness was, of necessity, excluded from the model formulation and only the linear dependence on particle diameter and relative humidity were retained (Equation 2).

$$F = k D_p (\alpha + \beta RH) \quad (2)$$

To relate the particle forces to the expected flight dynamic environments, the particle force for a given size (spherical particle of diameter  $D_p$  and a density  $\rho$ ) was divided by its mass to yield a formulation for the "basic" acceleration needed at the surface to affect the release of a given size particle (Equation 3).



$$g_o = \frac{L}{D_p \rho} (\alpha + \beta RH) \quad (3)$$

Assumptions:

Particle force behavior obtained from available data may be assumed true for other type particles/surface.

Force is linear with particle diameter at least on the average.

Humidity contributes the most to adhesive forces.

$k, \alpha, \beta$  are constants

$D_p$  = Particle Diameter

$\rho$  = Particle Density

In practice, the number of particles of a given size released from a surface under exposure to a given level of acceleration is not a step function behavior, i. e., particles of a given size do not remain lodged upon a surface and become released at a quantum level of surface acceleration. In fact, particles of the same size may start to be released at lower acceleration levels and a typical relationship between the number of particles released and the surface environment is shown in Fig. 8-1c.

In an attempt to model such a behavior, another empirical formula was constructed to provide a best curve fit to the limited available data and is given in a nondimensional form in Fig. 8-1d. The formula is described in more detail in Fig. 8-1e, where  $t$  is a constant assumed to be function of the particle diameter only. The values of  $g_o$  and  $t$  will be obtained employing a source data curve fit. The formulation is of necessity non-time dependent; in other words, it is assumed that the expected dynamic events are of sufficient duration such that they will dislodge all particles releasable at a given acceleration level. Such an assumption may cause an overestimate of the number of particles dislodged due to an excessively short impulse of a given acceleration level. In addition, the subject formula assumes that space vacuum environment affect on particle forces may be approximated by assuming a value of zero relative humidity, and that the remaining adhesive force is mainly due to molecular attraction. The formulation is also frequency independent, and no distinction is made between static and dynamic accelerations imparted to the

surface. Such an approximation is made of necessity due to the shortage of data that may enable the understanding of differences between the effect of two types of environments on particle release; nevertheless, in view of the small size of particles considered, such an approximation may become of significance only when the wave length of surface response reaches the order of particle size, which in turn may only occur at extremely high frequencies. Typical spacecraft responses have shown a severe roll-off in vibration levels above 2000 Hz for random vibration exhibition, and a cut-off frequency in the neighborhood of 5 kHz for the case of transient shock response. The reason being that higher frequency structural modes tend to be severely damped when compared to the lower modes.

The effect of direct acoustic environment excitation was considered employing the basic force model discussed previously. Order of magnitude analysis have shown that acoustic sound pressure levels of 180 to 200 dba at frequencies in the neighborhood of 16.5 to 1.65 mega-cycle are needed to create sufficient forces to dislodge particles between  $10\mu$  and  $100\mu$  in size. The high frequency is a consequence of requiring the environment to possess wave lengths of twice the particle diameter in order to create efficiently an effective pressure gradient across the subject particle (Fig. 8-1f).

This result has lead to the conclusion that direct acoustic environment excitation may not be a significant mechanism by which particles may be released from the various surfaces, however, excitation of the supporting structure acoustic environment may create sufficiently high acceleration levels on the various surfaces to cause the release of contaminants.

### 8.3.2 Launch Dynamic Environments

The following are estimates of typical launch phase dynamic environments. The subject environments are those envisioned to materialize during the launch phase of the Viking Mars launch in 1975.

8.3.2.1 External Acoustic Field. The acoustic field external to the shroud at lift-off is approximately uniform. During the transonic portion of flight, the external field at any point varies with position. The lift-off estimates are shown in Fig. 8-2a.

Figure 8-2b depicts the Viking shroud divided into regions and Fig. 8-2c shows the estimated transonic acoustic environment levels in each of the regions.

8.3.2.2 Internal Acoustic Field. Internal to the shroud it is assumed that the effect of the shroud structure in transmitting the acoustic excitation to the payload cavity is such that the field within the shroud is a reverberant acoustic field even during transonic flight. Estimated internal acoustic environments during lift-off and the transonic portions of the flight are given in Fig. 8-2d.

