NASA SP-4902

The Planetary Quarantine Program

origins and achievements

1956–1973

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

THE

Planetary Quarantine

PROGRAM **1956–1973**

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CHARLES R. PHILLIPS

Scientific and Technical Information Office 1974
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.

For sale by the Superintendent of Documents, U.S. Government Printing Office,
Washington, D.C. 20402, Price 85 cents Stock Number 3300–00578
Library of Congress Catalog Card Number 74–600 134

Foreword

THIS IS ONE OF TWO REPORTS dealing with the events which led up to the establishment of a Planetary Quarantine Program in the United States, the development of this program, and its status as of the summer of 1973. The reports partially fulfill the National Aeronautics and Space Administration's (NASA's) requirement that the program be recorded fully so that research and development need not be repeated in the future. Both were prepared for the NASA Planetary Quarantine Office by the Science Communication Division of the George Washington University Medical Center, under Contract NSR 09–010–027. The other report, written by Morton Werber and entitled *Objectives and Models of the Planetary Quarantine Program* (NASA SP–344), will be published in the NASA general technical series.

Now that the Apollo Lunar Exploration Program has come to a halt, at least temporarily, and the exploration of the planets is proceeding on an established, although not accelerated, basis, it is time to take stock of where we stand today.

One of the most exciting possible discoveries in space exploration would be the detection of extraterrestrial life. The Planetary Quarantine Program, both national and international, is an outgrowth of great scientific concern that the search for such life might be compromised by terrestrial microbial contamination during early space exploration projects before effective life detection systems could be added to the space program.

The very term "planetary quarantine" shows how the program has expanded. The first discussions and efforts used the term "sterilization." Then sterilization, an absolute term, was gradually replaced by "probability of contamination." The consideration that in cases where microorganisms could not be killed they could possibly be confined led to the concept of "quarantine." When trajectory control

came into use, flybys could be kept at sufficient distance from celestial bodies to avoid transfer of contaminants, while getting close enough to gain significant scientific information.

This report outlines United States effort in planetary quarantine, beginning with the expressions of alarm by biologists, then discussing how a program was put together and implemented, and finally indicating the academic, governmental, institutional, and industrial agencies and people involved. It ends with a brief summary of the accomplishments and present status of the Planetary Quarantine Program and will, we trust, serve as a partial explanation of how the planetary quarantine effort evolved and reached its present position.

LAWRENCE B. HALL
NASA Planetary Quarantine Officer
National Aeronautics and Space Administration

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Introduction

THE PRESENT-DAY SPACE PROGRAM can be considered an outgrowth of the development of military rocketry during World War II and the decade that followed. It is true that nonmilitary rocket research had taken place earlier. Space exploration would probably have come about eventually, even without this development, but the ready availability of the necessary hardware and engineering technology greatly accelerated the first ventures into space. The logic behind a space program, however, was much more than a desire for a spectacular engineering feat or a matter of political rivalry between major powers, although these may have been significant factors. Earth-bound astronomy had its limitations, and many important scientific questions could be answered only by actual exploration of space. Not the least of these questions concerned biology. Was life restricted only to the planet Earth?

Man had always thought not. The ancients had populated the sky, as had later science fiction writers, exemplified by H.G. Wells in his *War of the Worlds.* Modern-day biologists speculated on other worlds being populated too, but they thought mainly in terms of microorganisms or simple life forms which would be the first to evolve and would be present whether higher forms evolved or not. They were concerned lest in the rush to enter space their science would suffer. After all, had not the *War of the Worlds* been won by the bacteria of Earth? Could this conflict not be duplicated, say on Mars, by carelessness in early space ventures before man ever had a chance to look for extraterrestrial life there? Man could do little that would change the geology of the planets, but their biology, if any existed, could be radically changed even within a decade or so. Planetary quarantine arose from these considerations.

Scientific Concern Over Possible Contamination

THE SCIENTIFIC COMMUNITY, both national and international, was alerted by early space efforts and soon began expressing its concern over possible lunar and planetary contamination. The International Astronautical Federation took up this matter at its seventh Congress in Rome, in September 1956, a year before the Sputnik program. In the United States the National Academy of Sciences (NAS), acting as the focal point for organized scientific opinion within this country, served as the contact with other national and international scientific bodies. NAS first considered the harmful effects of contamination in 1957, and its president at the time, Dr. Detlev W. Bronk, recommended a Satellite-Life Sciences Symposium which was held May 14–17, 1958, in Washington. On June 4, 1958, Dr. Bronk established within NAS the Space Science Board (SSB), with Dr. Lloyd V. Berkner as its first chairman. Moving into the international arena, on February 8, 1958, NAS had formally transmitted their council's recommendations concerning contamination to the International Congress of Scientific Unions (ICSU). As a result of this action, ICSU formed an *ad hoc* committee on Contamination by Extraterrestrial Exploration (CETEX), which held its first meeting on May 12–13, 1958, at The Hague (*Science*, vol. 128, 1958). Dr. Marcel Florkin was the president of this body, and Dr. Donald J. Hughes from the U.S. was a member, representing the International Union of Pure and Applied Physics. All of these events had taken place before the establishment of the National Aeronautics and Space Administration (NASA).

Almost coincidental with the establishment of NASA, the ICSU at its meeting in Washington, October 2–4, 1958, formed COSPAR, an international Committee on Space Research. Dr. W. Albert Noyes, Jr., served as the U.S. National Representative at its first meeting, held in London, England, November 14–15, 1958. COSPAR has met annually ever since, with Dr. Richard W. Porter replacing Dr. Noyes as U.S. National Representative for the second meeting. Dr. Porter served in this capacity until the 1971 meeting at Seattle, Washington. Since then Dr. Herbert Friedman has headed the U.S. delegation at COSPAR. The plenary sessions of COSPAR and their locations appear in Table I.

Table I *Plenary meetings of COSPAR.*

1958	London, England
1959	The Hague, The Netherlands
1960	Nice, France
1961	Florence, Italy
1962	Washington, D.C.
1963	Warsaw, Poland
1964	Florence, Italy
1965	Mar del Plata, Argentina
1966	Vienna, Austria
1967	London, England
1968	Tokyo, Japan
1969	Prague, Czechoslovakia
1970	Leningrad, U.S.S.R.
1971	Seattle, Washington
1972	Madrid, Spain
1973	Constance, West Germany

COSPAR covered all aspects of space research, including biology, after they took over the functions of the *ad hoc* CETEX following that group's second meeting on March 9–10, 1959, at The Hague. Dr. Wallace O. Fenn and Dr. Donald J. Hughes represented the U.S. at the second and last CETEX meeting. Within the United States CETEX had its counterparts in EASTEX and later WESTEX, informal groups meeting from late 1958 through 1959, under the auspices of the NAS/SSB, with Dr. Bruno B. Rossi of the Massachusetts Institute of Technology (MIT) and Dr. Joshua Lederberg of Stanford University serving as respective chairmen.

Dr. Lederberg was also requested by the SSB to set up an *ad hoc* meeting to make recommendations concerning spacecraft sterilization. This committee met at Stanford on July 6–8, 1959. Besides Dr. Lederberg, who served as Chairman, members included R.C. Bauman, Goddard Space Flight Center, NASA; Richard W. Davies, Jet Propulsion Laboratory (JPL); Dr. G. Wesley Dunlap, General Electric

Company; and Dr. Charles R. Phillips, U.S. Army Biological Laboratories (BioLabs). George A. Derbyshire from SSB served as secretary.

The biology with which the SSB, and later COSPAR, concerned themselves covered all aspects as it related to the space program. This embraced space medicine, as well as life sciences, exobiology, spacecraft sterilization, and planetary quarantine. This report is concerned only with the latter two disciplines, but it is hard to isolate them from the other biological disciplines in the early part of the space program. For instance, the request for the sterilization of spacecraft was an outgrowth of exobiological concern. If alien life forms were to be found and examined, they must be kept separated, at least in the beginning, from the ubiquitous microorganisms of Earth. Later as the space biology program expanded, the various biological disciplines became better defined and were considered separately.

The Space Science Board of NAS and COSPAR were not the only scientific groups to express an early concern over possible biological contamination as the space program expanded. As early as December 1958, the United Nations formed a Committee on the Peaceful Uses of Outer Space (UNCOPUOS). The American Astronautical Society considered similar topics at several of its meetings. A paper on the sterilization of space vehicles was presented at the 10th International Astronautics Congress in London, August 31–September 5, 1959 (Davis and Comuntzis, 1960). The American Association for the Advancement of Science sponsored a symposium on Extraterrestrial Biology and Biochemistry at its Denver meeting in December 1959. This was organized and chaired by Dr. Charles R. Phillips.

The SSB of the National Academy of Sciences, together with its representation at COSPAR, served and continues to serve as the main outside scientific source of recommendations to NASA on planetary quarantine. Among the SSB members, most of whom had nonbiological backgrounds, those most concerned with planetary quarantine have been Dr. Allan H. Brown, Dr. Wolf V. Vishniac, and Dr. Colin S. Pittendrigh. They, together with Dr. Carl E. Sagan and Dr. Lawrence B. Hall, have been active on COSPAR Working Group 5, Space Biology, which was set up at the Warsaw meeting in 1963. The proceedings of the COSPAR meetings appear annually in *Space Research* (North-Holland, Amsterdam) beginning with Volume I, 1960, covering the Nice meeting. Papers dealing with the life sciences comprise a substantive section in the second volume of *Space Research* for the Florence meeting of 1961. Beginning in 1962, the papers on the life sciences have been published separately each year in a companion volume *Life Sciences and Space Research.*

One specific COSPAR-sponsored Symposium was held in London, England, just prior to COSPAR's 1967 plenary session there. These proceedings were published separately as COSPAR Technique Manual No. 4, *Sterilization Techniques for Instruments and Materiels as Applied to Space Research,* (Sneath, ed., 1968).

Other advisory bodies which have been set up by NASA itself, such as the American Institute of Biological Sciences (AIBS) consultants and the Life Sciences Committee of NASA, will be discussed later.

