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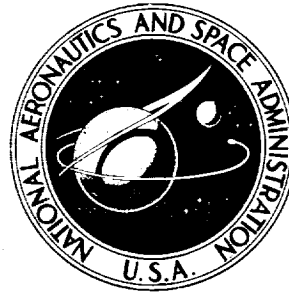
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APOLLO EXPERIENCE REPORT -
PROTECTION OF LIFE AND HEALTH

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16. Abstract

The development, implementation, and effectiveness of the Apollo Lunar Quarantine Program and the Flight Crew Health Stabilization Program are discussed as part of the broad program required for the protection of the life and health of U.S. astronauts. Because the goal of the Apollo Program has been the safe transport of men to the Moon and back to Earth, protection of the astronauts and of the biosphere from potentially harmful lunar contaminants has been required. Also, to ensure mission success, the continuing good health of the astronauts before and during a mission has been necessary. Potential applications of specific aspects of the health and quarantine programs to possible manned missions to other planets are discussed.

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SUMMARY

The subject of life and health protection is generically broad with respect to manned space flight. Indeed, the prime design criterion in all aspects of manned space flight is to ensure the health and safety of the flight crewmembers involved. For this document, the scope is limited to two specific programs: the Apollo Lunar Quarantine Program and the Flight Crew Health Stabilization Program.

The development of the requirements, philosophy, and guidelines that resulted in the quarantine program for the support of the Apollo lunar missions is discussed. Although the possibility of discovering an existing life system on the Moon was believed to be remote, it could not be ignored. Consequently, appropriate precautions were required for the quarantine program. Analyses of lunar material obtained during the Apollo 11, 12, and 14 missions and postflight examinations of the astronauts have verified that a life system is nonexistent on the Moon. However, the experience gained in establishing the quarantine program will be adaptable to possible manned missions to other planets for which the probability of existing life forms is higher.

The Flight Crew Health Stabilization Program was developed to minimize exposure of flight crewmembers to infectious micro-organisms during the prelaunch period. The program has three aspects.

1. Areas to which flight crewmembers have access during the 3 weeks before launch are strictly limited.

2. The number of personal contacts of the astronauts is limited during the 21-day prelaunch period.

3. The health of persons required to be in contact with flight crewmembers is strictly monitored.

The success of the program, implemented for the first time in support of the Apollo 14 mission, was evidenced by the absence of preflight, inflight, or postflight illnesses recorded for the crewmembers. The importance of such a program will be more critical for manned missions of longer duration.

INTRODUCTION

The subject of life and health protection is generically broad with respect to manned space flight. Indeed, the prime design criterion for all aspects of manned space flight is to ensure the health and safety of the crewmembers. However, the scope of this report is limited to the Apollo Lunar Quarantine Program and the Flight Crew Health Stabilization Program.

APOLLO LUNAR QUARANTINE PROGRAM

The Apollo Program has resulted in the first successful transport of men to the Moon and safely back to Earth. When the goal of sending men to the Moon was announced, it became apparent that considerations other than science and engineering would be required for an associated biomedical program sufficient to deal with the possibility of danger to the biosphere and to life on the Earth. These considerations ranged from local, State, Federal, and international regulations to a moral concern about the possible effect of returning an alien hazard to the environment of the Earth.

In the future, detailed planning will be initiated for manned space flights to other planets. Because of the relatively high probability of finding life on some planets, establishing criteria for the quarantine and biomedical evaluation of returned planetary material will be a prime factor in the detailed planning and implementation of such a mission. The precedent that future program planners will have to follow is the Apollo Lunar Quarantine Program. Therefore, the development of the requirements, philosophy, and guidelines that resulted in the Apollo Lunar Quarantine Program are presented to document the first procedure established to deal with the problems of extraterrestrial material. The factors that are basic to the development of a quarantine program of this type are (1) assumptions are made and (2) scientific guidelines are developed from these assumptions.

Requirements Definition

The Apollo Lunar Quarantine Program was initiated in the mid-1960's after President Kennedy established the transport of men to the Moon and their safe return before the end of the decade as a national goal. The July 1964 Back Contamination Conference of the National Academy of Sciences (NAS) was the first event specifically concerned with a lunar quarantine program. This conference was called by the NAS to consider the potential ramifications of a manned mission to an extraterrestrial body and the subsequent return of the men and spacecraft to Earth. Results of the conference were published in a report in which the NAS opinion was expressed that, although the probability that a life form existed on the Moon was extremely low, the results of introducing an alien life form into the biosphere could be catastrophic. The NAS then recommended that NASA personnel take all technically feasible steps to prevent the introduction of any alien organisms into the biosphere during the Apollo Program.

When the NAS statement was released, NASA administrators began to investigate the ramifications of the NAS recommendations. At that time, Federal regulations enforced by the U.S. Public Health Service (USPHS) and the U.S. Department of Agriculture (USDA) governed the entrance and transport of materials within the United States. In 1965, NASA personnel invited officials of these agencies to the Manned Spacecraft Center (MSC) to discuss the regulatory responsibilities for materials originating from extraterrestrial bodies. The USPHS and USDA representatives stated that it was the responsibility of these agencies to protect public health, agriculture, and other living resources and that the regulations applied to potentially hazardous materials originating from extraterrestrial bodies. It was also determined that, because the U.S. Department of Interior has the responsibility for the protection of national resources, representatives from that agency should be invited to participate in quarantine-program planning.

The establishment of an advisory body representing these Federal agencies was determined to be the most satisfactory method for implementing and enforcing a program of this type. Consequently, the Interagency Committee on Back Contamination (ICBC) was established in April 1966. The committee membership included the official representatives of the Secretary of Agriculture; the Secretary of Interior; the Secretary of Health, Education, and Welfare; the Administrator of NASA; and the President of the NAS. These representatives were given authority to act for the administrator of each agency. An interagency agreement, which served as a basis for the development of the quarantine program, was developed and approved. The development of program-implementation details was determined to be the responsibility of NASA; the committee would serve only as an advisory body to review and approve the plans proposed by NASA. The chronological milestones of the Apollo Lunar Quarantine Program development are presented in table I. Certain milestones are noteworthy because of potential applications for future long-duration interplanetary missions.

Because one of the goals of the Apollo Program was the return of lunar material, the physical-science requirements for the collection, return, and examination of these samples were being developed at the same time as the quarantine requirements. Although this document deals specifically with the quarantine program, it is noteworthy that, throughout the quarantine-program development, specific requirements were being transmitted to NASA by scientific advisory committees that had been formed to provide guidance for the quarantine program and for the physical-science examination of the lunar material. Often, the requirements of the advisory groups were contradictory. Whereas the primary concern of the physical-science advisory groups was to ensure that procedures and equipment were developed that would minimize the possibility of the contamination of the lunar samples by terrestrial organic and inorganic material, the primary concern of the biomedical advisory groups was to ensure that equipment and procedures were developed that would minimize the possibility of introducing the lunar material into the biosphere. Because of these differences, technical and managerial difficulties in program implementation occurred. These problems are discussed, as applicable, in this document.

TABLE I.- HISTORY OF THE ESTABLISHMENT OF QUARANTINE REQUIREMENTS

Date	Developmental milestone
July 1964	NAS Back Contamination Conference
Oct. 1964	Office of Space Science and Applications ad hoc committee
Feb. 1965	NAS Facility Requirements Review
July 1965	NASA Summer Conference on Lunar Exploration and Science
	Discussions between NASA Headquarters and USPHS personnel
Sept. 1965	MSC Back Contamination Conference with representatives from the NASA, the USPHS, and the USDA
Jan. 1966	Lunar Receiving Laboratory (LRL) final Design Criteria Report initiated
Apr. 1966	ICBC established
May 1966	LRL Program Office established
June 1966	Biological Protocol Contract initiated
June 1967	Biological Protocol Contract Report submitted
	LRL occupancy initiated
	Facility Certification Plan approved
Mar. 1969	Final simulation completed
June 1969	LRL certified to support quarantine
July 1969	Apollo 11 mission
Nov. 1969	Apollo 12 mission
Jan. 1970	Termination of quarantine recommended by ICBC
Feb. 1970	Planetary Biology Subcommittee meeting
Feb. 1970	NASA ad hoc committee on lunar quarantine
Mar. 1970	NASA decision to continue quarantine

After the advisory group concluded that lunar samples and all items exposed to lunar material should be quarantined as soon as possible after the spacecraft returned to Earth, the length of the quarantine period and the basis for the release of the equipment, crewmembers, and lunar materials had to be determined. Should a lunar organism or any other extraterrestrial organism exist, technical management decisions would have to be made even though specific knowledge of the potential disease agent was not available. After exposure to some terrestrial disease agents, the host may manifest disease symptoms within 24 hours. Other disease agents may lie dormant within a susceptible host for many years before the disease symptoms become evident.