### 8.3.3 Launch Phase Dynamic Environments

8.3.3.1 Random Vibration Environments. Two different estimates of the random vibration level of the shroud are shown in Fig. 8-3a. These curves are typical of most areas of the shroud at lift-off and transonic flight. During the transonic period of flight, however, local turbulence especially at region "D" (Fig. 8-1b), may introduce additional energy above 1 kHz, causing the wide-band vibration level to be as high as 200 - 250 g's RMS locally.

The estimated random vibration levels at the spacecraft/launch vehicle interface is shown in Fig. 8-3b. The solar panels and antennas may vibrate with an amplitude as high as 50 g's r.m.s. The spectral peak is estimated to occur in the neighborhood of 600 Hz.

8.3.3.2 Transient Dynamic Environments. Launch vehicle events are estimates to generate in the shroud an environment equivalent to 3 g's of sinusoidal wave in the range from 15 to 30 Hz for the low frequency transients (e.g., engine starts and stops) and as high as 20 g's of sinusoidal wave in the frequency range from 30 - 300 Hz.

The response of the spacecraft due to the launch vehicle transients is estimated to be equivalent to 3 g's of sinusoidal vibration over the frequency range from 20 to 200 Hz.

Pyro-events on the shroud, (namely shroud separation) causes a significant shock response of the shroud. Separation is accomplished by firing linear pyro-charges along circumferential and longitudinal separation joints in

the shroud. The estimated shock spectrum measured at one foot from the linear charge, for a typical shock of this type, is shown in Fig. 8-3c. The time history of such an environment may be approximated by a 500 g's; 2000 Hz decaying sine wave. The decay time is in the order of 3 msec. The shock attenuation with distance is estimated to be as shown in Fig. 8-3d and 8-3e. Worst case shock levels occurring on the separation joint itself are predicted to be as high as 2000 g's with most of the energy concentrated between 2000 Hz and 5000 Hz.

The most severe pyro-event on the spacecraft during the launch phase is that of the spacecraft separation. The shock spectrum of such an event, measured one foot from the source, is shown in Fig. 8-3b. Assumption is made that the time history is roughly that of a decaying 5000 Hz sine wave. The amplitude near the source may be as high as 3000 g's and the duration is, again, estimated to 3 msec. Attenuation with distance is shown in Fig. 8-3g.

#### 8.3.4 Space Flight Environments

Nominal environmental estimates for the space flight V-II type trajectory were made for a typical V-II (Viking Mars) mission.

8.3.4.1 Meteoroid Environment. The JPL-NSE Group meteoroid flux computer program (based on the Kessler meteoroid models contained in NASA SP-8038) was run for the typical Viking '75 type II trajectory (Launch 8/1/75, arrive 6/6/76). The program computes the following parameters for each successive day (N) after launch:

- R = Distance between the S/C and the sun (Heliocentric Radius)
- $\mu$  = Ratio between the spacecraft velocity to the velocity of a circular orbit of radius R
- $\theta$  = Angle between spacecraft velocity vector and tangent to sphere of radius R (degrees)
- $\rho$  = Heliocentric latitude, relative to the ecliptic plane (degrees)
- $\pi$  = Heliocentric longitude, relative to vernal equinox (degrees)
- $f_c$  = Flux of cometary particles (meter.  $^{-2}$ sec  $^{-1}$ )

$f_a$  = Flux of asteroidal particles (meter.  $^{-2}\text{sec}^{-1}$ )

$v_c$  = Relative impact velocity of cometary particles (Km/sec)

$v_a$  = Relative impact velocity of asteroidal particles (Km/sec)

In addition, the program also computes for the entire mission; mean velocities (and  $\delta$ ) and fluences from both cometary and asteroidal particles. Finally, the program computes the probability (Poisson) of no particle impact for each type of particle, with regards to different particle masses (grams) and spacecraft projected areas (meter<sup>2</sup>).

8.3.4.2 Electromagnetic Radiation. Spectral irradiance environmental estimate were obtained for the range of  $L = 850 - 220 \text{ \AA}$ . The flux was specified in percentage of the solar constant contained in wavelengths shorter than  $L$ . The solar constant (at 1.0 AU) is  $0.1353 \pm 0.0014 \text{ watts/cm}^2$ .

Figure 4 describes the variation of the solar radiation pressure with the distance from the sun  $R$ . Upper and lower bounds specified correspond to interaction with the various surfaces of reflectivity ranging between one and zero.