Early Beginnings of the Space Program

NASA WAS FORMALLY ESTABLISHED on October 1, 1958. An aeronautical research agency, the National Advisory Committee for Aeronautics (NACA) was reorganized and became the nucleus of the new organization. At that time the space program had already begun. *Sputnik I* had been launched by the U.S.S.R. on October 4, 1957, a year earlier. This was followed by *Sputnik II*, launched November 3, 1957. The U.S. Navy attempted to launch Vanguard satellites on December 6, 1957, and February 5, 1958. They succeeded on March 17, 1958. Meanwhile, on January 31, 1958, the U.S. Army had launched *Explorer I* whose instruments discovered the Van Allen belt. The U.S. Air Force attempted its first lunar probe with *Thor-Able I* on August 17, 1958, but failed. The Department of Defense Advanced Research Programs Agency (ARPA) had taken over the Explorer program with the successful launch of *Explorer 4* on July 26, 1958. After the establishment of NASA, these military projects passed into civilian control.

NASA and Its Planetary Quarantine Responsibilities

THE AUTHORITY FOR THE IMPLEMENTATION of the national and international recommendations concerning the prevention of contamination, and later concerning planetary quarantine, resides in the National Aeronautics and Space Administration, NASA, subject always to the final authority of the Congress, which established that agency and which appropriates the funds to carry out approved programs, and to the Federal Executive office, which approves the budgets NASA presents to the Congress.

In 1958, Dr. T. Keith Glennan, then President of Case Institute, Cleveland, Ohio, was named by President Eisenhower to be the first administrator of NASA. The other top officials were mainly drawn from the predecessor organization, NACA. For example, Dr. Hugh L. Dryden became Deputy Administrator, and Dr. Abe Silverstein became Director of Space Flight Programs.

NACA had been an engineering and physical sciences organization carrying out its own investigations in a complex of research centers: Ames in California, Langley in Virginia, and Lewis in Ohio. These centers had few capabilities in the biological sciences. To remedy this, Dr. Glennan in April 1959 brought into NASA as a special medical and biological advisor, Dr. Clark T. Randt, Professor of Neurology from Western Reserve University. Dr. Randt acted in this staff capacity for a year until he became the first director of NASA's Office of Life Sciences.

The first major problem facing NASA was to take over certain

military space programs from the Department of Defense and to coordinate them with the expanded NACA functions. In December 1958, Dr. Dryden delineated the functions of the various organizations reporting to NASA headquarters. The existing three NACA centers were to remain in-house research and development centers. Goddard Space Flight Center, to be constructed in Maryland, was given responsibility for Earth orbit missions. The Jet Propulsion Laboratory (JPL), whose contract with the Army Ballistic Missile Agency was to be assumed by NASA on January 1, 1959, was to handle all deep space missions. The first such program at JPL, Ranger, was still in the planning stage. Another NASA inheritance was the work being done by the Space Technology Laboratory (STL), a subsidiary of the then Ramo-Woldridge Corporation, under contract to the Air Force Ballistic Missile Division and later with the Department of Defense's (DOD's) Advanced Research Projects Agency (ARPA). STL was already engaged in the early Pioneer series of lunar shots and the Atlas-Able shots which were to follow. Only *Pioneer 4* (March 1959) was to escape the Earth's gravitational field. It missed the Moon by 37,000 miles. Even before NASA came into the picture, some effort had been made by the military, in response to the advice of the scientific community, to decontaminate, if not to sterilize, these space probes.

On September 14, 1959, Dr. Hugh Odishaw, Secretary of the Space Science Board, wrote to Dr. Glennan and to Dr. Roy Johnson of ARPA transmitting the recommendations of Dr. Lederberg's *ad hoc* Committee on Sterilization, saying that the recommendations had SSB's approval and requesting that they be followed. Dr. Glennan answered this request on October 13, 1959, pledging that NASA would attempt to carry out the recommendations. Also during October, Dr. Abe Silverstein sent JPL, Goddard Space Flight Center, and STL (through the Air Force Ballistic Missile Division) letters stating the following:

> The National Aeronautics and Space Administration has been considering the problem of sterilization of payloads that might impact a celestial body. Consideration was given to scientific questions, engineering problems, NASA's responsibility towards protecting scientific investigations into space, and the reputation and integrity of the United States. As a result of the deliberations, it has been established as a NASA policy that payloads which might impact a celestial body must be sterilized before launching.

The letters went on to list particular payloads of concern, gave several references, and suggested that the group at the U.S. Army BioLabs, Fort Detrick, Maryland, under Dr. Charles R. Phillips, had experience in

problems associated with sterilization and should be contacted. Shortly after, on November 12, 1959, Dr. Glennan transferred funds to the Army under a governmental interagency agreement to support their cooperation. Dr. Silverstein's letters could be considered the first official NASA policy directives on spacecraft sterilization.

Dr. Gerhard F. Schilling, one of the German rocket scientists who came to the United States following World War II, had taken over as NASA Project Manager for the Atlas-Able Pioneer series of shots. He became one of the first NASA officials charged with responsibility for space vehicle sterilization.

The various committees and scientific advisory panels set up by and reporting directly to NASA— as opposed to the outside scientific bodies discussed earlier—will be listed in a later section of this report. Two of these committees were primarily concerned with the establishment of biological competence and facilities within the NASA organization. The first was the NASA Special Life Sciences Committee, better known as the Lovelace Committee after its chairman, Dr. W. Randolph Lovelace, II. This was formally established on October 1, 1958, the same date as NASA itself. It had its foundations in an earlier Special Committee on Space Technology established by NACA in November 1957, a month after the first Sputnik launch. This NACA committee had been headed by Dr. H. Guyford Stever of MIT. It had seven working groups, one of which was on Human Factors and Training, headed by Dr. Lovelace. The new NASA Special Life Sciences Committee stemmed from earlier recommendations that NASA should "develop a capability as quickly as possible [in Life Sciences] starting with contract coverage concurrent with in-house support" and that a special Life Sciences Committee should be established to consider immediate problems. NASA promptly implemented these recommendations. This new committee consisted of Dr. Lovelace, Chairman; Brig. Gen. Don Flickinger, U.S. Air Force (USAF); and Dr. Wright Langham, Atomic Energy Commission (AEC), from the earlier Stever group. Additional members were Lt. Comdr. John M. Ebersole, Medical Corps, U.S. Navy, National Medical Center; Lt. Col. Robert H. Holmes, Medical Corps, U.S. Army; Dr. Robert B. Livingston, U.S. Public Health Service-National Institute of Health (USPHS–NIH); and Dr. Orr. E. Reynolds, DOD; with Capt. G. Dale Smith, USAF, serving as secretary. The committee tried unsuccessfully to interest various institutions and government agencies in entering into an agreement with NASA to manage a major life science program for them. The committee was dissolved on March 31, 1960, after the establishment of an Office of Life Sciences within NASA.

This Office of Life Sciences was formed after NASA, in August 1959,

set up another biological group, the *ad hoc* Bioscience Advisory Committee, better known as the Kety Committee after Dr. Seymour S. Kety, its Chairman. Other members were Drs. Wallace O. Fenn, David R. Goddard, Donald G. Marquis, Robert S. Morison, and Cornelius A. Tobias. Advisors included Stephen Dole, Dr. Joshua Lederberg, Dr. Melvin Calvin, and Dr. W. Randolph Lovelace, II. Dr. Randt served as executive secretary. The Kety Committee had met on October 15–16, 1959, and on January 25, 1960, and had recommended that an Office of Life Sciences be established as a major division of NASA.

Dr. Glennan accepted the recommendation and established the office on March 1, 1960, naming Dr. Randt as Director. This office was responsible for all biological and medical programs within NASA. The mandate included aerospace medicine, biological satellite experiments, exobiology, and the accompanying spacecraft sterilization program. Col. Charles H. Roadman, who was on assignment from the Air Force and had previous experience with aerospace medicine, was brought into the organization in June 1960. Other chief members of the staff were Drs. Freeman H. Quimby, George J. Jacobs, Richard S. Young, G. Dale Smith, Siegfried J. Gerathewohl, and Jack Posner. The latter served in an administrative position and, as such, was the first to oversee the sterilization projects underway at JPL and the U.S. Army BioLabs.

On April 1, 1961, Dr. Randt resigned as Director of the Office of Life Sciences. Colonel Roadman replaced him, first as Acting Director then as Director, until November 1, 1961, when, under a major reorganization, the four major offices of NASA headquarters, including the Office of Life Sciences were abolished. Four new major offices were established: (1) Manned Space Flight, Dr. D.B. Holmes, Director; (2) Advanced Research and Technology, Dr. Ira H. Abbott, Director; (3) Space Sciences, Dr. Homer E. Newell, Director; and (4) Applications, Director to be appointed.

The medical and biological programs within NASA, formerly all residing within the Office of Life Sciences, were split between three of these new offices. Aerospace medicine, headed by Brig. Gen. Charles H. Roadman, went into the Office of Manned Space Flight. Biological technology was placed in the Office of Advanced Research and Technology, while biosatellite experimentation, exobiology, and sterilization of spacecraft went to the Office of Space Sciences (OSS). Dr. Orr E. Reynolds was appointed the first Director of Biosciences Programs in OSS on February 11, 1962. Dr. Reynolds first had Dr. Quimby handle sterilization as a part of the exobiology program. On August 1, 1963, Capt. Lawrence B. Hall, a senior commissioned officer of the U.S. Public Health Service, was detailed, on request from the

NASA Administrator to the Surgeon General, to duty with NASA. His task was to develop the sterilization program. He became the first NASA Planetary Quarantine (PQ) Officer, assuming responsibility for direction and operation of the program. He retired from the Public Health Service on September 30, 1965, but has remained with NASA in the same position, as a civilian.