Therefore, by using terrestrial analogs (because no other guides were available), it was possible to justify quarantine periods ranging from less than 24 hours to the entire lifetime of an exposed host. However, by observation of plant and animal diseases, it has been determined that most terrestrial disease agents are capable of invading a host and causing evident disease symptoms within 21 days after exposure of the host. Most disease agents that are capable of causing epidemic or rapidly spreading diseases are sufficiently virulent to be transmitted in less than 21 days. Therefore, it was decided that a quarantine period of at least 21 days would be required after each Apollo mission.

Quarantine and intensive medical examinations of the flight crewmembers would determine if the crewmembers represented a hazard to the biosphere. The returned lunar samples and equipment also had to be quarantined and evaluated to ensure that release of these items into the biosphere did not represent a hazard to public health, agriculture, or other living resources. To accomplish this and other functions, the LRL, which was to be constructed at the MSC, would serve the following functions.

1. As a quarantine facility for returning Apollo flight crewmembers, equipment, and lunar samples

2. As an isolation facility where specific biomedical evaluations of the lunar samples could be conducted to determine if the samples contained any hazardous replicating micro-organisms

3. As an isolation facility where time-critical physical-science investigations could be conducted during the quarantine period. (Time-critical investigations are those for which data would be lost or seriously degraded if the experiments were not initiated during the quarantine period.)

4. As a facility for lunar-sample preparation and distribution to outside principal investigators for detailed scientific analyses

5. As a permanent repository and curatorial facility for all lunar samples

To coordinate and implement these requirements, the LRL Program Office was established in May 1966. The LRL Program Office was subdivided into the Requirements Office, the Engineering Office, and the Construction Office. The Requirements Office was composed of scientists specializing in geology, geochemistry, microbiology, human medicine, veterinary medicine, epidemiology, contamination control, and chemistry. These scientists served as liaison among NASA, the scientific community, and the other Federal agencies; coordinated the requirements submitted by each scientific discipline; and transmitted these requirements to the LRL Engineering Office. Engineering Office personnel then performed the design and engineering required to meet the Requirements Office specifications. After the design and engineering were completed, the Requirements Office and Construction Office cooperated in the conversion of the requirements into the actual construction of the LRL.

The coordination of the multidisciplinary, and often contradictory, requirements presented a unique series of problems. Many of these problems were associated with the hypothetical nature of an unknown lunar hazard. Therefore, if precise scientific and technical decisions were to be made, basic assumptions and guidelines had to be

followed. The following are the basic guidelines established for development of the Apollo Lunar Quarantine Program.

1. Hazardous, replicating micro-organisms exist on the Moon.

2. The preservation of human life should take precedence over the maintenance of quarantine.

3. Biological-containment requirements should be based on the most stringent means used for containment of infectious terrestrial agents.

4. The sterilization requirement should be based on the methods required for the destruction of the most resistant terrestrial forms.

5. Hazard-detection procedures should be based on an alteration of the ecology and classical pathogenicity.

6. The extent of the biological test protocol will be limited to facilities approved by the Congress, to well-defined systems, and to biological systems of known ecological importance.

Because a similar decisionmaking process must occur before future flights to other planets are made, each guideline warrants discussion.

First, the assumption was made that the Moon does harbor hazardous replicating micro-organisms. The nature of the risk involved or, more specifically, the level of risk involved had to be considered. The fact could not be ignored that, even though the possibility was extremely low that life of any kind could exist in the lunar environment, all terrestrial life could be destroyed if a hazardous agent did exist and was returned to the biosphere. Thus, the assumption had to be made that hazardous replicating micro-organisms exist on the Moon. From this point, scientific and technical decisions theoretically could be made without bias. Because of the lack of specific information concerning other planets, similar assumptions will have to be made before future interplanetary flight programs can be developed. Once made, the assumption must be followed by all levels of technical and managerial personnel to achieve a united effort for reaching the desired goals.

The second guideline, that the preservation of human life should take precedence over the maintenance of quarantine, may appear to be contradictory to the first guideline. However, this was a critical guideline upon which many decisions were made. (This guideline also will need to be made an integral part of the development of future interplanetary flight programs.) Together, guidelines 1 and 2 provided the basis for the Apollo Lunar Quarantine Program; that is, although the probability that life existed on the Moon was extremely low, the risk was sufficiently high that a quarantine program was justified. However, this risk was not considered great enough to permit an otherwise-avoidable loss of human life just to maintain the integrity of the program.

Many critical decisions, especially those involving emergency procedures, could not have been made without the establishment of the second guideline. Typical examples are emergency procedures for the escape of crewmembers if the command module (CM) began to sink after splashdown and emergency exit procedures if a major fire occurred

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in the LRL living quarters for quarantined personnel. Current proponents of the quarantine program for interplanetary missions have stated publicly that the risk of detecting a hazardous life form on Mars, for example, is sufficiently high that no justification exists for a break in the quarantine program. Opponents of the quarantine program for interplanetary missions believe that consideration of a quarantine program following an interplanetary mission is unnecessary. Therefore, this critical decision definitely will have to be resolved before beginning the development of a program for manned missions to other planets.

The third guideline became the basic criterion for the design and operation of the required containment systems. Again, the dilemma was that procedures and equipment had to be designed, fabricated, and operated to contain microbial agents that were assumed to exist on the Moon and about which no characteristics were known. It was decided that the biological-containment requirements should be based on the most stringent means currently used to contain infectious terrestrial agents.

The fourth guideline established that the sterilization requirements should be based on the method required for the destruction of the most resistant terrestrial life forms. In the operation of any laboratory facility dealing with hazardous agents, a prime area of concern is the method of sterilizing items that have been contaminated with hazardous organisms. Whereas the resistance characteristics of hazardous terrestrial micro-organisms are known, it is impossible, on a scientific basis alone, to define the times, temperatures, and environmental conditions required to sterilize unknown organisms. Therefore, to provide the design criteria for equipment and the guidelines for sterilization procedures, terrestrial spore-forming micro-organisms were used as models. Each sterilization procedure was developed by this method.

The fifth guideline concerns the detection of the assumed hazards. If a hazard is assumed to be present, the term hazard must be defined before a method of detection can be developed. It was decided to limit detection procedures to those that could detect an agent that would exhibit classical pathogenicity to some terrestrial life form or that could establish itself in a terrestrial environment and thereby alter the terrestrial ecology. This guideline limited the search to the detection of replicating micro-organisms. Parameters such as toxicity were eliminated because it was believed that, even if the lunar samples were highly toxic, the toxicity characteristics would be self-limiting and nonpropagating. It was believed that concentrations of toxic material in the limited amount of lunar matter obtained would be insufficient to cause any harmful effects, whereas a hazardous micro-organism possibly could establish itself in a terrestrial environment or host, replicate itself, and cause widespread harm.

The sixth guideline dealt with the methods to be used for the detection of replicating micro-organisms that could cause disease or could establish and replicate themselves in some terrestrial environment. The capability for the first level of decisionmaking was provided by these guidelines in that the efforts of the biological test program would be directed toward the specific detection of hazards to the biosphere. The program would not pertain to life detection per se. Because the program would be designed to detect a hazard to the terrestrial environment, only terrestrial environmental conditions were acceptable as test systems. Simulated lunar environments or simulated Martian environments were eliminated as test systems. However, even with this limitation, the scope of test alternatives was almost infinite.

Hazardous terrestrial micro-organisms characteristically exhibit a biological phenomenon known as species specificity, or ecological niche specificity; that is, most hazardous terrestrial micro-organisms have the capability to invade and cause disease only in specific species of animals or plants. In addition, terrestrial micro-organisms can become established only in limited ranges of environmental conditions. Philosophical evolutionists believe that the reason for this species or environmental specificity is that terrestrial micro-organisms have evolved in association with a specific environment and with the plant or animal system that they invade. Because of evolutionary changes in the host and in the environment and accompanying changes in the micro-organism, the capability of the microbial agent to invade certain species or certain environments has been limited. On the other hand, these evolutionists believe that, if a microbial agent has not evolved along with the host or environment, it will not exhibit this species specificity; that is, the host plant or animal systems will not have developed specific immunities or other forms of resistance to the micro-organism, and an agent will be able to invade any host. If the assumption is made that any unknown hazardous agent will not exhibit species specificity, then only one test system will need to be included in a biomedical evaluation program. However, an equally credible theory is that the capability of a disease agent to invade a host and cause disease is a dynamic process that continually changes throughout evolutionary periods; that is, during evolution, the host gains or loses certain resistance capabilities, and the pathogenicity or capability of the microbial agent to cause disease also changes. In this manner, invasion and disease production are dynamic processes. If this assumption of dynamic evolution is made, then evaluation of a large number of living systems is necessary to preclude a failure to detect the hazard because of species specificity. Ideally, a group of every living species currently existing in the biosphere should be challenged, and the ability of every terrestrial environment to support the growth of an assumed alien organism should be tested. In addition, within each species, a number of other test criteria could be devised, such as a male and a female of each species, pregnant females of each species, all age groups within a species, or stressed individuals compared with normal individuals within the same species. Because an almost infinite list of challenge procedures could be devised, some mechanism had to be developed to limit the test protocol to a rational, yet scientifically sound, biological test protocol program.