8.3.4.3 Interplanetary Magnetic Fields. The strength of the interplanetary magnetic field at 1.0 AU from the sun is about 5 gammas. The strength of the field is dependent upon the solar activity, with the maximum field strength occurring at maximum solar activity. Fluctuations may be from one-to-two orders of magnitude. An upper bound on the interplanetary magnetic field strength may be estimated at 100 gammas.

#### 8.3.5 A Broad Sensitivity Study

The objective of the effort described herein was to perform analyses and sensitivity studies to delineate those spacecraft events which sufficiently impact the allocation for the overall probability of contamination of a planet to merit further evaluation by analytical and experimental means.

The scope of the analysis included studies of nonsterile fly-by and orbiter spacecraft, as well as a sterile lander capsule attached to a non-sterile orbiter spacecraft.

Evaluations were performed of the relationship of the microbial burden at a specific mission event for a given element of the system to the burden at a previous event, as influenced by recontamination from another portion of the system. For instance, the ratio of the burden on the spacecraft at encounter to that at shroud separation was evaluated as a function of the probability of ejection during cruise and the number of events which provided a force sufficient to dislodge an organism from the spacecraft surfaces. Dislodging events were identified as midcourse firings, attitude control system firings and deployment of appendages for all spacecraft, and also separation of the bioshield cap and lander capsule for lander missions.

For all missions, the probability of contamination of the planet was shown to be directly proportional to the burden on the spacecraft at encounter. This burden was shown to be exponentially related to the probability of ejection during cruise. Additional details may be found in the Bionetics Corp., Final Report No. 71.25, December 30, 1970.

A recommendation was made for expanding the analytical model of recontamination of the lander capsule, which would involve developing more detailed equations for burden redistribution than presented in the report. It was indicated that these equations would be in a form suitable for computer programming for both probability distributions and discrete values. Analytical studies were recommended to determine the probabilities of ejection, transfer and adhesion of organisms, supported by experimental investigations.

Because of the sensitivity to the probability of ejection, it was found that knowledge of the burden at shroud separation was important. This requirement established the need to evaluate the transfer of burden to the spacecraft from the shroud during launch and for a precise estimation of the probability of organism ejection from spacecraft surfaces during cruise and after encounter.

#### 8.4 PROBLEM AREAS

The following is a summary of the problem areas that became apparent during the initial course of the effort, in relationship to the identified relevant recontamination parameters.

#### 8.4.1 Particle Adhesive Forces

As stated earlier in Section VIII, para. 8.3.1 particle adhesive forces are functions of a large number of variables. In order to formulate a meaningful relationship between the particle forces and the subject variables, one may restrict the conditions considered to only those that may be relevant to the spacecraft recontamination problem. For example, one may eliminate from the study particle and surface materials that are not likely to be encountered on a spacecraft...etc. Even when such descopeing of the model is exercised, it appears that the data available on particle adhesive forces do not categorically provide information of the effect of each of the "independent" variables on the particle adhesive force. Instead, experiments expectedly were designed to supply information on particle forces for a completely different objective, mainly from a surface cleaning point of view. This fact caused most of the data reported to reflect upper bound type information and with lumped affects of various variable included.

In addition, when a model is constructed which attempts to formulate the particle force as a function of a restricted number of variables due to the lack of explicit data, one experiences a spread in the results due to the effect of the random variation of the remaining independent variables that were of necessity, omitted from the subject formulation.

The force model obtained in this study was restricted to dependence on particle diameter and the surrounding environment's relative humidity. Other variables as materials of particles and surfaces, effect of the acceleration environment frequency, effects of prolonged exposure to space environment on particle force...etc., where of necessity omitted due to the lack of consistent supporting data.

