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Planetary Quarantine Department

Sandia Laboratory, Albuquerque, New Mexico

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APPENDIX

This document summarizes the Planetary Quarantine Department activities being pursued, and the progress made, during the second quarter of calendar year 1967.

1. Program Development and Analysis

   A. Description. It has been assumed that there is a need for a precise way of determining what specific actions are needed in order to achieve planetary quarantine objectives. That is, what must be done relative to each space vehicle in order to assure, insofar as possible, that the goals of planetary quarantine are attained. The determination of these specific actions in a cost-optimal fashion is termed program development and analysis.

   B. Progress. The distinction between (1) determining the actions for planetary quarantine objective achievement and (2) knowing how one can determine them, is made. A scheme has been developed which, we feel, does the latter, but further work is necessary to actually derive the former from it. The following is a brief description of this scheme.

   Objectives are defined to be statements containing variable quantities and specifying desirable values or modes of behavior for the variable quantities. Primary objectives of a program are those objectives which provide a raison d'etre for the program and provide a base against which the success of the program is measured.

   The first step in program development and analysis is the determination of the "significant factors" affecting the values or behavior of the variables occurring in the primary objectives. Then, these factors are related to the original variables using a mathematical model (or models). The choice of both the set of significant factors and the model is largely a matter of judgement. The existence of desired behavior or values for the variables occurring in the primary objectives implies, at least generically, the existence of desired behavior or values for the parameters in the model(s) representing the "significant factors". Statements about these new parameters and their desired behavior modes constitute the secondary objectives. One attempts to obtain a set of secondary objectives with the property that the achievement of the secondary objectives implies the achievement of the primary objectives.

This process may be repeated beginning with the secondary objectives, leading to tertiary objectives. The hope in repeating this process is that, eventually, all the objectives so obtained may be directly physically realized: either by measurement, control, or fiat.

If the scheme involves only generic representation of variables occurring in all of the objectives, that is, no specific values are desired initially, then with cost information about those objectives termed "directly physically realizable", it is possible to:

(i) obtain cost-optimal actions (relative to the tree) for any specification of variable values in the primary objectives, and

(ii) decide among possible specific primary objectives on the basis of cost (at least, in part).

A report of this work is being prepared.

2. Modeling of Primary Objectives

A. Description. As outlined above, the first step in program development and analysis is the relating of the primary objectives of the program to the "significant factors" influencing their attainment. A need was assumed for translating program non-contamination objectives into mission non-contamination requirements. It was further assumed that an important significant factor in the attainment of the non-contamination objective was the uncertainty inherent in any space exploration program.

B. Progress. A model has been developed and is available as, "A Sequential Decision Model of Planetary Quarantine Primary Objectives", Sandia Corporation Research Report, SC-RR-67-462.

In this document, the non-contamination objective of planetary quarantine was assumed to be of the form:

OBJECTIVE 1. The probability that any planet deemed important for study of extraterrestrial life, or precursors or remnants thereof, be contaminated during the next T years shall not exceed $(1 - \hat{P}_{N.C.})$. Here $\hat{P}_{N.C.}$ represents the least acceptable probability that a planet under consideration should not be contaminated in the time period T. The word "contamination" and the parameters T and $\hat{P}_{N.C.}$ were considered variable.

It was assumed that the primary desire for a non-contamination objective arises from scientific objectives. In examining scientific objectives, it was found that there appears to be much uncertainty in space exploration programs arising from uncertainties in:

- scientific information desired as a function of time
- performance of spacecraft and experiments
- knowledge about the planets being explored.

It was observed that with complete knowledge about a space exploration program, the time period, T, in Objective 1 could be determined. Also, it would be possible to determine n(T), the total number of missions to be launched in the vicinity of the planet in question during the period T. If these are known, then it is possible to derive mission requirements from Objective 1 in a simple fashion using the model

$$\hat{P}_{N.C.} = [1 - \hat{P}_C(n(T))]^{n(T)}$$

where $\hat{P}_C(n(T))$ represents the maximal acceptable probability of contamination from any of the n(T) missions.

The uncertainties occurring in space exploration make certain *a priori* knowledge of T and n(T) unlikely however, and a model reflecting this uncertainty seems desirable.

The sequential decision model presented in this document includes this uncertainty by allowing estimates of n(T) to be made periodically. At the same time, mission requirements may be derived from these estimates with the use of the model. At any decision stage, these requirements are derived in such a manner that Objective 1 will be attained if the requirements are satisfied by each of the additional missions estimated.