Three limitations were set for the biological test protocols in support of the Apollo Lunar Quarantine Program. One protocol limitation was that only well-defined test systems should be used. Test systems for which little or no baseline or background information was available would not be considered. If a hazard is to be detected, the capability to determine that a deleterious effect is occurring in the test system is required. Without baseline or background information on a particular test system, a deleterious effect may not be recognizable.

Another limitation on the biological test protocol was that systems of known ecological importance should be stressed. Determination of the most important life species on the Earth is difficult and often controversial. Each individual, depending on his background and interests, has a personal opinion of the relative importance of life forms. For instance, many ecologists believe that the so-called producers are the most important species and that the so-called consumers are of less importance because, if the producers are not available, the consumers will die out. Members of agriculturally related groups vigorously support the premise that the plant systems of economic importance (crop plants) are the most important species of the plant kingdom.

Public-health-oriented individuals believe that the prime goal should be the protection of human life. The justification for different test systems could be almost infinite.

The third limitation involved the size and activities of the facility, the scope of which was determined for planning purposes. Because of the program schedule, the Congress was approached early for the appropriation of funds for the LRL construction, and the request was made before the specific biological test protocol had been formulated. Ideally, the specific test program and the precise requirements for implementing the program should be defined before funds are requested. For this reason, it is not too early to develop the requirements for the implementation of a manned planetary mission.

The initial effort to provide the details of the biological test protocol began in 1966, when a contract was awarded to a medical school to provide maximum participation of the scientific community in the protocol development. In June 1967, NASA received a document containing a detailed compendium of tests that could be used for the detection of possible hazards from the lunar samples. From this compendium, the final selection of biological test systems was to be made by NASA officials and approved by the ICBC.

Specific Program Elements

Lunar-surface contamination. - It has been agreed by international treaty that all nations involved in the exploration of extraterrestrial bodies will take all steps that are technically feasible to minimize or eliminate the contamination of these bodies during exploration. Several problems complicate the implementation of this agreement. First, if automated, unmanned landers are used, the problems associated with minimizing or eliminating contamination sources are principally those technological problems involved with the design and fabrication of hardware that will withstand decontamination or sterilization or both. The problems associated with this technology development should not be minimized, as evidenced by the amount of engineering and design effort already expended in planning for unmanned vehicle exploration of other planets. However, these decontamination problems are simple when compared to those associated with manned exploration of other planets, because man is a virtual factory for the production and dissemination of viable microbial contaminants. The other main problem associated with preventing contamination of extraterrestrial bodies is the probability that a terrestrial life form can establish itself and survive in the alien environment.

The primary reasons for preventing contamination of extraterrestrial bodies are (1) to ensure that scientific analyses for the detection of viable life originating from an extraterrestrial body can be conducted without the complications associated with terrestrial contamination of such a body and (2) to ensure that, if life does exist on an extraterrestrial body, the ecological balance existing on that body is not disturbed by the introduction of terrestrial microbial life forms. The physical evidence concerning the environment of the Moon indicated that the probability was extremely small that a terrestrial life form could establish itself. This, in addition to the low probability that a viable ecological system could exist on the Moon, resulted in the relaxation (but not elimination) of the requirements for the prevention of lunar-surface contamination.

For example, it was specified in the Apollo Program engineering requirements that, in terms of hardware reliability, the lunar module (LM) should be assembled under clean-room conditions; however, no attempt was made to eliminate viable microbial particles. The elimination of the viable microbial organisms from LM hardware is unnecessary, because all functioning components are contaminated by terrestrial micro-organisms as soon as a crewmember enters the LM. However, extensive microbial monitoring was conducted in all assembly areas and on surfaces of the completed vehicles in an attempt to isolate and identify the viable micro-organisms that would be carried to the lunar surface. In addition, microbiological sampling has been performed on all Apollo flight crewmembers, and all micro-organisms isolated from individual crewmen during the sampling have been identified. The objectives for the conduct of this microbiological program were as follows.

1. To study the changes in the normal microflora of man in response to exposure to the spacecraft environment and to determine the extent of microbial transfer from one crewmember to another during confinement in the closed ecological system of the Apollo spacecraft

2. To obtain as complete a catalog as possible of all terrestrial micro-organisms that would be carried to the Moon

In the event that viable micro-organisms were detected in the lunar material, the characteristics of the isolated micro-organisms could be compared to those micro-organisms isolated from the spacecraft and crewmen.

It was recognized that the Apollo crewmembers represented the prime source of contamination to the lunar surface. Three other sources of contamination were determined to be (1) waste products such as feces, urine, and residual food; (2) viable terrestrial micro-organisms released during LM depressurization; and (3) micro-organisms present in the LM waste-water system. Procedures were defined to eliminate massive contamination of the lunar surface from these three sources. Of the three, waste products are the chief source of potential contamination. To minimize the thrust required for lift-off from the lunar surface, waste products had to be removed from the ascent stage of the LM. The initial plan was to throw the bagged waste products onto the lunar surface. Plastic containers were to be used for storing waste products, and it was evident that the integrity of the containers would be maintained only for a short time in the lunar environment. Therefore, the plan to discard the bags on the lunar surface was changed. Instead, all waste products were to be stored in the equipment bays of the descent stage to provide protection from the lunar environment. Even if the storage bags leaked or if the integrity of the containers was violated, the microbial contamination would be contained within the descent stage of the LM rather than deposited on the lunar surface.

The release of viable micro-organisms into the lunar atmosphere during LM depressurization also had to be minimized. Because two men would be confined within the closed ecological system of the LM, it was anticipated that the microbial content of the LM atmosphere would be extremely high by the time the crewmen were ready to leave the LM to begin lunar-surface extravehicular activity (EVA). Before the hatch was opened, the pressure inside the LM had to be reduced to be equal to that of the lunar environment. Opening a vent valve permits the escape of the LM atmosphere and

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results in pressure equalization. To minimize the escape of viable terrestrial micro-organisms at this time, a 95-percent, 0.5-micrometer filter was designed and fabricated for installation in the LM vent-valve assembly. The back pressure and flow rate of this filter were critical. Crewmembers were scheduled to be using the portable life-support systems during depressurization. Therefore, depressurization time had to be minimized so that the supply of life-support components would not be reduced below the level required for maximum stay time on the lunar surface. A filter was designed that permitted maximum depressurization of the LM and provided maximum filtration efficiency for removing viable microbial organisms. An additional safety feature that had to be considered concerned the possibility that the LM atmosphere could be contaminated by relatively large particles such as hair, skin, and fibers from suits or other items. In addition, it was believed that, after the first EVA, the high concentration of lunar dust brought into the LM might plug up the filter, thereby significantly increasing the time required for depressurization and jeopardizing the safety of the crew. Therefore, rather than installing the filter as an integral part of the LM depressurization vent system, the filter was fabricated as a unit that could be stowed in the LM and then installed on the vent system just before depressurization. Also, if any malfunction occurred in the filter assembly during depressurization, the filter could be removed manually by a crewmember, thereby permitting full depressurization.

The LM environmental control system (ECS) was identified as the third area that could contain potentially high levels of microbial contamination. In the LM, cooling was to be accomplished by means of a sublimator plate that would vent to the exterior. To reduce the amount of potable water that would have to be used in the sublimator to cool the LM, the waste-water system also was attached to the sublimator cooling loop. The waste water — which consists of urine, sweat, and other liquid waste from the crewmembers — contains a high concentration of microbial contamination, especially after it is stored. Engineering attempts to design a filter that would remove microbial contamination from the waste water before it entered the sublimator were unsuccessful. Tests conducted on prototype filters indicated a high probability that the filter would become clogged almost immediately and a bypass line would have to be used. If this situation occurred almost immediately after landing on the lunar surface, the filter would not be used, and the costs of design and fabrication would not be justified. In addition, engineers doubted that the filter would function satisfactorily in a 1/6g environment. The movement of the fluids through the waste-water lines was accomplished by using gaseous nitrogen pressure. In this situation, the waste water was supersaturated with nitrogen. Tests indicated that, when the liquid reached the filter/fluid interface, the nitrogen would come out of solution and would not pass the liquid filter. This event would result in blockage of the line by nitrogen gas; no liquid could pass through the filter, and the bypass again would be activated. Consequently, it was decided that the cost of including the filter on the LM waste-water system was unjustified, particularly because the probability existed that the filter system would fail under flight conditions.