The headquarters staff at the PQ office remained small, concerned with the direction of research and operations, particularly in its overall programming and funding aspects. Dr. Carl W. Bruch was brought in at the beginning of the PQ Program and stayed until September 24, 1966. James Miles, a NASA engineer, was assigned engineering responsibilities in the PQ Program from 1963 to 1965, when he transferred to other duties. Capt. Jack H. Fooks, also detailed to NASA by the Public Health Service, served as Sterility Control Officer for planetary quarantine from November 1, 1965, to December 31, 1967. Concurrently, Capt. Arthur H. Neill, a USPHS officer detailed to duty with NASA January 1, 1967, served as Deputy Planetary Quarantine Officer. He retired on May 31, 1971. Lt. Comdr. Donald G. Fox, also on loan as a USPHS commissioned officer, served as a Sterility Control Officer from October 1968 to August 30, 1971. During portions of 1971–1973, JPL maintained a series of detailees in NASA headquarters to the support of the technical aspects of the PQ Program. Mrs. Suzanne Gallagher, on loan as a USPHS civilian, has served as Administrative Officer from June 21, 1964, to the present.

The PQ Program operated from 1963 to 1971 under the Bioscience Programs, NASA Office of Space Science and Applications. When Bioscience Programs was eliminated in 1971, the PQ Program was transferred to Planetary Programs, Office of Life Sciences, for administrative purposes. To avoid any possibility of conflict between the regulatory responsibility of the PQ Program and the operational responsibility of the Planetary Programs, the NASA Director of Life Sciences was given an overall coordination role, and a direct line of communication was authorized, for use if needed, from the Planetary Quarantine Officer to the Associate Administrator, Office of Space Science.

The planetary quarantine staff at NASA headquarters has remained small because of staffing limitations in effect at the time of organization. Its administrative functions have of necessity been augmented under three contractual arrangements. Since 1965, the Biological Sciences Communication Project of George Washington University has handled documentation of both research supported by the PQ office and outside scientific literature. The American Institute of Biological Sciences, since 1964, has performed various functions

including the handling of details for outside conferences and meetings. Exotech Systems, Inc., under a series of contracts beginning in 1965, has provided a number of services in systems analysis, research integration, and operations research. These latter two contractual services will be discussed in more detail later.

NASA Advisory Groups

THE FIRST TWO ADVISORY GROUPS which NASA established in the life sciences, the so-called Lovelace and Kety Committees, have been mentioned. They were concerned with organizational and administrative aspects rather than with technical or program problems. After the Office of Life Sciences was established in NASA Headquarters (largely as a result of the recommendations of the Kety Committee), its Director, Dr. Randt, established three advisory committees. One on Flight Medicine and Biology was chaired by Dr. Lovelace. A second on Space Medical and Behavioral Sciences was chaired by Dr. Robert S. Morison of the Rockefeller Foundation. Spacecraft sterilization and planetary quarantine, as well as exobiology, were handled by a third group, the NASA Advisory Committee on Space Biology. Dr. Melvin Calvin of the University of California, Berkeley, was Chairman. Other members were Dr. Philip H. Abelson, Carnegie Institution; Dr. Sidney W. Fox, Florida State University; Dr. Norman H. Horowitz (Vice-Chairman), California Institute of Technology; Dr. Henry Linschitz, Brandeis University; Dr. C.S. Pittendrigh, Princeton University; Dr. Carl E. Sagan, then at the University of California, Berkeley; and Dr. Ernest C. Pollard, Pennsylvania State University. Dr. Richard S. Young, NASA headquarters, served as secretary.

Within NASA headquarters there was also established a Biosciences Subcommittee of the Space Sciences Steering Committee with Drs. Freeman Quimby, Chairman; Richard Young, Secretary; and George Jacobs, Siegfried Gerathewohl, G. Dale Smith, and Jack Posner, members. During 1960 and 1961, the groups held several meetings with invited visitors and consultants.

NASA also organized two *ad hoc* conferences on spacecraft sterilization, in which NASA officials met with invited scientists from other government agencies and outside institutions. The first of these was held at NASA headquarters in January 1961. It was chaired by Dr. Randt, and its proceedings were edited by Jack Posner and published as NASA Technical Note D–771. The second such meeting was held in July 1962 after the reorganization which abolished the Office of Life Sciences. This conference was chaired by Dr. Reynolds and George Hobby of JPL. Its proceedings were edited by Dr. Quimby and published as NASA Technical Note D–1357. Some 20 to 25 attendees were present at these two conferences.

The SSB also arranged special *ad hoc* meetings at which spacecraft sterilization, or the need for it, was a subject for consideration. Biology was one subject considered by the SSB summer study at Ames, Iowa. This will be discussed later. Three other SSB-sponsored meetings applicable to planetary quarantine, all held in Washington and chaired by Dr. Allan H. Brown, were "Conference on Hazard of Planetary Contamination due to Microbial Contamination of Interior of Spacecraft Components," July 28, 1964; "Conference on Potential Hazards of Back-Contamination from Planets," July 29–30, 1964; and "*Ad hoc* Panel on Study of Biological Quarantine of Venus," January 1967.

A recommendation from the second of these meetings, that both the samples returned from the Moon and the astronauts themselves be quarantined on their return until found free of possible extraterrestrial microorganisms, led directly to the decision by NASA to construct the Lunar Receiving Laboratory at Houston before the first Apollo mission landed on the Moon. This quarantine policy is discussed later in more detail.

American Institute of Biological Sciences

Formal advisory services were reestablished in 1965 for the PQ office through a contract with the AIBS. From then on, AIBS organized and managed technical seminars on planetary research and developed a technically qualified group to formulate and recommend the advice supplied by AIBS to the Planetary Quarantine Officer.

This advisory group has been known progressively as the AIBS Spacecraft Sterilization Advisory Committee (1965–1967), the AIBS Planetary Quarantine Advisory Committee (1968–1970), the AIBS Planetary Quarantine Advisory Panel (1970–1972), and, currently, the AIBS Planetary Quarantine Panel (1973).

The Chairman through all these changes of nomenclature has been

Professor Richard G. Bond of the University of Minnesota. Membership has changed from year to year, and not all current members have participated in each meeting. A list of members appears in Table II.

Table II *AIBS planetary quarantine advisory panel, 1965–1973.*

Members

Professor Richard G. Bond, Chairman
University of Minnesota
1965–

Dr. Robert Angelotti
Food and Drug Administration
1969–

Dr. John R. Bagby, Jr.
Colorado State University
1972–

Dr. John H. Brewer
Hardin-Simmons University
1965–

Mr. William B. Briggs
McDonnell-Douglas Astronautics Company
1972–

Dr. Allan H. Brown
University of Pennsylvania
1972–

Dr. Byron W. Brown, Jr.
Stanford University Medical Center
1969–1970

Mr. Mark A. Chatigny
University of California, Berkeley
1966–

Dr. Frank B. Engley, Jr.
University of Missouri
1967–

Dr. Franklin A. Graybill
Colorado State University
1972–

Professor Thomas W. Kethley
Georgia Institute of Technology
1965–1966

Dr. James C. Konen
Consultant, Ashland Chemical
1972–

Dr. Gilbert V. Levin
Biospherics Incorporated
1967–1973

Dr. Morton W. Miller
University of Rochester
1972–

Dr. Irving J. Pflug
University of Minnesota
1965–1972

Dr. Richard W. Porter
General Electric Company
1970–

Dr. Orr E. Reynolds
American Physiological Society
1971–

Dr. Gerald Silverman
Massachusetts Institute of Technology
1967–

Mr. H.D. Sivinski
Sandia Corporation
1972–

Dr. H. Earle Swim
University of Kentucky
1972–

Dr. John A. Ulrich
University of New Mexico
1965–

Dr. Wolf V. Vishniac
University of Rochester
1972–1973

Dr. William G. Walter
Montana State University
1965–1966

Mr. Robert P. Wolfson
Systems Consultant
1972–

Advisory Scientist

Dr. Irving J. Pflug
University of Minnesota
1972–

Coordinator

Ms. Mary-Frances Thompson
American Institute of Biological Sciences
1965–

The purposes of the Panel are to

1. Review the broad aspects of the PQ program
2. Review research data of PQ interest upon which NASA policy decisions are based
3. Prepare recommendations for technical changes in PQ policy or confirm policies
4. Evaluate research proposals

In 1965, the same year the first panel was organized, AIBS set up for the Planetary Quarantine Program a National Conference on Spacecraft Sterilization Technology on the California Institute of Technology campus in Pasadena. This was attended by about 300 persons. Some 36 formal papers were presented over a period of three days, and they, together with discussions, were published by NASA as SP–108 in 1966.

No large national conferences followed, although there was an international meeting in London in 1967 just before the COSPAR meeting there. The papers presented, together with discussions, were published by COSPAR as Manual No. 4 of their Technique Manual Series under the title *Sterilization Techniques for Instruments and Materials as Applied to Space Research.*

In 1968 the AIBS Planetary Quarantine Panel started the practice of holding smaller semiannual NASA Spacecraft Sterilization Technology Seminars. The purpose of the seminars was to permit the PQ Officer to monitor contracts, to inform the PQ Officer and the AIBS PQ Panel of progress made in the supporting research and technology program, and to foster an interchange of ideas and recent developments in spacecraft sterilization. For these seminars research contractors prepared abstracts rather than formal papers, since much of what was reported was work in progress. The panel and NASA officials selected from these abstracts the work they wanted presented in great detail; thus, the technology seminars consisted of informal oral presentations by certain contractors and discussions which were not formally published. Other contractors and prospective contractors were invited to attend the seminars if they wanted to keep up with work related to their own.

Following is a list of these Spacecraft Technology Seminars and their locations:

June 1968	Cape Kennedy, Florida
February 1969	Cape Kennedy, Florida
September 1969	Las Vegas, Nevada
April 1970	Atlanta, Georgia
December 1970	Williamsburg, Virginia
June 1971	Seattle, Washington

January 1972	Cape Kennedy, Florida
July 1972	San Francisco, California
January 1973	New Orleans, Louisiana
July 1973	Denver, Colorado

NASA Life Sciences Committee

Recently, the NASA Life Sciences Committee, operating under the NASA Space Program Advisory Council, has undertaken to review and advise on the adequacy of the planetary quarantine measures employed by planetary missions.

Planetary Quarantine Research

A RESEARCH PROGRAM IN THE LIFE SCIENCES had to be established after NASA's formation, since NACA had essentially no experience or in-house capability in the biological field which could be carried over into the new organization. The NACA research organization had been built almost entirely around its research centers. Under NASA, the research development program became contractor oriented.