#### 8.4.2 Resolution in Environmental Definition

Present state of the art spacecraft environmental definition provide "adequate" support for the design and hardware qualification of the spacecraft. From the recontamination point of view (and in some instance, more resolution in the detail of the environment) definition is felt to be warranted. For example, when one is considering the transport of dislodged particles during the spaceflight with respect to the spacecraft, for the assessment of particulate

migration; a knowledge of the Electro-magnetic fields generated by the various zones on the spacecraft in the various functional modes may be of interest instead of an upper bound estimate of the overall S/C electromagnetic fields intensity. An additional example from the launch phase may also be appropriate, which is related to the need of the definition of the launch phase dynamic environments on the shroud for each individual event and with proper time sequence, instead of a lumped "upper bound" environment estimate that envelops all the expected 95 percentile environments. The detailed environment definition may enable the proper time correlation between particle release during the launch phase and the aerodynamic transport mechanisms materializing within the shroud enclosure due to the decreasing launch pressure profile. In fact, although upper bound estimates of the dynamic environment are adequate for hardware design, these estimates may not be necessary for the question of recontamination. Since, for example, upper bound estimates of the dynamic environments on the S/C during launch may yield higher results for the particulate release from the S/C which is not a conservative estimate from a PQ standpoint.

#### 8.4.3 Difficulties in the Analytical Treatments

In some instances it is difficult to obtain an analytical model that is based on theoretical arguments and to simulate a complicated physical phenomena. To be more specific, when modeling the aerodynamics inside the shroud due to the decreasing pressure and the air bleeding from the shroud, one may at best employ a one dimensional simplification of the cavity enclosure and (through satisfying the continuity equation and knowledge of the variation in the cavity cross-sectional area) an estimate of the velocities that may arise may be made. An attempt to solve the overall 3-dimensional aerodynamics problem is prohibitive if not impossible.

Since the shroud internal aerodynamics is the major mechanism for transport of contaminants within the payload cavity, it appears that experimental testing for the various shrouds with the different venting designs may be a meaningful way of at least obtaining empirical results.



## 8.5 FUTURE ACTIVITIES

The following is a brief outline of the work to be done during the remainder of the fiscal year, and a note on the envisioned long term efforts needed to satisfy the subject investigation.

### 8.5.1 Remainder of FY '71 Work Plan

During the remainder of the current fiscal year plans are formulated to assemble the analytical model for the post launch recontamination. Work emphasis during this period is placed on the heliocentric and the aerocentric portions of the mission with the greatest emphasis being devoted towards the post biobarrier ejection.

The model assembly shall be carried out employing the Viking mission as an example for guidance; nevertheless, thought and provisions will be incorporated providing flexibility of the model for employment on other types of missions.

### 8.5.2 Envisioned Future Work Beyond Current Fiscal Year

To supplement the recontamination model constructed, a phase of development and refinement is felt to be in order. Due to the shortage of experimental data necessary to support quantitatively sound empirical relations for a multitude of the migration mechanisms, it is recommended that a series of experiments for the verification and refinement of such formula be performed. Such an effort will include the fundamentals of a combined discipline approach to investigate the deficiencies in the data used for constructing the various existing models, and the identification of the most relevant areas that require refinement. In addition, design and execute tests employing the existing JPL facilities for acquisition of sufficient data. Data evaluation and processing will be made employing the JPL-DAF (JPL - Data Analysis Facility).

It is also recommended that the refined analytical model be exercised using a variety of mission strategies and missions to assess the effect of such variables on the recontamination problem.

## 8.6 PUBLICATIONS

M. N. Mansour/Chris Haudenschild. "Post Launch Recontamination Studies". Presented at the Semi-Annual NASA Sterilization Technology Seminar, Williamsburg, Virginia, December 1-2, 1970.

## 8.7 REFERENCES

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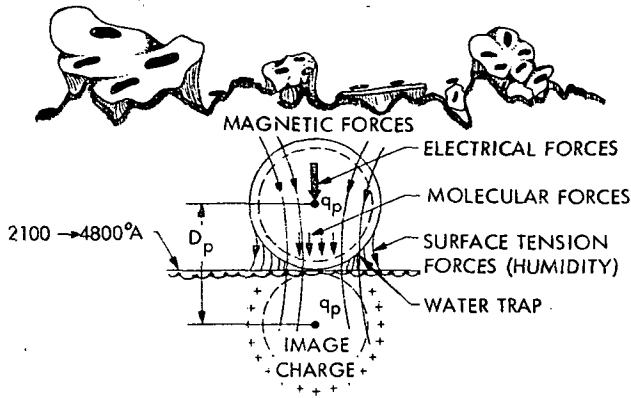
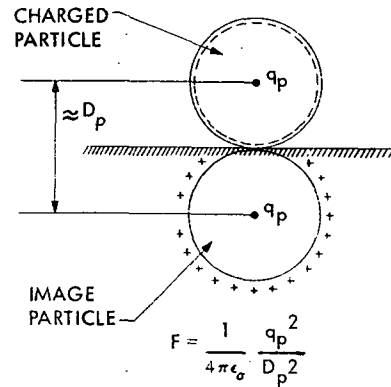