Another factor contributed to the decision to eliminate the filter on the waste-water system. Because the average pore diameter of the sublimator plate is approximately 4 micrometers, it was doubtful that a micro-organism could be transferred from the liquid environment through the sublimator plate into the vaporous environment outside the sublimator plate. Also, if a micro-organism were carried through the sublimator plate, it would be subjected immediately to the intense lunar environment.

Additional tests were conducted on the contamination levels of the waste-water system after the requirement to maintain an iodine concentration in the potable-water tank had been established. The requirement for the addition of iodine was generated after it was shown, during extensive ground testing, that micro-organisms from some unknown source invade and multiply in the LM potable water system. This situation results in potentially hazardous drinking water for the crewmembers. After testing many different microbial agents, it was determined that maintaining a very low level iodine concentration in the potable-water system inhibited replication of micro-organisms. Because the potable water containing iodine and the waste water were both used in the LM sublimator system for cooling, the iodine residue in the lines significantly reduced microbial contamination from the waste-water system.

Lunar-sample collection. - Because one of the primary objectives of the Apollo Program was the collection and return of lunar material, advisory groups were established to determine the requirements for sample collection. Types of samples to be collected, collection sites, tools to be used for collection, and containers in which samples would be transported to Earth were determined by considering the prerequisites for physical-science investigation. For quarantine requirements, the primary concern dealt with minimizing the contamination of lunar samples with viable terrestrial micro-organisms that would be isolated later during the investigations of the returned samples. It was decided that lunar samples should be collected by using only sterile tools and should be returned to the LRL in a sterile environment. The collection of lunar samples with hardware that contained minimum organic and inorganic contamination was also established as a physical-science requirement. The types of materials that could be used for fabricating tools and other items that would come in contact with lunar material were severely limited by the scientific requirements and weight restrictions. However, it was agreed that a high-temperature bakeout under vacuum conditions was the best method for removing volatile terrestrial contaminants from the hardware. This treatment, at a sufficient temperature for a sufficient period of time, would also satisfy the sterilization requirements for the hardware. One sample-collection tool that originated as a quarantine requirement was the subsurface core sampler. It had been agreed that, if any viable micro-organisms were present on the Moon, the organisms would be found below the lunar surface, protected from solar radiation that is characteristic of the lunar surface. Early attempts to design a satisfactory subsurface sampler were unsuccessful, principally because the tool would have to penetrate the lunar surface before the sample was collected, while experimental evidence indicated that it was highly probable that the lunar surface would be contaminated by micro-organisms leaking from the suits of the astronauts. (It had been shown during ground tests of the suits that leakage could occur through holes that were large enough to permit the egress of micro-organisms.) Therefore, to avoid sampling material contaminated by suit leakage, the requirement to collect only subsurface samples was developed. Several samplers were designed, but none was approved for production because the design was too complex and it was highly probable that the units would not work on the lunar surface. Consequently, the only subsurface samples obtained during the early Apollo missions were those collected by simple hollow core tubes that had to be driven into the lunar subsurface by the crewmembers. Evaluations of the cores collected during the Apollo 11, 12, and 14 missions have shown that terrestrial contamination cannot be detected in the lunar-surface materials.

Even though biologists were interested in subsurface lunar material, it was decided that the principal requirements for sample collection would be dictated by the advisory committees composed of physical scientists, whose interest was in surface material. Once the collection requirements had been established, the groups concerned with quarantine analysis determined the requirements for particular sample aliquots. In this instance, the managerial decision was wise because it was improbable that life existed in the lunar environment. However, when detection of a life form is believed to be probable (on Mars, for example), the sample-collection requirements for such missions, in terms of the type of sampling locations, will need to be developed mutually by the physical-sciences and biological-sciences advisory committees.

The procedures and hardware necessary for the stowage of the collected lunar samples were considered next. Because the lunar material had existed for millions of years in an almost-perfect vacuum, the physical scientists decided that the lunar samples should be transported to Earth under environmental conditions as near to those on the Moon as technically feasible. This decision necessitated the design and fabrication of a pressure vessel that could be filled with lunar samples and sealed on the lunar surface, and in which the internal environment could be maintained throughout the sample transfer from the lunar surface to the LRL. Because the pressure vessel had to be an ultraclean, gastight container, no additional requirements were necessary in terms of quarantine control. The Apollo lunar-sample return containers (ALSRC) were designed to contain approximately 1 cubic foot of lunar material and to be sealed on the lunar surface by using a knife-edge indium seal and a Viton O-ring double-seal arrangement.

Inflight contamination control. - Early in the Apollo Program, it was anticipated that, during the lunar-surface EVA, the exterior of the astronauts' suits would become contaminated with lunar material. In addition, when the ALSRC, cameras, film cassettes, and other items were returned from the lunar surface to the LM, a considerable amount of lunar material would be brought into the LM. As a result, specific hardware and procedures were developed to minimize the transfer of contamination from these sources to the biosphere. The procedures were initiated before the crewmen entered the LM after each EVA. Each crewman was instructed to brush the fellow astronaut's suit to remove as much loose lunar material as possible. A footpad was provided on the steps of the LM so lunar material could be scraped from the EVA boots. Also, the ALSRC and other items were to be brushed to remove as much lunar dust as possible before the items were placed in the LM. Once inside the LM, all items to be transferred to the CM were placed in sealed Beta-cloth bags to minimize the leakage of lunar dust into the LM or CM environment. Items that were not to be transferred to the CM, such as the EVA gloves and overboots, were discarded onto the lunar surface. After the last hatch closure on the lunar surface, the crewmembers were to use the vacuum system of the ECS to clean dust and other particulate matter from the interior surfaces of the LM. The vacuum system consists of a hose with brush attachment used in conjunction with the ECS suction. The LM ECS also serves as an excellent particulate-contamination-control system because the lithium hydroxide/activated charcoal filters of the ECS are highly efficient particulate filters. The LM is a closed ecological system in which the entire atmosphere is circulated through the lithium hydroxide canisters several times an hour; consequently, a high percentage of the particulate contamination can be removed in a short time, assuming no new contaminants are introduced and complete circulation is achieved.

After the LM ascent from the lunar surface and rendezvous with the CM, the LM crewmen transfer hardware and lunar materials to the CM. Because the CM enters the biosphere, procedures were developed to minimize the possible transfer of lunar contaminants from the LM to the CM. These procedures included wiping and vacuuming all items being transferred from the LM to the CM, establishing a positive air flow from the CM to the LM to prevent atmospheric contaminants in the LM from entering the CM, and bagging and storing items after transfer to the CM. When the transfer of the crewmembers and all hardware to the CM was completed and the LM had been separated from the CM, a vacuum system similar to that used in the LM was to be used to vacuum and clean the CM interior. These procedures, in addition to the particulate-removal capabilities of the CM ECS, would sufficiently restrict the level of particulate contamination in the CM on entry to the biosphere.

Other potential quarantine considerations involved the exterior of the CM. Because the CM does not touch the lunar surface and because of the intense heat caused during entry, the exterior of the CM (except for the docking probe) was considered to be an unlikely source of potential contamination. The docking probe, located on top of the CM, would be attached to the LM and would be subjected to the least intense heat during entry. However, the docking area of the LM would never be in direct contact with the lunar surface and would be subjected to solar radiation during the lunar-surface operations. Therefore, it was believed that a transfer of lunar-surface contaminants from the LM to the CM exterior during the docking procedure was a remote possibility.

Return to the terrestrial biosphere. - Once the CM containing the crewmen and lunar samples entered the terrestrial environment, careful control of potential lunar contamination was required. Because the exterior of the CM was not considered to be a source of extraterrestrial contamination, it was determined that splashdown into the ocean could occur without any special precautions against contamination. After splashdown, the CM ECS was to be deactivated. To maintain the integrity of the CM and maximize the safety of the crewmembers therein, it was determined that the crewmembers should remain inside the CM without opening the hatch. Because the ECS was deactivated, some mechanism for air exchange within the CM had to be provided to bring in fresh air and to eliminate or minimize heat buildup while recovery forces proceeded to the CM. A postlanding ventilation system was designed, which consisted of a fan that circulated fresh air from the outside through the CM and forced the air to the outside through a vent valve. This system was designed and fabricated before the initiation of quarantine requirements for the Apollo lunar missions.