Specifically, the model, in its simplest form is given by

$$(1 - \hat{P}_1)^{N_1} = \hat{P}_{N.C.} \text{ and for } k > 1$$

$$(1 - \hat{P}_k)^{N_k} = \frac{\hat{P}_{N.C.}}{\prod_{i=1}^{k-1} (1 - \hat{P}_i)^{M_i}}$$

where

N_1 is the <u>first estimate</u> of the total number of missions to be launched in the vicinity of the planet in question

M_1 is the number of these N_1 missions launched prior to the second estimate of the number of missions required,

and, in general, for $k > 1$

$\left(\sum_{j=1}^{k-1} M_j\right) + N_k$ is the $\underline{k^{th}}$ <u>estimate</u> of the total number of missions to be launched in the vicinity of the planet in question, and

$\left(\sum_{j=1}^{k-1} M_j\right) + M_k$ is the number of these missions launched prior to the (k+1)st estimate of the number of missions required.

Further, $\hat{P}_k$ is defined to be the maximum acceptable probability of contamination of the planet in question from any of the last N_k missions needed to fulfill the k^{th} estimate of the total number of missions required.

In theory, this model:

- requires no _a priori_ knowledge about T or n(T) or the meaning of the word "contamination",
- but, makes use of any such knowledge available,
- can make use of _a posteriori_ knowledge about mission requirements fulfillment, and
- implies possible penalties for operation without knowledge ($\hat{P}_k$ may decrease as a function of k, implying more demanding mission requirements).

The aforementioned penalties are minimized by

- accurate prediction of the number of missions required, and
- early readjustment of mission numbers when the need for a change is recognized.

These penalties may be compensated for by:

- the use of _a posteriori_ mission knowledge
- the improvement in contamination control technology, and
- improved knowledge about the planet being investigated.

Of all the models now available, this appears to be the only one which makes no _a priori_ assumption about T and n(T). However, this sequential decision model makes use of such information when it is available.

Two other possible planetary quarantine objectives were considered. These were

OBJECTIVE 2. The objective of non-contamination (Objective 1) should be attained in such a manner that the penalty associated with its achievement is acceptable nationally, and

OBJECTIVE 3. Means for achieving Objective 1 should be known before the year Y.

The sequential decision model presented in this document may aid appreciably in the achievement of Objective 3, due to the lack of need for precise a priori knowledge about the exploration program. It may also provide a foundation for studies aimed at the achievement of Objective 2 through the scheme outlined in Activity 1.

Thus, generally speaking, the sequential decision model developed in this document seems to possess those attributes which were assumed desirable on the basis of the nature of planetary quarantine objectives as they were envisioned here.

A more general model allowing various "classes" of space vehicles is given in the document as well.

3. Microbial Death Models

A. Description. One level of objective occurring in the hierarchy of objectives described in Activity 1 involves microbial death. Specifically, one desires knowledge about the probability that one or more microorganisms survive a thermal environment. Several models are available. Three items make advisable further work in the area of microbial death models:

(i) current models are based on no physical assumptions as to the mechanisms producing death, i.e., they are simply used to "fit data",

(ii) current models don't fit the various types of microbial death data available, and

(iii) current plans call for the extrapolation of these models considerably beyond measurable ranges.

Modeling efforts here are based upon the assumption that death in a thermal environment occurs as a result of chemical molecular destruction. The parameters occurring in the models are chemical reaction rate parameters.

B. Progress. To date, a model has been developed which exhibits two important characteristics:

(i) by varying the types of chemical reactions involved and their rates, this model yields all known "types" of microbial death curves, and

(ii) using Silverman's data at 106°C and 120°C one may determine reaction rates at these temperatures needed by the model to "fit" the data. Using the Arrhenius equation and the reaction rates so obtained, one can predict the needed reaction rates at any other temperature. When this prediction is compared with Silverman's data at 135°C, the fit is almost perfect. This is a result which produces confidence in the model.

Current activity is centered around attempts to include the influence of environmental factors other than heat, e.g., water activity and air flow.

A report discussing the basic model is available as: "A Rational Model for Spacecraft Sterilization Requirements", by J.P. Brannen, Sandia Corporation Research Report, SC-RR-67-256.