The first of the research contractors was JPL. This continuing project is by far the largest research effort which NASA has supported in this field. Although technically a contractor, JPL has, in effect, operated as a major NASA research center.

When NASA took contractual control of JPL on January 1, 1959, JPL too had little experience in biology or the life sciences. Among the first to become involved in sterilization problems at JPL was Richard W. Davies, who had been in contact with Dr. Lederberg and was a member of his *ad hoc* committee on spacecraft sterilization which met in the summer of 1959. Also involved soon after JPL became a NASA prime contractor was Marcus G. Comuntzis, an engineer concerned with the Ranger program. They gave a joint paper on spacecraft sterilization in London in the summer of 1959. In it they recommended various goals, including one that the probability of landing a viable organism on Mars or Venus should be less than one in a million.

This was followed up in JPL by an engineering study conducted by Leonard D. Jaffe (Jaffe, 1963, 1964). He took into consideration the current state-of-the-art, both in sterilization and in trajectory control,

and concluded that these probabilities should be lessened considerably for Venus and that those for Mars should be reduced to about a 10^{-4} probability. The further development of these goals in terms of probabilities is covered in Werber's companion report mentioned in the Foreword to this volume.

JPL also started early to build up an in-house biological research capability. In March 1959, JPL arranged for George L. Hobby, then associated with Dr. Dean Burke at the National Institutes of Health, to come into their organization as a staff biologist. He reported for duty in August 1959 and began to build up a small internal biological organization. Frank A. Morelli was an early member of this group.

Since then, a large number of JPL staff members have been associated with sterilization and planetary quarantine activities either on a full-time or part-time basis. The research effort grew particularly after the establishment of the PQ office within NASA headquarters, which offered a central source of program planning and funding. Much of the research is difficult to sort out from other JPL activities associated with funded programs not directly related to planetary quarantine. For example, there was a large effort from the start to determine which spacecraft components were unaffected by various types of sterilization treatments and to develop new sterilizable components when the available ones were damaged by heat or other techniques. Trajectory computations also had a bearing on planetary quarantine. Many JPL research efforts were directly funded by NASA's PQ office and were related directly to that program.

The Planetary Quarantine Program at JPL is now supervised by Dr. Charles W. Craven. He was Project Officer for early Voyager project work, supported by various contractors including General Electric, with Robert Wolfson as principal investigator. This led to a clear definition of overall planetary quarantine parameters, which in turn led to more than a score of early laboratory investigations to better define problems of die-off and recontamination—die-off due to ultraviolet radiation and recontamination due to exhaust gases and spalling.

George F. Ervin had an early assignment as Capsule Systems Sterilization Engineer for Voyager, and he provided the Planetary Quarantine Program with a fresh look at procedures and methodology. He exercised considerable engineering acumen in the development of sterilization specifications and the NASA planetary quarantine handbook, NHB 8020.12. This documentation has been and continues to be a key element in Viking development activities.

Victor J. Magistrale carried out early coordination work on a laboratorywide basis to develop the sterilizable parts for various

spacecraft, including electronic components, scientific instruments, batteries, and materials. At that time sterilization requirements included exposure to both dry heat and ethylene oxide. In this effort he worked closely with James R. Miles, the Sterilization Program Manager at NASA headquarters.

Alexander S. Irons worked in the area of sterilization methodology with both dry heat and ethylene oxide. He defined exposure times, conditions of exposure, i.e., amount of moisture, and carried out studies to better define clean rooms and to develop means of quantization. This included work in the Experimental Assembly Sterilization Laboratory (EASL). He later projected his work into the civil systems area, developing a readily sterilizable pressure breathing machine for use in hospitals. This is considered a direct transfer of NASA technology to the civil sector.

Dr. Joseph J. McDade conducted early studies to define clean-room work areas. These studies included definition of expected microbiological fallout and accumulation of biological load on spacecraft surfaces. In addition, he did pioneering work to quantitize microbiological population. Later work in cleaning spacecraft surfaces has proven of value in the cleanup of all the various Mariner spacecraft.

Dr. Joseph A. Stern and Dr. Richard H. Green selected and directed a team of workers to provide the Viking project discipline, as well as other planetary quarantine achievements. They refined early clean-room studies and advanced the quantization of microbiological populations.

Gunther Redmann worked with the prototype Sterilization Development Laboratory (SADL) and with simulated lander capsule equipment to collect data showing the level of bioload to be expected through normal assembly and test of Viking hardware. These data proved that extensive sterile life protection and handling of flight hardware were unnecessary. In addition, his work showed the merit of the class 100 type of clean tent which was later adapted for use with the two Mariner 71 spacecraft.

Dr. Daniel M. Taylor refined spacecraft cleaning methodology and continued the operation of bioassay laboratories required to support the Viking lander through launch. His studies of radiation effect on microorganisms, combined with effects of the space environment and exposure to dry heat, have proven of great value in defining planetary quarantine requirements for planned missions to Jupiter and Saturn.

Alan R. Hoffman worked in systems analysis, mathematical modeling, and development of planetary quarantine computer programs in support of the overall Viking Planetary Quarantine

Program. He has also projected his sytems analysis methodology into studies for missions to the outer planets to provide planners with a selection of strategies for encounters with the planets and their satellites.

Aside from the effort at JPL, there were many other contractors working on planetary quarantine research. Some were early participants in the NASA sterilization effort. A larger number came in after the establishment of the Planetary Quarantine office at NASA headquarters. These contractors, the scope of their research effort, principal investigators, and duration of study are listed in the Appendix. The reader is referred to the BSCP bibliography for a review of published results.

Implementation and Policy Directives

DR. ABE SILVERSTEIN'S LETTERS written in October 1959 were partially quoted earlier, together with the comment that they constituted the first formal NASA policy directive on spacecraft sterilization. They all contained the statement that "payloads which might impact a celestial body must be sterilized before launching." This was an unequivocable statement, with no qualification, and sterilization is an absolute term.

While this directive could not have been completely unexpected, since those involved with imminent launchings were aware of the recommendations the biologists had been making, its immediate application posed innumerable difficulties. To begin with, these activities were in the hands of physical scientists and engineers who had little previous experience with biology, much less with sterilization techniques, and no knowledge of what the application of these treatments would do to the spacecraft they were designing. Sterilization at that time was usually thought of in hospital terms, involving small items such as those used in surgery. The technique predominantly used was autoclaving—wet steam at pressures of about 25 psi over atmospheric—and was usually conducted in small pressure chambers. This was hardly applicable to spacecraft.

The Lederberg *ad hoc* committee on spacecraft sterilization had stated that one research group, the U.S. Army BioLabs, had experience dating back to World War II in sterilizing objects as large as army trucks and as delicate as laboratory balances. They recommended that this experience be utilized. Dr. Silverstein's letters repeated this recommendation, and, shortly afterward, NASA and the U.S. Army signed an interagency agreement formalizing this cooperation. BioLabs

had developed gaseous sterilization techniques, particularly around the use of volatile and noncorrosive ethylene oxide, which could be used in simple plastic containers at ambient temperatures and pressures. The SSB and Dr. Silverstein's directives recommended that this technique be explored.

A complicating factor which eliminated sole reliance on a simple terminal gaseous sterilization of an assembled spacecraft soon evolved. This gaseous treatment would take care of microorganisms only on exposed surfaces. Lederberg had expressed concern that microorganisms might be protected between the threads of screws, for example, or in plastics or potting materials used to protect electronic components. The lunar launches then in the planning stage involved hard landings, which could cause such buried contamination to become exposed. Until this time, only surface sterilization had been a concern. No surgeon after an operation would crumble the instruments he had used and drop them into the open wound before he sewed up the incision he had made. This, however, was essentially what could happen on a hard lunar landing. In the absence of any restraining atmosphere, the exposed contaminated parts could be transported, depending upon their initial velocity and trajectory, to distances far beyond the landing site.

The Army BioLabs group looked into this matter of buried contamination. After exploratory experiments, they found that hardy microorganisms could indeed survive certain polymerization processes of plastics, and, moreover, that many electronic components—capacitors, resistors, transformers—as received from the manufacturer contained viable microorganisms inside them which grew when the components were cracked or crushed open, even after being surface sterilized with ethylene oxide.

This information was reported at the annual convention of the Society of American Bacteriologists in Philadelphia in May 1960 and subsequently published in *Science* (Phillips and Hoffman, 1960).

There were only two known sterilization techniques at that time which could be used for such buried contamination—heat and penetrating radiation. Radiation had considerably less effect on microorganisms than on higher forms of life. Very high dosages were required, in the order of three to five megarads, rather than dosages in the hundreds or low thousands which were lethal to higher life forms. Many spacecraft components simply could not withstand this treatment. Heat too had its drawbacks. Sterilization dosages were well worked out for autoclaving, requiring only 15 to 20 minutes at temperatures around 125°C. But steam could no more penetrate to the buried microorganisms than could the sterilizing gases. Heat in that

case had to be dry heat, even if applied in an autoclave. Microorganisms in the dry state, as opposed to those freely exposed to wet steam, were much more resistant. At temperatures in the range of 160°C to 170°C, four or more hours were required for sterilization. Moreover, because of these long exposure times and high temperatures the process had been little used and, hence, there were few data available. No data were available on dry heat sterilization rates at lower, and presumably less damaging, temperatures. The Army BioLabs in a few exploratory experiments determined that at 125°C exposure times extending to 24 hours would probably be required.

Meanwhile JPL was finding in planning for the Ranger program that it was not possible to live up to the absolute terms of the Silverstein directive.

The whole Ranger program was beset with difficulties, of which attempts at sterilization were only a part, but a particularly annoying part. This whole experience has been carefully documented in *Project Ranger. A Chronology* (Hall, 1971). This publication lists chronologically all the pertinent documents dealing with the Ranger history, together with a short summary of their contents. The following paragraphs summarize rather briefly the part that sterilization played in this attempt at lunar exploration.