Fig. 8-1(a). Relevant forces

Fig. 8-1(b). Electrical forces



$$q_p = 1.6 \times 10^{-11} D_p$$

(1000 CHARGES ON  $10 \mu^{\phi}$ )

$$F = 2.3 \times 10^{-7} \text{ dynes}$$

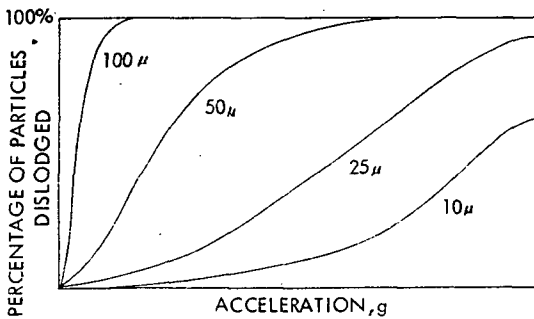
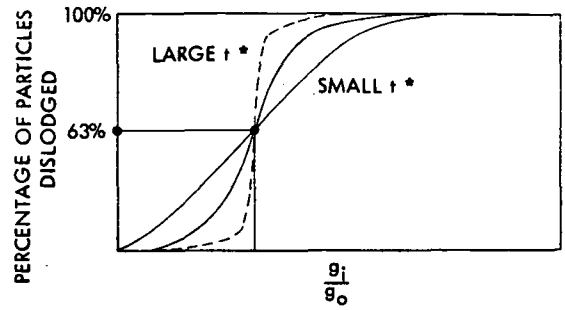


Fig. 8-1(c). Relationship between particle dislodgement and acceleration

Fig. 8-1(d). Nondimensional acceleration



$$(Nd)_i = N_o \left[ 1 - \exp \left( - \left( \frac{g_i}{g_o} \right)^t \right) \right] - C$$

$$[N_d(D_p)]_i = N_o(D_p) \left[ 1 - \exp \left( - \left( \frac{g_i}{g_o(D_p)} \right)^t \right) \right] - C$$