4. Prediction of Microbial Burdens Prior to Sterilization

A. Description. One of the significant factors associated with the variables occurring in microbial death prediction objectives is the microbial burden of the item being sterilized. That is, all known microbial survival data indicates that the "effectiveness" of heat sterilization depends upon quantitative knowledge of the microbial burden. As a first step to predicting this burden in the case of space vehicles, a model was developed ("An Assembly Contamination Model", E. J. Sherry, C. A. Trauth, Jr., Sandia Corporation Research Report, SC-RR-66-421.) in which the parameters were random variables. Means for correlating these parameters with data taken are needed. In order to obtain these, it is necessary to be able to sample large irregularly shaped surfaces accurately. A device to do this has been developed (Activity 5, below). Experimentation with irregular surfaces in laminar air flow environments is under way, (Activity 6, below). Modeling, based on this experimentation, is needed to provide a means of estimating the microbial burden on a spacecraft during (and possibly prior to) assembly.

B. Progress. The project has just been begun. The delay in pursuing this area after the report, "An Assembly Contamination Model", referred to above, was made necessary by the need to develop devices and techniques for assaying large, irregular surfaces accurately.

5. Surface Sampling Research and Development

A. Description. The need for a reliable means of assaying large, irregularly shaped surfaces was described in Activity 4. In a laminar air flow environment, burdens are known to be light, so that a device capable of assaying lightly loaded, large, irregularly shaped surfaces was desired.

B. Progress. A vacuum probe, using sonic energy to dislodge particles adhering to surfaces has been developed. This device consistently removes +95% of the viable particles from large flat aluminum surfaces. A report on this device is available: "A New Approach to the Microbiological Sampling of Surfaces: The Vacuum Probe Sampler", V. L. Dugan, W. J. Whitfield, J. J. McDade, J. W. Beakley, F. W. Oswalt, Sandia Corporation Report SC-RR-67-114. Further efforts have been expended to improve the counting efficiency of the vacuum probe using membrane filters. The most promising of these improved procedures entail either washing the filter housing with a solution of 1% peptone water or swabbing the interior walls with sterile swabs wetted with 1% peptone. The assay of the colonies obtained from either the washing or the swab methods along with the membrane filter delivers a much improved system efficiency.

Three filter vacuum probes were taken to Goddard Space Flight Center to monitor the Anchored Interplanetary Monitoring Platform (AIMP) for microbiological loadings. Several sections of the spacecraft's surface, the spacecraft's shipping container, and the electronics modules which comprise the bulk of the system were sampled before and after decontamination by both the vacuum probes and by standard swab techniques. This was done to establish a correlation between the best standard techniques and the vacuum probe as both relate to the microbiological sampling of space hardware. Also, a set of swab samples were taken from surfaces which had just previously been sampled by the vacuum probe. The primary reason for this test was to gain information on the efficiency of the probe as not only a microbiological sampling instrument but also as a cleaning tool. As of this date, the results of these tests have not been completely tabulated by the Goddard personnel.

A series of tests have been performed to establish the dependence of the vacuum probe's critical orifice upon atmospheric pressure. This was done using a Brook Model DS-1111 Flowmeter which is a certified primary standard. The results of this study show that the orifice reaches its critical flow rate (point at which flow ceases to increase with decreases in vacuum pressure) when the downstream orifice absolute pressure is approximately one-half that of the upstream absolute pressure. Therefore, when using a probe tip which has a critical flow rate of two standard cubic feet per minute (SCFM) at sea level, a vacuum source with a capability of pulling at least two SCFM at a vacuum pressure of at most 15 inches of mercury (one-half atmosphere) must be used. As altitude increases and atmospheric pressure decreases the flow rate necessary to reach the critical flow rate decreases in very nearly a linear fashion for any particular orifice size. All of these tests were conducted in a specially built pressure chamber which could simulate conditions from below sea level to 10,000 feet in altitude.

6. Experimentation in Laminar Flow Environments

A. Description. A large problem in planetary quarantine is the correlation of measurements that can be made with actual spacecraft loading. The objective of this experimentation is to provide reliable data on which modeling of this problem can be based. (See Activity 5)

B. Progress. A limited amount of progress has been made in the development of a physical model for the optimum collection and retention of microorganisms; however, the completion of the new filterless laminar flow facility in the near future will greatly accelerate this program. The curtained laminar flow room without the filters will provide laminar airflow conditions with the capability for loading physical models with intramural microorganisms. A number of model studies and airflow studies are now being scheduled.