On March 8, 1960, JPL established spacecraft sterilization guidelines for the Ranger project, and in April a Spacecraft Sterilization Panel decided that they would only generate techniques with *Rangers I* and *II*, which were to be Earth orbiters. Then they would utilize these techniques with *Rangers III*, *IV*, and *V*, which were planned to take TV pictures prior to hard lunar impacts. Later in April 1960, JPL released detailed in-house procedures which included first a dry heat treatment and then a terminal gaseous sterilization at the launch site.

Further studies with spacecraft components were taking place during the delays that occurred in the Ranger program, and JPL was finding it impossible to sterilize all Ranger components internally. Such terms as "sterilization to the extent feasible" began to creep into correspondence. Then on December 23, 1960, after considerable staffing, NASA issued a memorandum to Program Directors at NASA headquarters and Directors of field stations on the subject: "Decontamination and sterilization procedures for lunar and planetary space vehicles." The memo was signed by Hugh L. Dryden, NASA Deputy Administrator, for T. Keith Glennan, Administrator. The directive restated that "effective decontamination and sterilization procedures for lunar and planetary space vehicles are essential." It called for extensive studies to be initiated to achieve this goal. Sterilization plans for each mission would be prepared for the

NASA Associate Administrator and no mission would be flown until he had approved the planned procedures. Waivers could be granted if certain essential components could not be sterilized internally as well as externally.

The requested studies, particularly on dry heat sterilization, were initiated at JPL. In addition, NASA headquarters supported an extensive basic research program on dry heat with other contractors, beginning with the Wilmot Castle Company contract in March 1961. This effort has continued under various investigators to the present.

At this point it is advisable to list the various U.S. lunar and planetary flight missions, together with their launch dates, or projected launch dates in the cast of certain planned planetary missions (see Table III). To keep the chronology straight, it should be noted that the first object to impact the Moon was the U.S.S.R. *Luna 2* launched in September 1959. Soviet officials stated that *Luna 2* had been given a sterilization treatment prior to launch, but details of the methods used were never made available.

Ranger I, not launched until August 1961, went into a lower Earth orbit than planned. As a result of the failure of its Agena booster, *Ranger II* failed in its November 1961 launch attempt and did not go into orbit. *Ranger III*, the first attempted lunar lander, missed the Moon by about 23,000 miles, and the TV pictures are unusable. Not until April 1962, with *Ranger IV*, was the U.S. able to repeat the Soviet accomplishment of landing an object on the Moon. This flight was by no means a complete success. No TV pictures were returned. The space vehicle went out of control and crashed on the far side of the Moon.

Table III *U.S. space launches of planetary quarantine interest.*

Lunar missions		
Aug 58	Thor-Able Pioneer	Failed
Oct 58	Pioneer 1	Failed
Nov 58	Pioneer 2	Failed
Dec 58	Pioneer 3	Failed
Mar 59	Pioneer 4	Flyby, missed Moon
Nov 59	Atlas-Able 4	Failed
Sep 60	Atlas-Able 5A	Failed
Dec 60	Atlas-Able 5B	Failed
Aug 61	Ranger 1	Failed, nonlunar
Nov 61	Ranger 2	Failed, nonlunar
Jan 62	Ranger 3	Flyby, missed Moon
Apr 62	Ranger 4	Impact, no TV
Oct 62	Ranger 5	Flyby, missed Moon
Jan 64	Ranger 6	Impact, no TV
Jul 64	Ranger 7	Impact, TV
Feb 65	Ranger 8	Impact, TV

Table III *(Continued).*

Mar 65	Ranger 9	Impact, TV
May 66	Surveyor 1	Soft landing, TV
Sep 66	Surveyor 2	Impact, no TV
Apr 67	Surveyor 3	Soft landing, TV
Jul 67	Surveyor 4	Impact, no TV
Sep 67	Surveyor 5	Soft landing, TV
Nov 67	Surveyor 6	Soft landing, TV
Jan 68	Surveyor 7	Soft landing, TV
Aug 66	Lunar Orbiter 1	Orbit, then impact
Nov 66	Lunar Orbiter 2	Orbit, then impact
Feb 67	Lunar Orbiter 3	Orbit, then impact
May 67	Lunar Orbiter 4	Orbit, then impact
Aug 67	Lunar Orbiter 5	Orbit, then impact
Dec 68	Apollo 8	Manned circumlunar
Mar 69	Apollo 9	Manned orbit
May 69	Apollo 10	Manned orbit
Jul 69	Apollo 11	Manned landing
Nov 69	Apollo 12	Manned landing
Apr 70	Apollo 13	Aborted landing; manned circumlunar
Jan 71	Apollo 14	Manned landing
Jul 71	Apollo 15	Manned landing
Apr 72	Apollo 16	Manned landing
Dec 72	Apollo 17	Manned landing
Aug 71	P&F Satellite	Orbit, launched from Apollo 15
Apr 72	P&F Satellite	Orbit, launched from Apollo 16; impact
Jul 66	Explorer 33	Flyby, missed lunar orbit
Jul 67	Explorer 35	Selenocentric (lunar) orbit
Jun 73	Explorer 49	Selenocentric (lunar) orbit
Mars missions		
Nov 64	Mariner 3	Failed
Nov 64	Mariner 4	Flyby, TV
Feb 69	Mariner 6	Flyby, TV
Mar 69	Mariner 7	Flyby, TV
May 71	Mariner 8	Failed
May 71	Mariner 9	Mars probe in orbit, TV
1975	Viking	Lander and orbiter (proposed)
Venus missions		
Jul 62	Mariner 1	Failed
Aug 62	Mariner 2	Flyby
Jun 67	Mariner 5	Flyby
Mariner Venus/Mercury 1973 mission		
Nov 73	Mariner 10	Flyby
Outer planets missions		
Mar 72	Pioneer 10	Jupiter flyby
Apr 73	Pioneer 11	Jupiter, Saturn flyby
Aug 77	Mariner	Jupiter, Saturn flyby (proposed)

Ranger V, launched in October 1962, had a power loss, missed the Moon, and again sent back no pictures. *Rangers III*, *IV*, and *V* had all received dry heat treatments and a terminal sterilization treatment with gas.

The series of Ranger failures aroused a storm of protest, both within the government and in the press. In spite of the fact that some failures were definitely due to other causes, there were claims that the sterilization treatments, particularly dry heat, were at least partially responsible. This could not actually be proven, but the suspicion caused a heavy flow of memoranda and letters both within NASA and JPL and between them. Waivers grew instead of decreased in numbers. What was more, the climate was changing. The scientific community had never presented a unified front demanding sterilization for lunar, as opposed to planetary, missions. Those claiming it was unnecessary were becoming more vocal. In July 1962 at the NAS Iowa Summer Study, the Working Group on Biology, with Dr. Allan H. Brown as Chairman and Dr. C.S. Pittendrigh as Vice Chairman, concluded that "contamination of the Moon does not constitute as serious a problem as is the case of the planets. Nevertheless, lunar contamination should be kept at a feasible minimum." They added, "Planning for Manned Landings on the Moon and planets must be based on the assumption that sterility precautions will still be required during the phase of manned exploration."

Moreover, priorities were changing. The manned space program was well along. President Kennedy had stated to Congress in May 1961 that the U.S. would land a man on the Moon "within this decade." And wherever man went, his flora of microorganisms would accompany him. The hope now was that contamination could be kept to such a minimum that it would not interfere with tests for the presence of biological matter on returned lunar samples.

As early as November 1962, JPL was told to stop dry heat treatments on components for the future Ranger vehicles. There was a last ditch effort to keep the requirement for a terminal gaseous surface sterilization treatment of the assembled vehicle, but that too was dropped in later correspondence.

This change of policy was not made official until September 9, 1963, when NASA issued its Management Manual NMI–4–4–1, "NASA Unmanned Spacecraft Decontamination Policy." The management instruction stated under policy for the Moon that

1 The NASA policy is based on acceptance of the scientific opinion that lunar surface conditions would mitigate against reproduction of known terrestrial microorganisms and that, if subsurface penetration of viable organisms were to be caused

by spacecraft impact, proliferation would remain highly localized.

2 It is the NASA policy to protect the Moon from widespread or excessive contamination until sufficient information has been obtained concerning the Moon, to ensure that scientific studies will not be jeopardized.

The management instruction further stated under "Required Procedures" that clean-room assembly policies be adopted, sporicidal agents be used when "appropriate" to reduce surface contamination, and final assembly be wrapped and handled in such a way as to prevent accumulation of contamination during its shipment to the launch site. This was the policy followed on the subsequent Ranger spacecraft, as well as on the Surveyor and Lunar Orbiter spacecraft.

Ranger VI again failed to return TV pictures, but the last three Rangers, *VII*, *VIII*, and *IX*, were complete successes, and the live TV pictures returned, up until the vehicles crashed on the Moon's surface, were viewed by millions throughout the world. The despair over the U.S. space program turned overnight into complete pride of accomplishment.

Ranger was followed by the seven Surveyor launches, five of which—including the first—successfully showed closeup details of the lunar surface. Also, the Lunar Orbiter program's five missions effectively mapped the Moon and furnished the basis for choosing landing sites for the Apollo astronauts. The late President Kennedy's goal was accomplished on schedule when *Apollo 11* astronauts Armstrong and Aldrin set foot on the moon on July 20, 1969.

The abandoned lunar sterilization policies were replaced by quarantine policies. On August 24, 1967, NASA entered into an Interagency Agreement, "Protection of the Earth's Biosphere from Lunar Sources of Contamination," with the Departments of Agriculture; Interior; and Health, Education, and Welfare. All of these agencies had regulatory responsibilities concerning prevention of introduction of alien plant, animal, or human parasites or disease into the United States. The National Academy of Sciences was also a party to this interagency agreement. Under this agreement, the Manned Spacecraft Center in Houston issued Management Instruction 8030.1, dated January 9, 1967, and entitled "Assignment of Responsibility for the Prevention of Contamination of the Biosphere by Extraterrestrial Life." This was followed by the implementary "Quarantine Schemes for Manned Lunar Missions," prepared by the Interagency Committee on Back-Contamination which had representatives of all parties to the interagency agreement.