$$g_i > g_{i-1}$$

$$C \equiv 0 \quad i=1$$

$$C \equiv \sum_{n=1}^{i-1} \left[ N_d(D_p) \right]_n \quad i \geq 2$$

$g_o \equiv$  CHARACTERISTIC ACCELERATION LEVEL FOR 63% PARTICLE REMOVAL

$g_i \equiv$  ACCELERATION ENVIRONMENT LEVEL DURING THE  $i^{th}$  EXPOSURE

Fig. 8-1(e). Particles dislodged per exposure

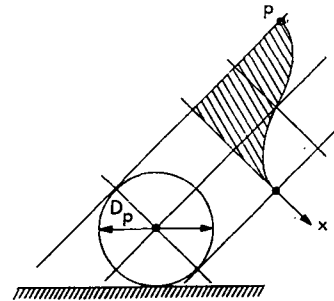


Fig. 8-1(f). Effect of acoustics

FOR A PARTICLE SIZE RANGE  $10\mu$  TO  $100\mu$

WAVE LENGTH  $\approx 2 D_p$

FREQUENCY  $\approx 16.5$  TO  $1.65$  mc

SOUND PRESSURE LEVEL  $\approx 180 - 200$  db

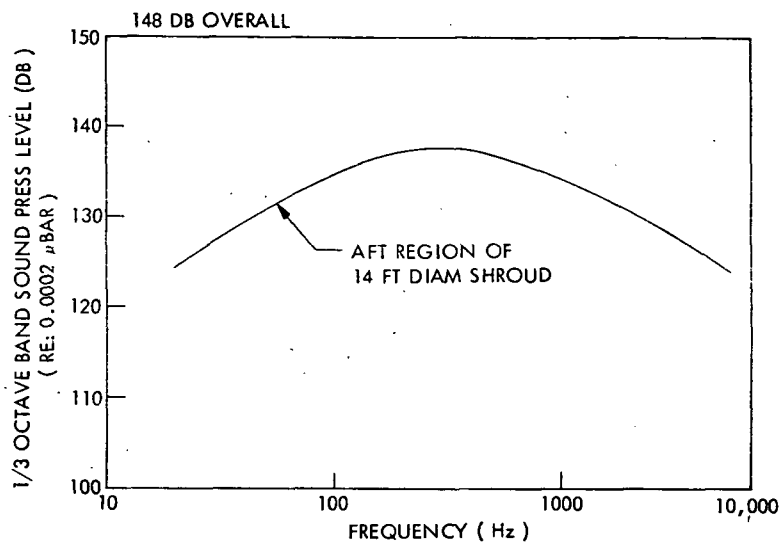


Fig. 8-2(a). Exterior lift-off acoustic spectrum

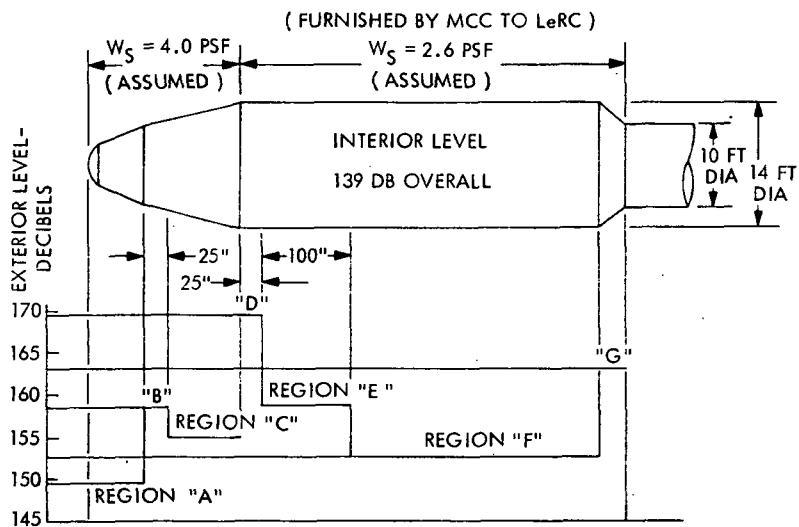


Fig. 8-2(b). Predicted transonic acoustic environment

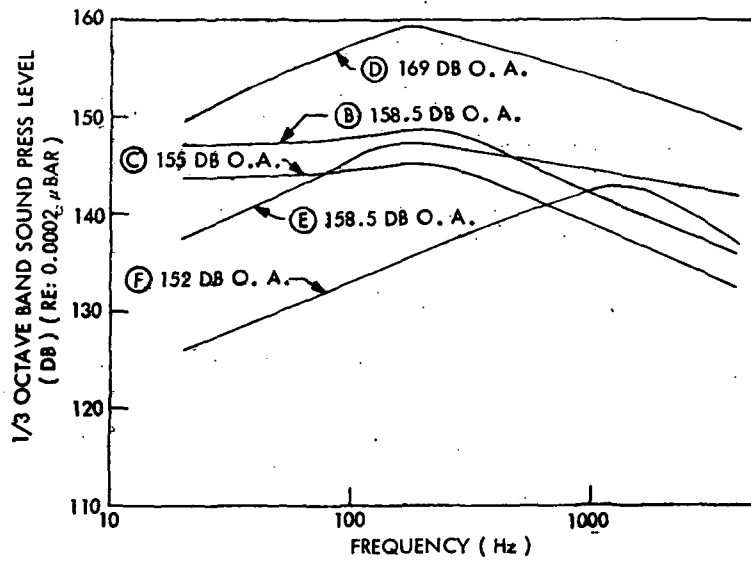


Fig. 8-2(c). Exterior transonic acoustic spectrum

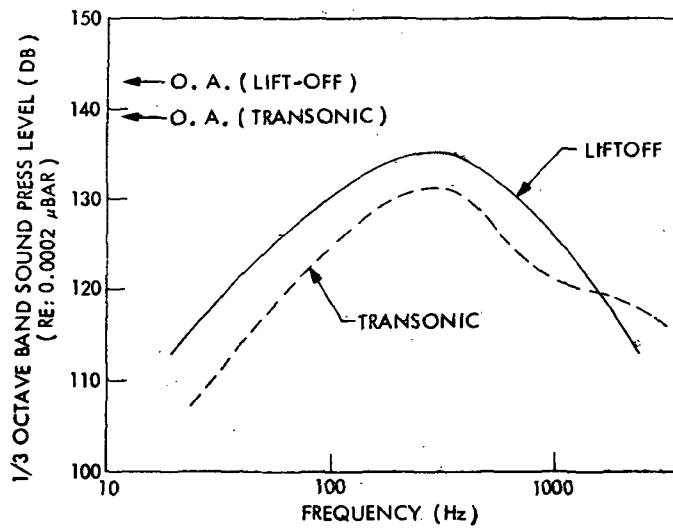


Fig. 8-2(d). Launch and boost internal acoustic spectrum

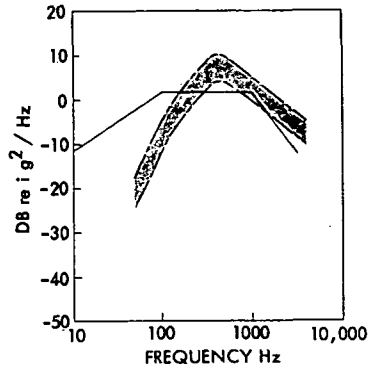


Fig. 8-3(a). Shroud vibration spectrum

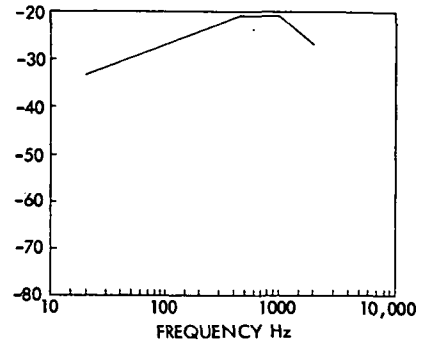


Fig. 8-3(b). Spacecraft vibration spectrum

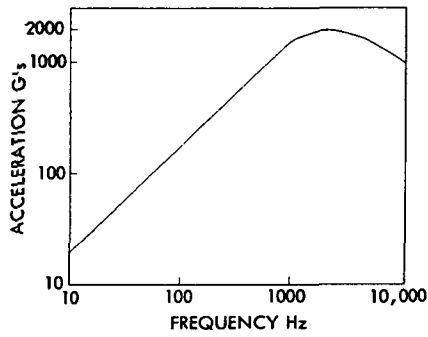