After quarantine requirements were initiated, the system was examined, because potentially contaminated air would be exhausted from the CM to the terrestrial environment. The installation of a filter to prevent this potential contamination was considered. To provide a filter of sufficient surface area to minimize back pressure and to provide a fan with sufficient power to move air through the filter would require a major redesign and refabrication of the CM; therefore, this approach was not economically feasible. Next, the use of water-cooled garments for the crewmembers was considered. In these garments, fresh sea water would be circulated through a closed system surrounding the astronaut's body to remove body heat; then, the uncontaminated water would be dumped back into the ocean. The pumps, garments, and associated hardware

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required for this operation also were considered economically unfeasible at that stage in the Apollo Program. Factors considered in reaching a final decision were as follows.

1. The extremely remote possibility that a hazardous life form existed on the Moon

2. The extensive procedures required during the return from the Moon to the terrestrial environment to minimize the amount of contamination in the CM

3. The high dilution factor of the air and water surrounding the recovery zone

4. The use of protective garments and biorespirators that would eliminate the exposure of individuals to the air vented from the CM

Therefore, it was determined that the postlanding ventilation system of the CM need not be modified to provide absolute contamination control. In the future, when manned missions are planned to a planetary body for which the probability of existing life is much higher than that for the Moon, the rationale may no longer be valid.

Next, in terms of contamination control, the procedures for removing the crew-members, lunar samples, and hardware items from the CM and transporting them to quarantine isolation in the LRL were developed. Initial program plans called for CM retrieval and transport to the deck of the recovery ship while the crewmembers and all associated hardware remained inside. However, from evaluation of structural braces of the CM and the cranes on potential recovery vessels, this operation appeared to be unsafe for the crewmembers inside the CM. If such a pickup were to be performed in a stable environment, such as from the ground, few transfer problems would exist. However, the pickup would occur in the dynamic environment of the sea, where the CM and recovery ship would be pitching and rolling at an undetermined rate and magnitude. Under these conditions, the stresses involved in attaching a crane hook to the CM and lifting the CM to the deck of the recovery vessel could cause damage to the CM and could endanger the crewmembers. Therefore, it was decided that the crewmembers would be removed from the CM before the CM was lifted to the deck of the recovery vessel. This procedural change necessitated revision of the previously established techniques and procedure for contamination control. The revised procedure specified a frogman-assisted egress of the crewmembers from the CM. The frogmen would be protected from potential lunar contamination by maintaining the integrity of their internal breathing apparatus during installation of the flotation collar on the CM. Further-more, recovery swimmers were to spray areas of potential contamination, such as the hatch and docking areas, with a germicidal solution to decontaminate these areas before the hatch was opened. The crewmembers were to emerge from the CM after donning biological isolation garments, which would effectively prevent the transfer of microbial contaminants from the respiratory tract and body surface to the exterior environment. After pickup by helicopter, the crewmen, still wearing the biological isolation garments and physically isolated from the helicopter crewmen, would be transported to the recov-ery vessel. The flight surgeon, who was to be quarantined with the crewmembers, also would be on board the helicopter.

Upon arrival at the primary recovery vessel, the helicopter would be towed to a hangar deck close to the mobile quarantine facility (MQF), in which the three Apollo crewmen, the flight surgeon, and the recovery technician would be transported to the quarantine area of the LRL. The deck area traversed by the crewmembers during the transfer from the recovery helicopter to the MQF would be decontaminated with glutaraldehyde. The CM hatch would be sealed at sea after egress of the crewmen, and the area surrounding the hatch would be decontaminated with a germicide. When the CM exterior had been decontaminated, all decontamination equipment and the life-rafts used by the Apollo crewmen were to be sunk at sea. Later, the CM would be hoisted aboard the primary recovery vessel and placed close to the MQF.

The MQF, which was designed to house a maximum of six persons for 10 days, is similar to a standard mobile home, except that the unit was designed and operated to maintain strict biological isolation. Each unit was built on a standard aircraft-loading pallet to permit tiedown in an Air Force aircraft for transport from the recovery zone to the LRL. The interior of the MQF is maintained at a pressure lower than the outside atmospheric pressure, and all air vented from the MQF is filtered through absolute biological filters. Special storage facilities are provided for liquid and solid wastes generated within the MQF. To ensure maintenance of quarantine requirements, the MQF was provided with multiple power sources, including ship power, aircraft power, standard 110-volt power, and a built-in emergency generator system. Biological-containment requirements also were maintained during transport.

After the CM was placed on board the recovery ship near the MQF, a flexible plastic tunnel was installed between the CM and the MQF. The Apollo crewmembers, flight surgeon, and the recovery technician then walked from the MQF through the plastic tunnel to the CM from which the flight film, the ALSRC, and other flight hardware were removed and transferred to the MQF. Then, the CM hatch was sealed, the surrounding area was decontaminated, and the tunnel was moved inside the MQF. Because some experiments planned for the lunar materials were time critical, the samples removed from the CM to the MQF were packaged in vacuum-sealed plastic bags, sterilized with sodium hypochlorite, and then locked out of the MQF. The sterilized packages were placed in shipping containers, which were vacuum-sealed and provided with sufficient flotation so they would not sink if lost at sea. Then, the shipping containers were transported immediately by aircraft to the LRL. The crewmembers, the flight surgeon, and the recovery technician remained in the MQF until the primary recovery vessel reached the nearest port. There, the MQF and the occupants were transferred from the primary recovery vessel to a C-141 transport plane for the flight to Ellington Air Force Base, Houston, Texas.

Lunar Receiving Laboratory. - The LRL is the first facility designed for biological containment of potentially hazardous extraterrestrial materials while scientific analyses are performed. Early design criteria for the facility stipulated the use of a double biological barrier. All work with material potentially contaminated with hazardous agents is limited to gastight cabinetry systems in which all manipulations are performed by means of arm-glove systems.

In the LRL, each ALSRC is opened in a vacuum system designed to operate in a pressure range of approximately 10^{-7} torr. Rock boxes are opened and initial lunar-sample manipulations are performed using arm-glove systems; the operator remains at

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atmospheric pressure while using the gloves at a pressure differential of 1 atmosphere. For physical/chemical, biological, or biomedical evaluations, lunar samples and all items contaminated with lunar material are kept in biological cabinets that are designed and fabricated of stainless steel and glass in such a manner that strict biological isolation is maintained. The cabinets were designed to have a leak rate of less than 0.05 ounce of Freon per year, which represents the state of the art in leak detection.

Air entering the cabinetry systems is filtered through absolute biological filters; air leaving the cabinet systems passes through absolute biological filters, is incinerated, and again passes through absolute biological filters to the outside environment. The biological cabinet systems are isolated within individual rooms, each designed for specific functions such as work with animals or virological analyses of lunar samples. Each room is maintained at a lower atmospheric pressure than that of the connecting hallways. Thus, contamination is limited to a single room if the integrity of the biological cabinetry in one room is violated.

The area containing the biological cabinetry rooms is surrounded by a secondary biological barrier. This secondary barrier consists of the following design and operational features.

1. All penetrations through the walls of the area are sealed with caulking compound rather than being left open as is the case in most building construction.

2. All liquid effluents from the area are sterilized with steam at a pressure of 235 psi before entering the normal sewage-treatment system.

3. All items leaving the secondary biological barrier are sterilized by using ethylene oxide, steam, formalin, formaldehyde gas, or sodium hypochlorite.

4. The entire secondary biological barrier is maintained at an atmospheric pressure that is lower than that of the outside environment. Thus, if the integrity of the primary barrier is violated, all contamination is isolated within the secondary biological barrier.

5. An intricate alarm system is used to ensure that all exits from the secondary barrier are locked immediately if any violation in the primary-barrier integrity occurs. This system results in the immediate quarantine of all items and personnel within the secondary barrier.

6. For the usual operational mode of the secondary biological barrier, it is assumed that lunar materials will remain isolated within the primary biological barrier.

The LRL personnel enter through an intricate change-room maze where street clothing is removed and laboratory clothing is donned. Entrance to the secondary barrier is through an ultraviolet airlock that maintains contamination control and provides the interface to the differential pressures between the interior and exterior of the secondary barrier. A reverse procedure applies when personnel leave the laboratory. After egress from the secondary biological barrier, personnel first must remove laboratory clothing, pass through a shower area where all parts of the body are thoroughly washed, and then enter the change-room area where street clothing can be donned.