NPD 8020.13, April 4, 1969; NPD 8020.14, July 16, 1969; NMD/A

8020.15, July 16, 1969; and NMD/M 8020.16, July 23, 1969, all implemented the interagency agreement dealing with back-contamination, extraterrestrial exposure, and authority to deal with any cases that might occur. These quarantine provisions were two-fold in purpose. One was the prevention of back-contamination. However unlikely one considered the existence of live microorganisms on the Moon to be, they could not be completely ruled out beforehand, and the covert introduction of alien life forms to the Earth's biosphere could be catastrophic. A second reason was protection of the precious lunar samples from any possible terrestrial contamination until they could be carefully examined for the presence of any trace biological component, viable or nonviable. The Lunar Receiving Laboratory was therefore built at the Manned Spacecraft Center in Houston, and the Mobile Quarantine Facility was constructed to transport both astronauts and samples there from the naval recovery carrier. During the short helicopter trip from the splashdown site to the carrier, the samples were in sealed containers and the astronauts wore a specially designed Biological Isolation Garment. The public, as well as the scientists, detected several possible gaps in the quarantine procedure, and protests, particularly from the medical profession, were numerous, but these were blunted by the fact that all the gaps had been foreseen and were authorized by regulatory authorities outside of NASA.

On September 6, 1967, NASA issued NPD 8020.8, "Outbound Lunar Biological Contamination Control: Policy and Responsibility." It noted that, while the object of the early phases of lunar exploration had been "complete sterility," each probe that impacted the Moon had carried a number of microorganisms. It quoted the recommendations of the SSB to minimize contamination and to develop a sterile drilling system so that subsurface lunar samples could be collected and returned aseptically during the Apollo missions. This directive was updated by NPD 8020.8A on May 2, 1969, just before the *Apollo 11* manned landing.

NASA NMI–4–4–1, which lifted lunar sterilization requirements, kept them for planetary missions, however. It stated, "It is the policy of the NASA to prevent the biological contamination of the planets until sufficient information has been obtained concerning the planets to ensure that biological studies will not be jeopardized and that no hazard to earth exists."

Not listed in Table IV were two planned 1966 Mars flights which were cancelled, primarily for budgetary reasons, and never became attempted launchings. Both, however, were of considerable planetary quarantine interest during the planning stages. A planned Voyager

launch was to land an Automated Biological Laboratory on the surface of Mars. A sterilization plan was written for this launch before the project was cancelled. The second cancelled launch, Mariner-Mars 1966, was to have been a flyby, although at one time in the planning stages a small landing capsule was considered.

NASA NMI–4–4–1 was replaced on September 6, 1967, by NASA Policy Directive 8020.7, "Outbound Spacecraft: Basic Policy Relating to Lunar and Planetary Contamination Control." This document restated that no planetary mission would transport terrestrial life to the planets "within probabilities established by issuances implementing this policy." For the first time, the unworkable absolute ban was dropped. It also specified that "microbial life landed on the Moon . . . shall be identified, quantified and, insofar as possible, located" so that it could be identified as terrestrial if found in returned samples. The implementation of this latter directive appeared in NHB 5340.1A, "NASA Standard Procedures for the Microbiological Examination of Space Hardware," October 1968.

Basic quarantine policy for planetary missions appeared in NPD 8020.10 also dated September 6, 1967, and updated by NPD 8020.10A, "Outbound Planetary Biological and Organic Contamination Control Policy and Responsibility," August 1, 1972. Both documents contained the following provision:

> *Biological Contamination.* The basic probability of one in one thousand (1×10^{-3}) that a planet of biological interest will be contaminated shall be used as the guiding criterion during the period of biological exploration of Mars, Venus, Mercury, Jupiter, other planets and their satellites that are deemed important for the exploration of life, life precursors or remnants thereof.

NASA directive NHB 8020.12, "Planetary Quarantine Provisions for Unmanned Planetary Missions," April 1969, directed that quarantine plans for planetary missions be submitted to the Planetary Quarantine Officer for approval, and again spoke not in absolute terms, but in probabilities of contamination, in line with the international agreements.

Program Accomplishments

AS DISCUSSED IN THE PREVIOUS SECTION, NASA lunar policy was changed from one of sterilization, or attempted sterilization, of the space vehicles involved to one of an attempt to minimize and localize contamination. The policy on planetary missions remained unchanged, save for the fact that it was stated in probability terminology rather than in absolute terms. Sterilization may be an absolute term, but there is always some probability as to whether this absolute condition is achieved in any particular case. Because of this difference in policy the accomplishments of the lunar program and the planetary program will be discussed separately.

LUNAR MISSIONS

The effectiveness of the lunar program can best be summed up in a simple statement. No microorganisms were recovered from the lunar samples returned during the Apollo program. This was true of both *in vitro* and *in vivo* tests (Holland and Simmons, 1973) at the Lunar Receiving Laboratory. This was a result both of the efforts to limit contamination in the earlier unmanned launches and of the effort to take the samples under aseptic conditions in the Apollo manned landings, in spite of the fact that the lunar surface was indeed contaminated. An estimate of the amount of contamination which the Moon received was made (Dillon, *et al.*, 1973), as was required under NASA Policy Directive 8020.7. The Sandia Laboratory investigators who conducted this analysis took into consideration the spacecraft bioburden at launch, the bioburden change in cislunar space, the

distribution of organisms on the lunar surface, and the changes in the terrestrial density on the lunar surface subsequent to its original dispersal. They estimated that the number of viable microorganisms per square meter of lunar surface at the times the Apollo samples were taken was between 1×10^{-4} and 1×10^{-5}.

Another interesting study (Flory and Simoneit, 1972) was concerned with the maximum amount of terrestrial organic chemical contamination which might be expected to be found on the returned Apollo samples. It should be noted that while it was considered unlikely that live microorganisms would be found on the Moon, the organic geochemists expected to find organic chemicals there, as they had found them in meteorite samples which had landed on the Earth. In these latter cases, the question of whether the organic compounds found had come from terrestrial contamination upon impact and retrieval had always been raised. It was hoped that the origin of organic compounds recovered from the lunar samples would be free of such doubt. The study reported only on *Apollo 11* and *Apollo 12* samples, but concluded,

> It can be stated that a contamination control plan was developed and implemented which eventually resulted in providing investigators with lunar samples containing less than 0.1 ppm total terrestrial organic contamination. It should be noted that this is as low or lower than the experimental blanks obtained in organic geochemistry research laboratories.

There was one flurry of excitement on returned lunar samples which should be discussed. *Apollo 12* landed near the site where *Surveyor 3* had achieved a soft landing and had left instruments on the lunar surface. The astronauts brought back several of these instruments for examination of what had happened to them after 31 months of exposure to the lunar environment. One of those returned was a section of the electrical cabling of the Surveyor's TV camera. This cabling was known to have a high level of internal contamination associated with its wiring bundles. Moreover, the surface wrappings of this cable had been deliberately contaminated with several thousand *Bacillus subtilis* spores. No organisms were recovered from the wrapping or the internal section of the cable (Knittel, *et al.*, 1972). However, one of the returned instruments was the camera itself; though not sterile at launch it had not been deliberately contaminated as had the cable wrappings. This too was examined microbiologically, and one microorganism was recovered from a part of the polyurethane foam insulation in the camera interior (Mitchell and Ellis, 1972). After much investigation, in which several microorganisms were recovered from the backup camera

which had remained on Earth, the organism recovered from the camera which had remained on the Moon was identified as alpha hemolytic *Streptococcus mitis*. The investigators concluded that it was of terrestrial origin and had survived the lunar exposure and return trip, but other scientists challenge that conclusion. The question remains unresolved.

Planetary Missions

The NASA planetary quarantine provisions for missions to the planets are much more rigorously controlled than were the lunar missions, which were considerably relaxed after the issuance of NASA Management Manual 4–4–1 in September 1963. They follow the directive of NPD 8020.10, September 1967, that allocated a basic probability of 1×10^{-3} that a planet of biological interest would be contaminated and the requirements of NHB 8020.12 that quarantine plans for unmanned planetary missions be submitted to the Planetary Quarantine Officer for approval. The NASA PQ Officer suballocates the basic probability of 1×10^{-3} to each unmanned planetary mission based upon the type of mission and the total number of flights estimated to be conducted during the period of biological interest.

On the basis of these plans, an initial estimate is made of how much of this suballocated probability is needed by that particular mission. Following the flight, a revised calculation is made and a value given to the probability that the planet was contaminated by that particular mission and, thus, how much of the allocation had been used. The evolvement of the basic formula for these calculations is discussed in Werber's companion volume. The formula currently used is

$$P_c = \sum_i m_i(O) \cdot P(vt) \cdot P(uv) \cdot P(a) \cdot P(sa) \cdot P(r) \cdot P(g).$$

where,

P_c	Probability of contamination
$m_i(O)$	Initial microbial burden (at launch, after decontamination)
$P(vt)$	Probability of surviving space vacuum-temperature
$P(uv)$	Probability of surviving *uv* space radiation
$P(a)$	Probability of arriving at planet
$P(sa)$	Probability of surviving atmospheric entry
$P(r)$	Probability of release
$P(g)$	Probability of growth

A simplified model which combines the survival factors into the probability of the release of an organism in a viable state is

$$P_c = m \cdot P(r) \cdot P(g)$$

It is evident that some of these values such as m and $P(r)$, can be derived from laboratory data. $P(r)$ is the probability of release of microorganisms from the spacecraft hardware and is determined on the basis of experimental data for similar hardware and simulated planetary environmental conditions. The value for the microbial burden, m , is derived by taking into consideration sampling of the assembled spacecraft for viable organisms and determining from laboratory experiments how much this number was reduced by the known effectiveness of the subsequent sterilization or decontamination treatment to which the spacecraft was exposed. The value assigned to the probability of growth after release on a particular planet, $P(g)$, has to be, of necessity, much more of a value judgment. In either case the PQ Officer officially assigns numbers to these values, depending upon recommendations made to him by his various consultants, particularly AIBS. These assigned values, of course, are subject to revision as new information becomes available. The latest compilation of these approved parameters appears in a looseleaf notebook entitled "Planetary Quarantine Parameter Specification Book." It was especially prepared for the information of the international community and was made available at the COSPAR meeting in Constance, West Germany, May 1973. Each volume is serially numbered, issued to a specific individual, and kept up to date by periodic revisions and supplements.