7. Implementation System

A. Description. The objective of this project is to design a system based upon the modeling being done (particularly, the assembly modeling) to provide estimates of space vehicle microbial burdens by part, component, subassembly or,interior, exterior, occluded categories during the assembly (and possibly manufacture and sterilization) phase(s) of the vehicle. Several estimates will be given depending on information source.

B. Progress. The result of this activity may be viewed, in general, as an information system. It is necessary to specify the inputs, the nature of the processor and the outputs. In these terms, the processor represents a computer code based upon much of the modeling and experimentation described above. The type of inputs desired should, again, be determined by the experimentation and modeling.

In actual usage, the sources of the inputs will depend upon the exploration program being monitored. The desired output will depend upon the flight program and the NASA Planetary Quarantine Organization's responsibilities for that program. Exclusive of the experimentation and modeling described above, progress in this activity has involved obtaining descriptions of flight programs and the NASA Planetary Quarantine responsibility for each. Sources of inputs have been identified (where possible), and some progress has been made in specifying the desired outputs.

8. Experiments in Ultrasonication

A. Description. One of the primary methods relied on in standard procedures for the microbiological examination of space hardware is the collection of microorganisms on 1" x 2" stainless steel strips which are then assayed. The only major problem associated with the assay of the stainless steel strips arises in the removal of the micro-size organisms by ultrasonic cavitation, the standard method utilized. A program designed to develop improvements in the ultrasonication procedures which are being extensively used has just been completed.

B. Progress. The results of the research program have been to shorten ultrasonication time from twelve minutes to two minutes for a single set of samples, to reliably effect a mean of 99+% removal of the microorganisms, and to stabilize the temperature of the sonication fluids being used. A report describing these improvements is available as: "An Improved Sonication Method for Removal of Microorganisms from Surfaces", by F. W. Oswalt, J. J. McDade, C. M. Franklin, V. L. Dugan, Sandia Corporation Research Report, SC-RR-67-492.

9. Retrieval of Terrestrial Microorganisms from the Lunar Surface

A. Description. The present study has as its goal the determination of the probability that a lunar lander experiment retrieves at least one viable terrestrial microorganism that has been deposited on the moon by previously impacting spacecraft. The major problem to be solved in achieving the goal of the study is the problem of estimating the contribution of each spacecraft impacting on the moon to the distributed microbial loading on the lunar surface. More specifically, the problem of computing the probabilities mentioned above can be broken down into four sub-problems that require attention. These are problems of:

(i) the attenuation of the initial (at launch) microbial burden of a spacecraft during the time occupied in transit from launch to impact on the moon,

(ii) the dispersal (or transfer to the lunar surface) of the surviving microorganisms upon impact of the spacecraft,

(iii) the attenuation of the dispersed microorganisms as a function of their residence time on the lunar surface, and

(iv) the possibility that microorganisms can be transported away from their initial points of deposition after the impact dispersal.

B. Progress. A literature search has been completed which, besides providing a general background for attacking the problems, indicates that there is no mechanism that can transport microorganisms away from their points of deposition over the time scales we are concerned with. Thus, sub-problem (iv) is settled until new evidence required that it be reconsidered. Sub-problem (iii) is also resolved; how agreeably resolved depends, of course, upon the acceptability of microbial death models used and the assumptions made about the degree of protection offered to some of the microorganisms by imbedding in the lunar soil. The amount of detail with which sub-problem (i) can be treated depends largely upon the detail provided for individual spacecraft flights. Sub-problem (i) is, in principle, settled but subject to revision according to the amount of information that is made available to us. Work on the key problem of the whole study, sub-problem (ii), is in progress.

10. Principles of Contamination Control

A. Description. The objective of this activity was to prepare a document, suitable for management use, describing the need for,and problems arising in,contamination control. The document is to be published by the Office of Technology Utilization, NASA.

B. Progress. A meeting was held May 16, 1967, by Mr. Morris Sandel, Technology Utilization Division, NASA, and Messrs. Whitfield, Paulhamus and Garst, 2572, to discuss the References and Bibliography Section of the "Principles of Contamination Control". It was agreed that cited references were not appropriate for this document, but that each of the major sections should have a bibliography pertaining to the section topic. These sectional bibliographies were prepared and forwarded to the Office of Technology Utilization on June 13, 1967.

11. Contamination Control Study

A. Description. The objective of this activity is to prepare a detailed working document about contamination control for use by contamination control engineers, design engineers, and so forth.