To ensure that the health of LRL personnel was not compromised by working in the area, each worker was subjected to extensive medical examinations before each Apollo lunar mission. Because of the potential hazard of working with lunar material, a requirement was established that pregnant employees, all persons taking medication, and those requiring medical aids such as crutches, braces, or hearing aids would not be permitted to enter the secondary biological barrier. In addition, serum pools were collected from each individual who might be exposed to lunar material. The stored samples would serve as a baseline for analysis of any medical complications that might arise in the years following the exposure. Because the possibility existed that personnel working within the secondary biological barrier could be quarantined for indefinite periods, each person was asked to sign a work agreement devised by the NASA Legal Office. The agreement specified that the person who accepted a job within the secondary biological barrier would consent to isolation if necessary. In effect, when the agreement was signed, the individual waived all rights to any legal action that could be used to exclude him from quarantine requirements. The work agreement was particularly important because the work force included not only U. S. Government civil service employees, but also employees of contractors, members of labor unions, and employees of institutions of higher learning. In addition to the work agreement, all individuals who would be entering the secondary biological barrier agreed that they and their families would undergo an intensive medical surveillance program. This medical program, conducted in cooperation with the USPHS, was designed to detect any changes in health resulting from exposure to lunar material and to prohibit personnel who had an infectious disease from entering the secondary biological barrier.

Because of the intense scientific interest in the returned lunar material, problems were associated with limiting the number of persons who would have access to the sample laboratory. Managerial personnel and members of the large advisory contingent initially wanted permission to enter the secondary biological barrier and view the lunar material. Approval of all requests for access would have resulted in such congestion that work could not have been accomplished within the area. First, the names of a large contingent of NASA managerial personnel were removed from the approved access list on a voluntary basis. Next, it was decided that it would be unnecessary and even unwise to approve access of advisory personnel who were not participating in the work, because maintenance of biological containment depends upon the integrity, training, and personal attributes of individuals. Some advisors coming to the area only during the lunar missions would not be sufficiently trained or technically qualified to operate within the constraints of biological containment. Therefore, the approved access list to the secondary biological barrier was limited to those personnel who had day-to-day work responsibilities in the area. Access to the laboratory was strictly controlled by the MSC Security Branch. The names of all personnel permitted to enter the laboratory were placed on an approved access list, and each person entering the area was required to have a special badge.

No plans were provided in the initial LRL design for inclusion of the crewmember quarantine facility. However, as the program was examined, it became evident that some isolation capabilities must be provided not only for the flight crewmembers but also for the medical and support personnel required during a quarantine period. Therefore, the crew reception area was designed and built adjacent to the LRL sample operations area. The area was designed to be surrounded by a secondary biological barrier with the same design and operational features as those described previously for the sample operations area. The secondary barrier was determined to be a

sufficient biological isolation because no lunar samples would be handled within the crew reception area. The area was designed to provide complete housing facilities, a recreational area, and a medical facility where complete postflight medical examinations would be conducted and medical emergencies could be handled. Quarantine personnel included the three Apollo crewmembers, the flight surgeon, the recovery technician, medical laboratory technicians, cooks, stewards, and sufficient housekeeping and maintenance personnel.

Maximum medical and emergency capabilities were provided within the crew reception area to permit the safe quarantine of personnel without jeopardizing quarantine requirements. For example, a complete X-ray facility, a surgery suite, and other associated medical equipment were provided in the area. In case of a medical emergency, a Department of Defense emergency medical team was on standby to be flown immediately to the LRL to perform the required emergency procedures within the facility. Thus, the need to break quarantine requirements by moving the patient from the facility is eliminated. However, it had been specified early in the program that human life would always take precedence over quarantine maintenance. Therefore, a major emergency within the facilities, such as a fire, would lead to an evacuation of the area by the quarantine personnel. These assumptions and guidelines will need to be reevaluated when missions are planned to a planet for which a higher probability of a natural ecological system exists.

The crew reception area also contains an interview room, in which a glass biological barrier separates the flight crewmembers from a second area in which interviews, postflight debriefings, and news conferences are conducted. Members of the crewmen's families use this area for visits with the crewmen. Finally, a quarantine space for the CM was provided in the crew reception area.

Adjacent to and connected with the sample laboratory and crew reception area is an administrative and support area that contains the office space and support laboratories for all functions conducted within the facility. This area is outside the biological barriers; operations in this area continue between and during the Apollo missions in support of various agency-oriented functions.

FLIGHT CREW HEALTH STABILIZATION PROGRAM

During the conduct of any manned space flight program, the threat of an infectious-disease occurrence in one or more crewmembers is always present. Although the threat is present throughout all phases of the astronaut training and flight programs, it is more critical and potentially hazardous during some phases than during others. The astronauts represent a small population of individuals whose everyday activities directly affect some future flight program. Therefore, days lost from the conduct of mission-support activities because of illness from an infectious disease represent potential delays in the advancement of some flight program. These effects become more pronounced with regard to the prime and backup crewmembers during the period immediately preceding a manned-spacecraft launch. During the last several weeks before a launch, every day is scheduled with specific goals that must be accomplished to ensure that each crewmember is fully trained and ready for the mission.

Several potential dangers are associated with the occurrence of infectious diseases during a period immediately before launch. One or more crewmembers may be exposed to an infectious disease agent, become ill, and not be sufficiently recuperated by the planned launch day to be committed to flight. The durations of launch windows for Apollo missions are limited to a few hours, and, if the physical condition of a crewman is unsatisfactory at the planned launch time, launch delays of at least a month might be required. Potentially the most hazardous threat during the prelaunch period is exposure of a crewman to an infectious disease agent during the last few days or few hours before launch. The disease probably would not be detected during the physical examinations of crewmembers immediately before launch. The crewmembers would be committed to flight, and it is highly probable that disease symptoms would become evident during the flight. The involved crewmember is endangered because of mission stress and the lack of complete treatment capabilities on board the spacecraft, which could result in the manifestation of more severe symptoms than those usually associated with the same disease in the terrestrial environment. Also, the situation is potentially hazardous for the other crewmembers because the small, closed, ecological system of the spacecraft is conducive to disease transmission. Even if the disease is not transmitted, the safety of the other crewmembers may be jeopardized by the loss of the capabilities of the crewmember who is ill. Such an occurrence will be more serious and potentially hazardous as the durations of manned missions increase and as operational procedures become more complex. Not only do the health and safety of the crewmembers become critical, but the probability of mission success is lessened if the illness occurs during flight. Aborting a mission to return an ill crewmember before mission goals are completed is costly and potentially dangerous.

Many special conditions that are characteristic of the environment within a manned spacecraft are conducive to disease development and transmission. In the absence of satisfactory treatment procedures, infectious disease represents a serious threat to the health of crewmembers and to the successful completion of missions. Control and prevention are the most effective ways to deal with infectious disease in manned space flight. However, a control and preventive program should not be implemented for specific space flights only. To be effective, the program must be continuous for all flight crewmembers. Control and prevention are most critical during the last few weeks before a manned mission, and special countermeasures are necessary for the mission crewmembers. Described herein are the rationale and development of the Flight Crew Health Stabilization Program that was developed to minimize the exposure of flight crewmembers to infectious diseases during the last few weeks before an Apollo mission.

History of Infectious Disease Processes During Manned Space Flight

During Project Mercury, consideration was given to isolation of the crewman before the flight. However, because Project Mercury was the first manned space flight program and the missions were of short duration, highly reliable hardware and well-trained crewmembers were the primary considerations. The risk of developing and manifesting a disease during a short-duration flight was extremely low. Even so, crewmember activities were somewhat restricted in terms of contacts with persons not directly involved in flight activities. Some concern was expressed about the fatigue of the crewmen as a result of the vigorous preflight training schedules and about

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the effects this stress would have on their immunity. Some cold and flu symptoms were noted in the crewmembers during the preflight period, but no inflight illnesses occurred during Project Mercury.

When mission durations were increased during the Gemini Program, the possibility that an infectious-disease occurrence would adversely affect mission success also increased. However, because medical personnel were still providing active support for the Mercury flights during the time the Gemini flight-training equipment was installed and training programs developed, little attention could be given to implementing the strict isolation of the Gemini astronauts during a prelaunch period. However, medical personnel were successful in obtaining some reduction in the number of persons with whom the crewmembers had personal contact and were successful, to a limited extent, in having the flight crewmembers live in special quarters at the launch site. During the prelaunch period, access to these living quarters by other persons was closely controlled. Before most of the Gemini space flights, exposures and illnesses occurred, including colds, influenza, beta hemolytic streptococcus, and mumps.