Two of the services performed by Exotech Systems, Inc., for the PQ office are maintaining a data bank for the information acquired by that office and keeping the Planetary Quarantine Status Board up to date by summarizing all the information on the probabilities of contamination by those missions already flown and the projected allocations of P_c to those missions in the planning stages.

This status board is a rather complicated compilation and will be summarized here, rather than reproduced in full. There have been six Mariner Missions to Mars (Table III). For the first two of these, the initial allocations of P_c were 4.5×10^{-5}. The initial allocations for the next two were reduced to 3×10^{-5}. These were all flybys, and the post-flight calculation indicated no probability of contamination. The same was true of *Mariner 8*, a planned orbiter which failed. *Mariner 9*, now in orbit around Mars, was given an initial allocation of 7.1×10^{-5}; the post-launch estimate of P_c was 1.6×10^{-5}, and this value

stands as the probability that Mars has been contaminated to date by U.S. missions (Fox, Hall, and Bacon, 1972). A revised estimate of the allocation for each of the two Viking lander missions planned for 1975 is 1×10^{-4}.

The story is similar for Venus. Three flyby missions were attempted; two were successful. Estimates are that no contamination was made by the U.S. in these missions. A planned Mariner (MVM) flyby later in 1973 has been given an initial allocation of P_c of 7×10^{-5} for both Venus and Mercury.

Two Pioneer spacecraft intended to fly by Jupiter have been launched. Should the first provide acceptable scientific data, the second may be placed on a trajectory to Saturn after swinging by Jupiter. Their initial allocation of a P_c is 6.4×10^{-5}.

The Viking mission to be launched in 1975 and designed to orbit and land on Mars in 1976 has been given an initial allocation of 7.2×10^{-5}, with a supplement of 2.8×10^{-5} recovered from the previous successful missions to Mars. Currently the Viking project has chosen to assign allocations of 3.2×10^{-5} to the orbiter and 2×10^{-5} to the lander, with 2.8×10^{-5} allowed for ejecta, and the 2×10^{-5} held in reserve for assignment in case of unforeseen need.

In summation, the biological aspects of the U.S. space program can, in spite of all its initial difficulties, be considered a success. The space missions have been accomplished without compromise of the planetary quarantine restraints.

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Appendix
Planetary Quarantine Contractual Research

In this Appendix the discussion is limited to the scope of the contracts, the dates that they were in effect, and the principal investigators involved. Individual abstracts of these contracts appear below in chronological order. No effort is made to describe and evaluate the results obtained from these contracts. The George Washington University Biological Sciences Communication Project (BSCP) has recently published a comprehensive *Bibliography of Scientific Publications and Presentations Relating to Planetary Quarantine*, 1966–1971 (GWU–BSCP 73–10P; 1973). This bibliography lists contract reports, as well as publications in the open literature, by both contractors and outside researchers. It includes some 1300 references and is well indexed. Anyone wanting to look further into research accomplishments is referred to this document. Copies of the documentated research reports and published research articles can be obtained from BSCP.

Institution	Starting date
Atomic Energy Commission, Sandia Laboratories	1966
Avco Corporation	1965
Becton, Dickinson & Co., Research Center	1968
Dudley Observatory, New York State Department of Health	1965
Dynamic Science Corporation	1961

Florida State University, Department of Statistics	1966
Grumman Aircraft Engineering Corporation	1961
Hardin-Simmons University	1972
Illinois Institute of Technology Research Institute	1961
Jet Propulsion Laboratory	1959
Massachusetts Institute of Technology	1962
Naval Biomedical Research Laboratory	1972
North Dakota State University, Department of Polymers and Coatings	1968
Northrop Corporation, Northrop Space Laboratories	1965
St. John's University, Department of Biology	1964
Stanford Research Institute	1972
Syracuse University, Biological Research Laboratories	1964
University of Minnesota, Department of Environmental Health	1964
U.S. Army Biological Laboratories	1959
U.S. Public Health Service, Center for Disease Control—Atlanta	1964
U.S. Public Health Service, Center for Disease Control—Phoenix	1964
U.S. Food and Drug Administration, Cincinnati	1965
Wilmot Castle Company	1961

Institution U.S. Army Biological Laboratories, Ft. Detrick, Frederick, Maryland 21701

Principal investigators Charles R. Phillips, Robert K. Hoffman, Herbert M. Decker, Dorothy M. Portner, David R. Spiner

Starting Date: 1959
Termination Date: 1972

Scope: Initially this interagency agreement was to make available to NASA experience with sterilization techniques for various types of laboratory and military hardware, particularly through the use of ethylene oxide. Later studies included the determination of buried contamination in plastics and electronic components used in spacecraft and between mated surfaces; dry heat sterilization for buried contamination; other types of chemical sterilization,

particularly with formaldehyde and peracetic acid; sterilization of fluids, either gaseous or liquid, by filtration; the effect of ultra-high vacuum on microorganisms; the long-time buildup of contamination on surfaces exposed to either laboratory or clean-room atmospheres, with the finding of the so-called plateau phenomenon where contamination leveled off after long exposure; and other short-range experiments.

For the Manned Spacecraft Center at Houston, help was given in planning for the Lunar Receiving Laboratory and in testing the Mobile Quarantine Facility and the astronauts' Biological Isolation Garment.

Under subcontract, the American Sterilization Company developed an ethylene oxide exposure chamber in which the resistance of spacecraft components to this sterilizing technique could be determined.

Institution Illinois Institute of Technology Research Institute, 10 West 35th Street, Chicago, Illinois 60616

Principal investigators Richard Ehrlich, Ervin J. Hawrylewicz, Charles A. Hagen

Starting Date: 1961
Termination Date: 1969

Scope: The research program involved studies of the survival of terrestrial aerobic and anerobic microorganisms in simulated extraterrestrial environments. Of prime importance was the viability of vegetative microorganisms and the rate of germination of bacterial spores after various lengths of exposure to simulated Martian environment. The environmental parameters of interest were the composition of gaseous atmosphere, pressure, composition of soil, presence of available water, and diurnal temperature fluctuations. The experimental program was designed to provide information required to estimate the probability of contamination of Mars and other planets.

Institution Wilmot Castle Company, Rochester, New York 14602
Principal investigators Carl W. Bruch, Martin G. Koesterer, Mary K. Bruch, Norman Davis, Robert R. Ernst

Starting Date: 1961
Termination Date: 1964

Scope: This work consisted of a survey of dry heat resistance of various spore-forming microorganisms, including a laboratory study of

reaction rates at various temperatures and how this was affected by various protective agents such as dirt or soil.

Institution Grumman Aircraft Engineering Corporation, Bethpage, L.I., New York

Principal investigators Robert J. Del Vecchio, Raymond Davis, K.M. Forman

Starting Date: 1961
Termination Date: 1968

Scope: The program involved a study of the influence of a closed, artificial environment on the growth and viability of certain terrestrial bacteria, including the development of sampling devices and techniques to determine the microbial contamination of aerospace-controlled environments and a review of information on the environments of Mercury, Venus, and Mars.

Institution Dynamic Science Corporation, 1445 Huntington Drive, South Pasadena, California 91030

Principal investigators John B. Opfell, Curtis E. Miller, Allan L. Louderback, Earl G. McNall, William T. Duffy

Starting Date: 1961
Termination Date: 1965

Scope: The work incorporated evaluation of various liquid sterilants used in spacecraft sterilization, preparation of a sterilization handbook, and study of the recovery of microorganisms inoculated into solid propellants.

Institution Massachusetts Institute of Technology, Department of Nutrition and Food Science, Cambridge, Mass. 02319

Principal investigators Gerald J. Silverman, Norman S. Davies, Cecil G. Dunn

Starting Date: 1962
Termination Date: 1968

Scope: Two main investigations were undertaken. The first was in collaboration with National Research Corporation (as a subcontractor) and measured the effect of simulated extraterrestrial environments (mainly the effects of ultra-high vacuum, temperature, ultraviolet

light, gamma radiation, and similar features) on microbial survival.

The second program concerned dry heat resistance of microbial spores as influenced by internal and external moisture. The effects of either were dramatic; water, even at temperatures over 100°C, could be highly protective or, if present at too great a level, destructive.

Institution Syracuse University, Biological Research Laboratories, Syracuse, N.Y. 13210

Principal investigators Ralph A. Slepecky, Jere Northrop, John Gillis

Starting Date: 1964
Termination Date: 1967

Scope: This was primarily a theoretical study of the greatly enhanced resistance of bacterial spores over that of vegetative cells.

The research program was concerned with the relationship of metal content to resistance, dormancy, and germination of bacterial spores and sporulation of bacterial spore formers: the metal composition of intact spores; the relative binding of metals to the spore; the kinetics of metal release on germination; the kinetics of metal incorporation as correlated with sporulation stages; and various relationships between metals and resistance of spores.

Institution St. John's University, Department of Biology, Jamaica, N.Y. 11432

Principal investigators Michael A. Pisano, Raymond M.G. Boucher, George T. Tortora, I. Edward Alcamo

Starting Date: 1964
Termination Date: 1967

Scope: Studies were conducted on the effect of acoustic vibrations in connection with gaseous sterilizing agents to see if the rate of sterilization could be increased. Preliminary studies were done with ethylene oxide, and the synergistic effect of high-intensity airborne sound waves with propylene oxide were studied more intensively.

Institution University of Minnesota, Division of Environmental Health, Minneapolis, Minn. 55455

Principal investigators Richard G. Bond, George S. Michaelsen, Irving J. Pflug, V.W. Greene, Donald Vesley, Jacob E. Bearman

Starting Date: 1964
Termination Date: Continuing

Scope: Under a series of grants and contracts, the University of Minnesota has undertaken a training research program for the NASA Planetary Quarantine Office and has established a Space Science Center on their Minneapolis campus. Not only has training taken place at the Center, but a teaching group has given short courses at various locations across the U.S.

The research program at the Space Science Center has been on environmental sterilization. Particular attention has been given to dry heat sterilization, and to developing destruction rate data on mated surfaces and with encapsulated microorganisms as well as those on open surfaces. The role of moisture in dry heat sterilization has been studied and theories developed on the mechanisms involved.