B. Progress. A completely revised outline was developed for the NASA Contamination Control Handbook. This outline will serve as a skeleton for the Handbook, although some minor additions and re-arrangements may occur.

An extensive effort is being made to obtain technical information from competent manufacturers on products, materials and techniques related to contamination control. More than 200 contacts have been made by telephone and letter. The results of this approach are very encouraging. Some of the more significant results to date are:

1. A substantial quantity of technical information and data has been received on such subjects as gas and liquid filtration, cleaning solvents and chemicals, cleanliness monitoring techniques, various types of cleaning equipment, and clean environment facilities of all types.
2. Attendance was invited and accepted to a one-day cleaning seminar in Minneapolis, Minnesota.
3. Representatives of E. I. duPont de Nemours Co., Turco Products, and Hamilton Manufacturing Co. have visited Sandia to discuss the Handbook and to contribute information.
4. Contacts have been established with other companies to visit their facilities and obtain data on specialized contamination control techniques.

Initial work has begun on the microbial decontamination section of the Handbook.

A preliminary rough draft of the subsection on vapor degreasing has been completed.

Personnel involved with this contract attended the Sixth Annual Technical Meeting of the AACC in Washington, D. C., May 15-18,1967. The purpose of attendance was to evaluate latest developments in techniques, materials and equipment, and to participate in the technical sessions. Several contacts were made which should be valuable in preparing the Contamination Control Handbook.

Mr. F. J. Beyerle, MSFC, Huntsville, visited Sandia on April 25, 1967, to review progress on the NASA Contamination Control Handbook and to participate in a planning session for the NASA/AEC Contamination Control Conference to be held in Albuquerque on September 12-14, 1967. In regard to this conference, a tentative agenda has been completed and speakers are being secured.

Mr. W. J. Whitfield participated in a NASA Contract Oral Review Meeting in St. Louis on April 27, 1967, at which he reviewed developments and current activities on NASA Contracts R-09-019-040 and H-13245A.

Mr. Anello Ross, Fairchild-Hiller Corp., visited Sandia on June 12-13, 1967, to exchange information on contamination control procedures. Under a contract with the USAF, Fairchild-Hiller is preparing an operator's manual for clean environments for photographic processing areas.

APPENDIX

Publications:

1. Brannen, J. P., "A Rational Model for Spacecraft Sterilization Requirements", SC-RR-67-256.
2. Oswalt, F. W., McDade, J. J., Franklin, C. M., Dugan, V. L., "An Improved Sonication Method for Removal of Microorganisms from Surfaces", SC-RR-67-492.
3. McDade, J. J., Whitcomb, J. G., Rypka, E. W., Whitfield, W. J., Franklin, C. M., "The Microbial Profile of a Vertical Laminar Airflow Surgical Theater", SC-RR-67-456.
4. McDade, J. J., Trauth, C. A., Jr., Whitfield, W. J., Sivinski, H. D., "Techniques for the Limitation of Biological Loading of Spacecraft Before Sterilization", for presentation at COSPAR.
5. Trauth, C. A., Jr., "A Sequential Decision Model of Planetary Quarantine Primary Objectives", SC-RR-67-462.

Presentations:

1. Whitfield, W. J., "Development of an Increased Sampling Rate Monitoring System", American Association for Contamination Control, National Meeting, Washington, D. C., May, 1967.
2. Brannen, J. P., "Program Development and Analysis", Marshall Spacecraft Center Quarterly Review, St. Louis, April, 1967.
3. Whitfield, W. J., "Planetary Quarantine Research", Marshall Spacecraft Center Quarterly Review, St. Louis, April, 1967.
4. Whitfield, W. J., "Clean Room Technology", East Central Chapter of the American Association for Contamination Control, Huntsville, Alabama, April, 1967.

5. Whitfield, W. J., "Principles of Laminar Air Flow", Annual Meeting, Association of Microbiology, New York, May, 1967.

6. Sivinski, H. D., "Planetary Quarantine", U. S. Naval Research Organization, Albuquerque, April, 1967.

7. Sivinski, H. D., "Planetary Quarantine Activities", Armed Forces Communications and Electronics Association, Border Chapter, White Sands Missile Range, June, 1967.

8. McDade, J. J., "Bacterial Monitoring of Medical Ultra-Clean Facilities", Annual Meeting of the American Association for Contamination Control, Washington, May, 1967.

9. McDade, J. J., "Laminar Air Flow in the Surgical Theater", Annual Meeting, Association of Microbiology, New York, May, 1967.

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