During the early development of the Apollo Program, steps were taken by medical personnel to document and implement a preventive-medicine program to decrease the risk of crewmember illness during the prelaunch and inflight periods. However, after the disastrous preflight fire on the first Apollo spacecraft scheduled for a manned mission, the emphasis was again shifted toward ensuring the reliability of flight hardware. No attempt was made to control the preflight personal contacts or the activities of the Apollo 7 crewmembers. During the prelaunch period, two of the Apollo 7 crewmembers had upper respiratory infections, but treatment was successful and the launch occurred on schedule. However, all the Apollo 7 crewmembers were ill during and after the flight. After the Apollo 7 mission, a medical plan was developed that applied to the prime and backup crewmembers. The intent of the plan was to minimize the exposure of crewmembers to infectious diseases during the 14 days before the Apollo 8, 9, and 10 missions and during the 21 days before launch of Apollo 11 and subsequent missions. The program was designed to ensure optimal immunity, to reduce person-to-person contacts, and to ensure rapid diagnosis and treatment of any diseases that might occur during the preflight period. However, as had been the case in the Gemini Program, the Apollo Program training schedules had been developed, and the flight crewmembers were more concerned about maximizing their training and familiarity with hardware than they were with the potential threat associated with infectious diseases. During the Apollo 8 preflight period, all crewmembers had a viral gastroenteritis. Treatment was successful and the spacecraft was launched on time; however, viral gastroenteritis recurred in all three crewmembers during the flight. After the mission, all the Apollo 8 crewmembers had upper respiratory infections and gastroenteritis again. During the Apollo 8 preflight period, a break in the preventive-medicine program had occurred when the flight crewmembers attended a dinner at the White House. Several individuals who attended the same dinner had symptoms of influenza at the time. As a result, NASA Headquarters requested the preparation and implementation of a policy directive to control communicable diseases and injuries with respect to flight crewmen. Basically, the program was designed to constrain crewmember activities that were hazardous and not directly related to flight preparation. The residence of the crewmembers was to be limited to the crew quarters at the launch site during the prelaunch period, and control and screening of personnel who had access to the quarters and conference rooms were to be provided. Special precautions also were outlined for the purchase and supply of food for the crewmen, and

inspection procedures were prescribed to ensure proper food supplies were being used. However, the program details still were being negotiated and were not implemented for the Apollo 9 mission. During the preflight period of the Apollo 9 mission, all three crewmen had viral upper respiratory infections, and launch of the spacecraft was delayed for 3 days. During the postflight period, two of the crewmembers had influenza. Afterwards, additional discussions were held between the NASA operations centers and NASA Headquarters concerning the details of a program that could be implemented to prevent such crewmember illnesses. Specifically, MSC personnel were directed to provide a plan for protecting the crewmembers of the Apollo 11 mission, which was to be the first manned landing on the Moon. Again, while program details were being developed, the Apollo 10 mission was flown. Two of the Apollo 10 crewmembers had influenza approximately 30 days before the flight, but no crewman became ill during or after the mission.

Because the goal of the Apollo 11 mission was to achieve a manned lunar landing, concern over preventive-medicine procedures was increased. No formal steps were taken in terms of implementing and enforcing any strict isolation of the flight crewmembers. However, special precautions were taken, including the use of a laminar-flow room during preflight press conferences and the cancellation of a proposed presidential dinner during the preflight period. No Apollo 11 crewmember illnesses occurred during preflight, inflight, or postflight periods. After the successful Apollo 11 mission, the impetus for implementing a strict preventive-medicine program decreased.

Because of publicized events involving prime crewmen in contact with large public groups, the activities of the crewmembers were monitored more closely before the Apollo 13 mission. However, crewmembers resided in motels in the vicinity of the launch site until 5 days before the launch date rather than residing in the crew quarters. During the preflight period, the flight crewmembers were exposed to rubella and rubeola. When a backup crewman developed rubella, medical personnel became concerned about the disease potential in the prime crewmembers. Immunity levels on all the crewmembers were determined, and it was discovered that one prime crewman was susceptible to rubella. Because of the potential danger that rubella symptoms would become evident during flight, a backup crewmember was substituted for a prime crewmember.

Because of the Apollo 13 incident, the effect that an infectious disease can have on a mission became obvious to management and to the crewmembers. Crewmembers realized that years of training and planning for participation in a particular mission could be wasted simply as a result of exposure of the crewman to an infectious disease agent. As a result, NASA managerial personnel demanded the development and implementation of a strict program for minimizing or preventing the exposure of flight crewmembers to infectious diseases during the prelaunch period.

During the development of this program, various aspects of disease occurrence among astronauts were examined in detail. The infectious diseases that occurred among the astronaut population from 1965 to 1970 are listed in table II. Statistics recorded during the course of the Apollo Program show that 57.2 percent of the crewmembers have been ill at some time during the 21 days before launch. Based on these observations and on the observation of crewmember activities during earlier manned Mercury and Gemini missions, the Flight Crew Health Stabilization Program was developed and implemented for the Apollo 14 mission.

TABLE II. - OCCURRENCE OF INFECTIOUS DISEASES IN THE

ASTRONAUT POPULATION FROM 1965 TO 1970

Disease	Number of occurrences
Upper respiratory system infection	92
Influenza	20
Pharyngitis	26
Streptococcal pharyngitis	14
Bacterial pharyngitis	1
Viral pneumonitis	3
Bronchitis	14
Otitis media	7
Otitis externa	7
Genitourinary infection	18
Pyelonephritis	1
Skin infection	7
Sinusitis	19
Gastrointestinal infection	27
Conjunctivitis	2
Miscellaneous	5
Total	263

Program Plan

The purpose of the Flight Crew Health Stabilization Program is to minimize or to eliminate the possibility of adverse alterations in the health of flight crewmembers during the preflight, inflight, and postflight periods. The elements of the program designed to minimize exposure of crewmembers to infectious disease, which might result in the subsequent development of symptoms in flight, are shown in figure 1. Each program element is discussed in terms of the direction taken for implementation of the program for Apollo 14 and subsequent missions.
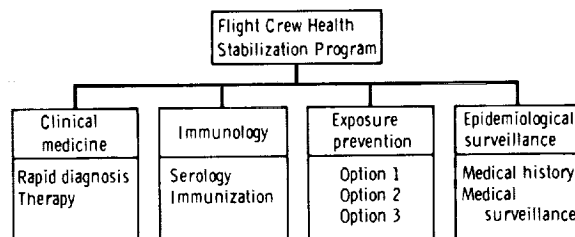
Figure 1.- Elements of the Flight Crew Health Stabilization Program.

Clinical medicine. - The first aspect of a successful preventive-medicine program is the provision of satisfactory clinical-medicine support for astronauts and their families. Because of the criticality of the health of all the astronauts, a clinical-medicine program is provided by the Government for all crewmembers and all members of their families. This health program is initiated immediately upon selection of flight crewmembers and is continuous for all astronauts and their families as long as they are astronauts on flight status. Both routine and emergency physical examinations are provided. Rapid diagnosis of disease and prompt, effective treatment of each astronaut and the members of his family are ensured by facilities for virological, bacteriological, immunological, serological, and biochemical evaluations at the MSC laboratories. The specific details of the astronaut medical-care program are discussed in a later section.

Immunology. - The ideal immunological program would include immunization of all astronauts and their family members against all disease agents to preclude the manifestation of disease symptoms. However, satisfactory immunizations are available only for a limited number of diseases. Immunizations are not available for the diseases that are responsible for the greatest number of illnesses in the flight crewmembers. These diseases are the upper respiratory and gastrointestinal diseases, both bacterial and viral.

All known immunizations were screened carefully by NASA medical personnel and by a special microbiology advisory committee of the NAS. The immunizations listed in table III are those currently used for astronauts and their families. Other available immunizations have not been included for the following reasons.

1. Effectiveness of the immunization for disease prevention is questionable.

2. A high percentage of traumatic side reactions result from some immunizations.

3. The probability of crewmember exposure to the disease agent is so remote that immunization is unwarranted.

Immunization of astronauts and their family members occurs only after serological tests are performed to determine immunity levels. Serological tests are tetanus, syphilis, typhoid, mumps, poliomyelitis, rubella, rubeola, and yellow fever. In addition, the tuberculosis skin test is performed.