Institution U.S. Public Health Service, Center for Disease Control, Phoenix Laboratories, Phoenix, Arizona 85014

Principal investigators Martin S. Favero, John R. Puleo, Norman J. Petersen, Walter W. Bond, Gerald J. Tritz, Gordon S. Oxborrow, Norman D. Fields, James H. Marshall

Starting Date: 1964
Termination Date: Continuing

Scope: Under an interagency agreement, work was undertaken on methods for quantitatively recovering microorganisms and bacterial spores from surfaces and solids; establishing microbiological profiles of a variety of environmentally controlled areas ranging from conventional industrial clean rooms to laminar-flow clean rooms; and developing the technology of air sampling and surface sampling in these environments. This element of work culminated in the establishment of a field laboratory at the Kennedy Space Center in Florida where 25 to 30 (to date) automated and manned spacecraft were sampled in an attempt to establish microbiological profiles. Sampling or culturing procedures that were developed at the Phoenix Laboratories were refined and field-evaluated at the Cape Kennedy Laboratory.

Other main research interests concerned recovery of heat- and ethylene-oxide-injured bacterial spores; recovery techniques for anaerobic spores; use of ultrasonic energy as an adjuvant for surface recovery techniques; and development and evaluation of the vacuum probe for surface sampling. Another main line of research concerned the dry heat inactivation of bacterial spores.

This group introduced the concept of utilizing naturally occurring spores associated with spacecraft as the major indices of heat resistance rather than subcultured spores of *Bacillus subtilis* var. *niger*. Laboratory evaluations and onsite inspections were conducted throughout the course of the agreement.

Institution Food and Drug Administration, Cincinnati Research Laboratories, Cincinnati, Ohio 45226

Principal investigators Jeptha E. Campbell, Ralston B. Read, Jr., Robert Angelotti, James T. Peeler

Starting Date: 1965
Termination Date: Continuing

Scope: Through a series of interagency agreements, the principal investigators, under the auspices of the Robert A. Taft Sanitary Engineering Center, the National Center for Urban and Industrial Health, the Environmental Protection Agency, and, currently, the Food and Drug Administration, have conducted research and specifically assigned investigations on problems of dry heat sterilization. The major topics addressed by this group included establishing D and z values for the selected test organisms *Bacillus subtilis* var. *niger*, demonstrating the effect of the immediate environment on the thermal stability of spores, and establishing D and z values for the organisms residing within components (buried contamination) and within mated surfaces.

More recently, special attention has been given to the relationships between time, temperature, and humidity on the thermal inactivation of spores and to the development of experimental systems for testing and evaluating thermal sterilization cycles under a variety of humidity and temperature conditions. This system is suitable for measuring survival in the probability ranges of 10^{-2} organisms per test unit.

Institution AVCO Corporation, Lowell, Massachusetts 01815

Principal investigators D.H. Trussel, Edward A. Botan

Starting Date: 1965
Termination Date: 1969

Scope: Under a series of contracts with different NASA research centers, calculations were made of total microbial burden on spacecraft, and a Terminal Sterilization Chamber (TSC) and a Model Assembly Sterilizer for Testing (MAST) were designed and constructed.

Institution Dudley Observatory Division of Laboratories & Research, New York, State Department of Health, Albany, N.Y. 12200

Principal investigators John Hotchin, Peter Lorenz, Curtis Hemenway

Starting Date: 1965
Termination Date: 1969

Scope: Studies on the survival of microorganisms in space were carried out in rocket, balloon-borne, and satellite exposure experiments.

Institution Northrop Corporation, Northrop Space Laboratories, 3901 West Broadway, Hawthorne, California 90250

Principal investigators W.H. Cooper, R.J. Calof, A.L. Debolt, J.R. Hamer

Starting Date: 1965
Termination Date: 1966

Scope: A study was made of critical sterilization problems on a Mars entry probe. In particular, the ability of various spacecraft components or parts to withstand dry heat treatments and ethylene oxide exposure were investigated.

Institution Florida State University, Department of Statistics, Tallahassee, Florida 32306

Principal investigators Richard G. Cornell, Myles Hollander, John J. Beauchamp, S. Eric Steg

Starting Date: 1966
Termination Date: 1970

Scope: Probability models were developed for the description of decontamination strategies for the exploration of Mars and for the decontamination of individual spacecraft. Statistical consultation was provided on a number of problems encountered by other investigators involved in the Planetary Quarantine Program.

Institution Atomic Energy Commission, Sandia Laboratories, Albuquerque, New Mexico 87115

Principal investigators H.D. Sivinski, Charles A. Trauth, Jr., Willis J. Whitfield

Starting Date: 1966
Termination Date: 1973

Scope: For lunar programs, Sandia Laboratories has developed the computerized information system used for estimating the terrestrial bioburden of the Moon as a function of lunar coordinates and time. From this, scientists are able to provide estimates of the likelihood that returned lunar samples are contaminated with terrestrial organisms.

For planetary programs, research activities were concentrated in approximately eight areas: (1) assessment of the importance of laminar-flow clean-room technology on planetary quarantine success; (2) development of better understanding of the dry heat sterilization of homogenous and heterogeneous microbial populations; (3) development of better understanding of the sterilizing effects of radiation in space; (4) development of better sterilants (notably, thermoradiation and odorless formaldehyde solutions and gels); (5) development of models for bioburden estimation and prediction and statistical standards for spacecraft sampling; (6) development of highly accurate bioburden sampling devices; (7) study of means of translating program objectives into realizable spacecraft requirements in the presence of much uncertainty about the specific long term nature of the program; and (8) general scientific consulting.

Institution North Dakota State University, Department of Polymers and Coatings, Fargo, North Dakota 58102

Principal investigators A.E. Rheineck, Loren W. Hill, S. Peter Pappas

Starting Date: 1967
Termination Date: Continuing

Scope: Studies have been done on whether spores remain viable in polymeric resins that are crosslinked by chemical curing agents. Inherent toxicity of resins and curing agents is determined, and the toxic effects resulting from high temperatures produced by exothermic curing reactions are investigated.

Solvents are used to assist in the degradation of crosslinked polymers so as to obtain higher recoveries than are possible through the mechanical degradation of dry polymers. Solvent selection is made using the solubility parameter approach. Systems studies include such things as cured epoxy resins and silicone potting compounds. Other polymeric materials used in spacecraft components will also be investigated.

Institution Becton, Dickinson and Company, Becton, Dickinson Research Center, Research Triangle Park, North Carolina 27709

Principal investigators G. Briggs Phillips, William S. Miller, J.J. Tulis, V.A. Pace, Jr.

Starting Date: 1968
Termination Date: 1972

Scope: Methods for the sterilization of potting compounds and mated surfaces were investigated. The mixture of formaldehyde or formaldehyde complexes was studied in particular.

For the Langley Research Center, a magnetically connected plastic vacuum probe surface sampler was developed, fabricated, and tested.

Institution U.S. Public Health Service, Center for Disease Control, 1600 Clifton Road, N.E., Atlanta, Georgia 30333

Principal investigators Peter Skaily, George W. Gorman, Donald C. Mackel, D.K. Riemensnider, H.V. McEachern, Anita Highsmith, Nancy L. Shearin

Starting Date: 1964
Termination Date: 1972

Scope: Investigations conducted at the Center for Disease Control addressed three areas: (1) dissemination of microorganisms from humans, (2) germicidal activity of ethylene oxide gas, and (3) destruction of bacterial contamination on surfaces exposed to low-level heat.

In the dissemination studies, the quantitative and qualitative characteristics of microorganisms shed by different individuals were determined. Various skin treatments and clothing barriers were investigated to determine whether shedding rates could be reduced.

Studies were conducted to determine the destruction rate of bacterial spores and naturally occurring extramural microorganisms exposed to ethylene oxide gas. The rate of die-away was determined for microorganisms in various chemical and physical states, as was the survival rate following exposure to different concentrations of ethylene oxide gas.

Bacterial survival on intramural surfaces under conditions of controlled heating and relative humidity was studied, and the die-away rate of bacterial spores to low-level heating was determined.

Institution Office of Naval Research, Naval Biomedical Research Laboratory, Oakland, California 94625

Principal investigators Robert L. Dimmick, Mark A. Chatigny, N.A. Vedros

Starting Date: 1972
Termination Date: Continuing

Scope: The laboratory is conducting studies on the possibility of microbial metabolism, growth, and propagation while in aerosols. The work is directed toward evaluation of $P(g)$ for microorganisms entering the atmosphere of Jupiter where there are predicted zones with environments suitable for growth of terrestrial microorganisms. The work is being done in collaboration with Biospherics, Inc., of Rockville, Maryland, utilizing Biospherics' technology for ultrasensitive detection for microbial metabolism by evaluation of radio-labelled CO_2 provided in the growth substrate. Other test systems use special microbial mutants to demonstrate the presence of products of cell division even though actual physical division may not have occurred.

Institution Stanford Research Institute, Menlo Park, California 94025

Principal investigators D. Warner North, J. Michael Harrison, Consultant: Joshua Lederberg

Starting Date: 1972
Termination Date: Continuing

Scope: Stanford Research Institute has undertaken a review of the basic probabilistic models of contamination currently being used in the PQ Program. A primary question is whether models now in use account adequately for the informational dependencies that exist among events important to the contamination process. Effort is also being devoted to the construction of a more detailed model of microbial proliferation on the planet Mars.

Institution Hardin-Simmons University, Department of Biology, Abilene, Texas 79601

Principal investigators Terry L. Foster, Luther Winans, Jr.

Starting Date: 1972
Termination Date: Continuing

Scope: This investigation consists of a comprehensive population study of psychrophilic microorganisms isolated from the soils near the

manufacture and assembly areas of the Viking spacecraft. It includes enumeration, isolation, characterization, and temperature studies on microorganisms capable of growth at low temperatures. Selected isolates are then subjected to some of the environmental conditions suggested for Mars to determine if they are capable of growing under these conditions.

* U.S. GOVERNMENT PRINTING OFFICE: 1974 O—556-543

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