Fig. 8-3(c). Shroud shock spectrum

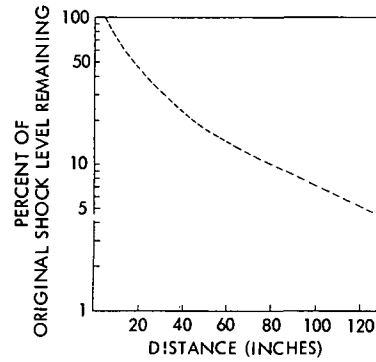


Fig. 8-3(d). Attenuation for ring frame of skin/ring frame structure

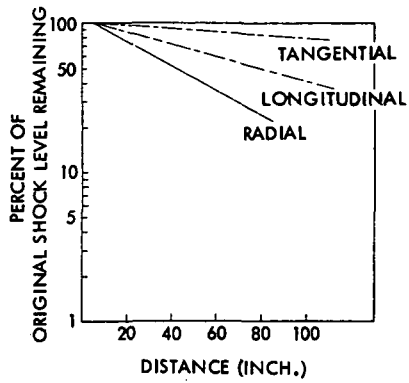


Fig. 8-3(e). Attenuation for longeron or stringer of skin/ring frame structure

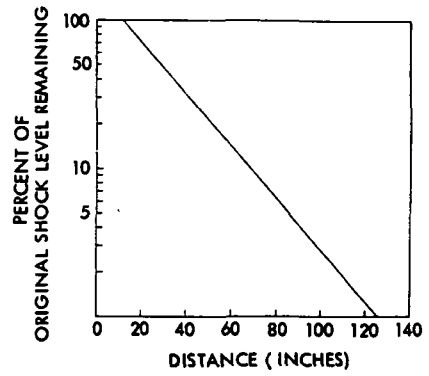


Fig. 8-3(f). Spacecraft structure attenuation

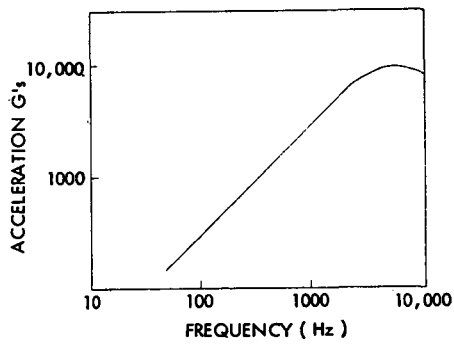


Fig. 8-3(g). Spacecraft shock spectrum



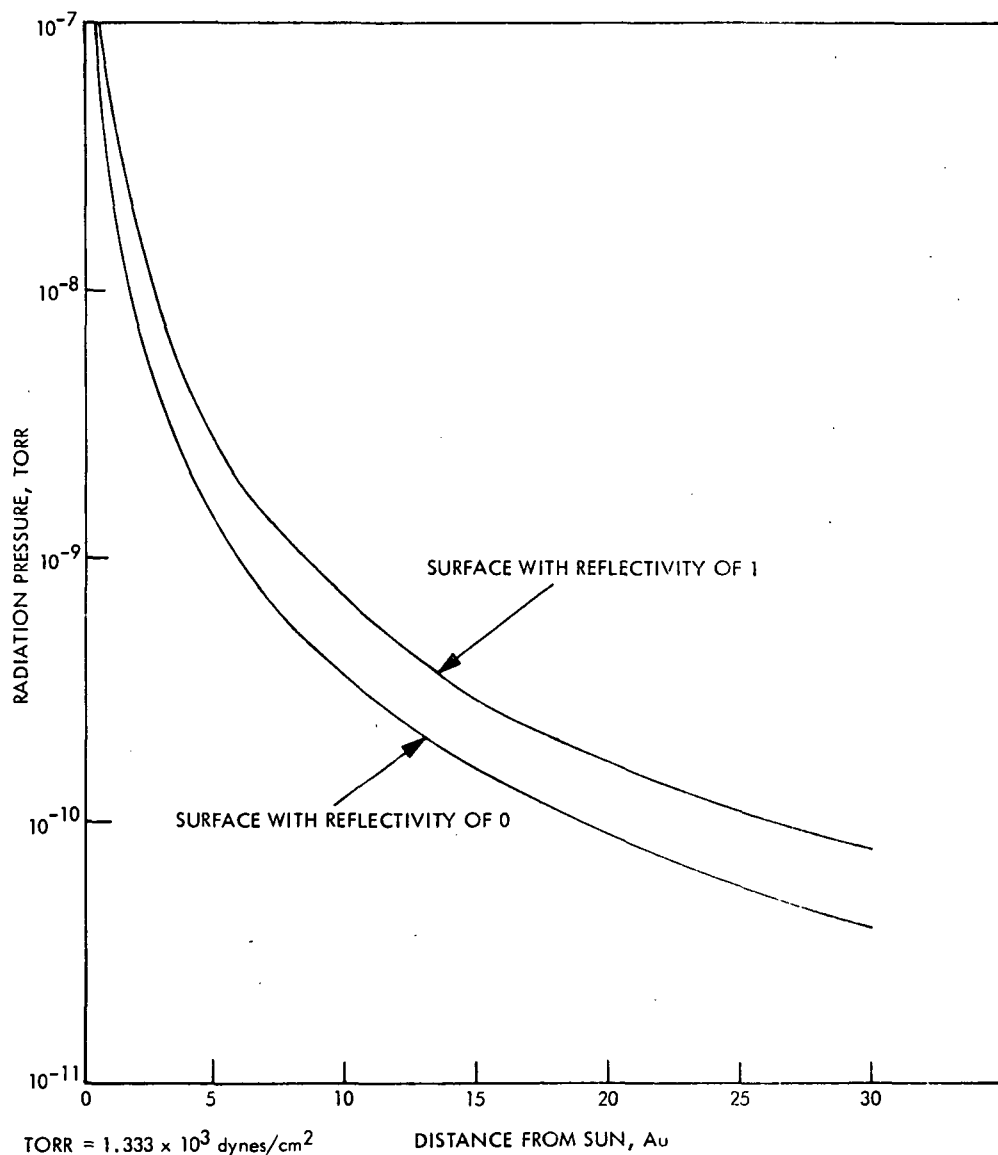


Fig. 8-4. Radiation pressure as a function of distance from the Sun in astronomical units (Au)