TABLE III. - APOLLO PROGRAM IMMUNIZATION REQUIREMENTS[a]

Disease	Required immunization, astronaut	Required immunization, family members of astronaut
Diphtheria	Yes	Yes
Pertussis	No	Yes
Tetanus	Yes	Yes
Typhoid	Yes	No
Influenza	Yes	No
Mumps	Yes[b]	Yes
Poliomyelitis	Yes	Yes
Rubella	Yes[b]	Yes
Rubeola	Yes[b]	Yes
Smallpox	Yes	Yes
Yellow fever	Yes	No
Other	(c)	(c)

[a]Schedule is that recommended by personnel of the USPHS and of the American Public Health Association.

[b]Immunization if no serologic response is obtained.

[c]Only as indicated for travel to endemic areas.

Exposure prevention. - Prevention of crewmember exposure to disease is the most important aspect of a successful preventive-medicine program. Regardless of the effectiveness of all the other phases of the program, if the exposure to infectious diseases is not minimized or eliminated, the program as a whole will not be successful. Fomites (contaminated inanimate objects), contaminated consumables (e. g., air, food, and water), and personal contacts are the primary sources of infectious diseases. Fomites probably represent the least hazardous source of infectious diseases. However, certain spacecraft areas such as communications loops are controlled by providing separate headsets and microphones for each crewmember.

Contaminated consumables represent potential sources for crewmember exposure to infectious disease agents. To prevent transmission of an infectious disease to a crewmember through the air, a closely controlled environment must be provided in which crewmembers can reside during the prelaunch period. The usual building air-handling systems represent a major threat in terms of spreading microbial agents from

one population to another. Regardless of how closely the activities of crewmembers are controlled, if they are working and residing in rooms that are supplied with circulated, conditioned air from other rooms in which nonmedically controlled individuals are working, the crewmembers will be exposed to undetermined sources of infectious diseases. Therefore, all areas in which crewmembers are to reside or work have been modified by the installation of ultra-high-efficiency bacterial filters in all air-supply ducts. Thus, an environment is provided in which crewmembers can reside and work without being exposed to microbial agents from other sources. In addition to providing filtered air, the air-handling systems are balanced in a manner that provides higher atmospheric pressure in those areas inhabited by the crewmembers as compared to atmospheric pressure outside. In this situation, all air leakage around windows and doors or through penetrations in floors, walls, and ceilings will be in the direction away from the crewmembers rather than inward.

The foods that will be eaten by crewmembers also are a source of potentially infectious micro-organisms. Because this potential source of infection could be intentional, as well as accidental, no set or publicized pattern of food procurement has been established. Thus, deliberate contamination of the foods for crewmembers would be difficult. The procurement of food for crewmembers in the quarters is handled by the quarters cooks under the monitoring of the medical team members. Portions of each lot of food purchased are subjected to microbiological evaluations to ensure the safety of the food; all food-preparation areas are inspected daily for cleanliness and maintenance of satisfactory sanitary conditions.

Drinking water is another potential source of infectious disease agents. Sources of drinking water are limited to drinking fountains in the quarters and various working areas. To ensure that the municipal water-treatment procedures are satisfactory and that safe water is provided to the crewmen, water samples are taken daily and subjected to microbiological evaluations.

Personal contacts represent the greatest source of infectious disease; consequently, minimizing possible disease exposure from this source is required. First, a strict limitation of the number of persons who have contacts with the crewmembers during the critical preflight period is necessary. Initial examination of the Apollo training schedule revealed that several hundred persons performed mission-related activities in the presence of the flight crewmembers. This number did not include several hundred other persons who might have contact with the crewmembers during activities away from the launch site. The areas to be visited by crewmembers were strictly limited, and the number of persons in contact with crewmembers during premission activites was reduced to approximately 150.

Second, a medical surveillance program of the primary contacts has been instituted. The purpose of the program is to ensure that the probability of disease transmission from the persons who do have contact with the flight crewmembers is low. Details of medical surveillance will be discussed in the following section. Finally, the isolation of crewmembers from potentially infected carriers has been implemented. These potential carriers include transient populations, groups known to have a high incidence of diseases, and uncontrolled contacts. During the prelaunch period of all manned space flights, numerous personnel travel to the launch site to conduct necessary preflight operations; others come from all over the world to watch the launch.

Many of these persons are apt to be carriers of micro-organisms that differ significantly from those found in the local population. The high-incidence groups are composed principally of children (including those of the astronauts), who are the most common carriers and transmitters of upper respiratory and gastrointestinal infections. Isolation of the astronauts from their own children during the prelaunch period was a critical item in program implementation. This regulation was proven to be valid by the epidemiological data obtained during program implementation in support of the Apollo 14 mission. The third group of infectious disease carriers with whom crewmembers may have contact are the so-called uncontrolled contacts. Included in this group are personnel who only by accident may come in contact with the flight crew and about whom no medical information is available.

Of the several options available for implementing an exposure-prevention program, three were considered.

Option 1. Building a launch-site facility that would house and isolate the crewmembers and all primary contacts during the last 21 days before launch. This course of action would be the most effective way to prevent the infectious disease processes. However, because of high construction costs in relation to the limited number of Apollo flights remaining, construction of a new facility was rejected.

Option 2. Modifying existing facilities to provide housing for the flight crewmembers and all primary contacts. It was determined from engineering evaluations of the necessary modifications that the conversion would be too costly and, therefore, unjustified.

Option 3. Providing strict isolation of the prime and backup crewmembers in the crew quarters and limiting personal contacts to medically approved persons. Although these medically approved individuals would be permitted to reside at home, the condition of their health would be monitored constantly to minimize possible exposure of the flight crewmembers to an infectious disease agent. This plan was selected for use, and the epidemiological surveillance program was developed.

Epidemiological surveillance. - The purpose of the epidemiological surveillance program is to ensure that individuals in contact with the crewmembers are healthy, thus minimizing the risk of infectious disease transmission to the crewmembers. This program was initiated approximately 90 days before the launch of the Apollo 14 mission, at which time it was determined who would need to be in contact with the flight crewmembers during the 21 days before launch. Complete medical histories and other critical information were obtained, and extensive physical examinations of each primary contact were performed approximately 60 days before launch. Microbiological samples also were obtained from each contact to determine if the contacts were carriers of any highly contagious disease agent. If the medical requirements were met, the contact was approved for access to the flight crewmembers during the 21-day period before launch. Each primary contact and all his family members were under medical surveillance during the 21-day period. Primary contacts were required to report to the medical examination team anytime they or any of their family members became ill or were exposed to any infectious disease.

Daily reports were obtained from all schools attended by the children of the crewmembers or primary contacts. The reports included the total number of absences from each school and, specifically, the absences of any children of crewmembers or primary contacts. Monitoring the health of primary-contact children proved to be valuable because, in approximately 30 percent of the cases of illness in primary contacts, similar illnesses had occurred previously in one or more of their family members. In addition, daily reports were obtained from the public health authorities in the launch-site area to determine trends and incidences of specific diseases within the population where primary contacts would have exposure. Complete and up-to-date records on all crewmembers, primary contacts, and their family members were provided by means of a computerized data system that connected the MSC medical analyses laboratories with the medical surveillance office at the launch site.

CONCLUDING REMARKS

The guidelines and rationale used for the implementation of the Apollo Lunar Quarantine Program have been discussed. The possibility of discovering an existing life system on the Moon was believed to be remote. Analyses of lunar material obtained during the Apollo 11, 12, and 14 lunar missions and postflight examinations of the astronauts have verified this assumption. No alterations in the health of crewmembers exposed to lunar material have occurred, and no indication of any replicating life forms has been discovered in any of the lunar samples.

Although the assumptions and guidelines have been valid for manned lunar landings, careful consideration must be given to the development of new assumptions and guidelines when programs are initiated for manned missions to planets for which the probability of existing life forms is several orders of magnitude greater than the probability of life existing on the Moon.

A health-stabilization program to minimize the exposure of astronauts to infectious diseases is warranted. The importance of this program will be more critical for longer duration manned space flights, such as those now planned for the Skylab Program or that will be planned for planetary missions. The program that was developed and implemented for the Apollo Program consists of three basic aspects. Firstly, the areas to which flight crewmembers have access during the 3 weeks before launch are strictly limited. These areas are operated in a manner that minimizes environmental biological contamination. Secondly, the number of persons with whom the crewmembers have contact during the 21 days before launch is limited. Finally, methods have been implemented to ensure that all persons who do have contact with the flight crewmembers are healthy and do not represent a source of infectious disease. This program was implemented for the first time in support of the Apollo 14 mission. No preflight, inflight, or postflight illnesses occurred. It is anticipated that a stricter isolation program will be necessary as mission durations become longer and as the potential threat of infectious disease becomes greater in terms of mission success.

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