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PLANNING STUDY FOR AN ORGANIC CONSTITUENTS INVENTORY PROGRAM

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I. INTRODUCTION

One of the most important scientific objectives of the Apollo Lunar Landing Program is the collection and return to Earth of a sample of the lunar surface. If sufficient care is used in obtaining and returning the lunar specimens to scientific investigators, an unprecedented opportunity will exist for analyzing samples of extraterrestrial material that is uncontaminated by the Earth's environment. One hundred and ten scientists from the United States and six other countries have been selected to conduct experiments with the first samples of the Moon's surface which will be returned by U. S. astronauts. The investigators represent a variety of disciplines and they will study the sample to determine the composition of the lunar surface and to search for evidence of its origin. The major investigative areas are mineralogy and petrology, chemical and isotope analysis, physical properties, and biochemical and organic analysis.

The Lunar Receiving Laboratory at the NASA Manned Spacecraft Center, Houston, Texas will be a central complex where lunar surface materials will be received, quarantined and processed for distribution to principal investigators. The sample will be stored under vacuum and most of the operations with the samples in the laboratory will be performed under vacuum in order to keep the collected material in an environment similar to the Moon's. All of the operations with samples in the laboratory will be performed behind biological barriers to eliminate organic and inorganic contamination and to insure that Earth quarantine is not violated.

From the outset of the planning for this mission the scientific community has expressed concern over the possible contamination of samples prior to their return to Earth laboratories. This has resulted in careful consideration being given to mission planning, design and development of sample collecting tools, and efforts to limit the contamination introduced by the astronauts and their vehicle. Contamination inputs due to the lunar landing module and the astronauts which cannot be prevented are to be carefully accounted for so that an evaluation can be made of their effects on the sample. In addition to the contamination due to the Apollo Mission and associated sampling procedures are the inputs due to some 24 spacecraft which have impacted the Moon, or are in decaying orbits about the Moon, due to pre-Apollo missions dating since 1959. This report is concerned with an evaluation of feasible procedures for evaluating those pre-Apollo inputs and establishing and maintaining an inventory of the organic constituents delivered to the surface of the Moon by the spacecraft.

II. OBJECTIVE AND SCOPE OF THE STUDY

The objective of this study is to provide for NASA Headquarters Planetary Quarantine Program an evaluation of requirements for implementing the recommendation of the Space Science Board of the National Academy of Sciences for an inventory of all organic constituents of terrestrial origin on the Moon. The purpose of this recommended inventory is to provide for interpretation of analytical results from future collections of lunar material. The planning study is to include an estimate of costs associated with establishing and operating an inventory system.

III. APPROACH TO THE STUDY

1. Definition of the Problem

In order to objectively study the requirements for implementing the Space Science Board recommendation, an inquiry was made to determine the finding and conclusions leading to that recommendation. Further perspective was gained regarding the problem of lunar surface contamination by unknown varieties and quantities of organic materials, through discussions with many of the scientists who will study the first lunar sample returned to Earth.

A survey of appropriate areas of the technical literature was performed to identify the programs which involved payloads destined for the Moon. The documentation and other information sources for each program were then investigated to evaluate the data resources feasible of application in an inventory.

2. The Essential Elements of an Inventory

Identification of the information needs of the principal investigators of the first lunar surface sample was pursued through a series of communications with seven of the twelve who will lead investigations in biochemistry and organic analysis.

The information resources available to apply against the needs of the scientists were searched out through discussions with the managers of U. S. programs of lunar exploration, and representatives of the contractors who built payloads for lunar missions. A large part of the information needed to assess organic material contamination of the Moon relates to programs of the U. S. S. R., and various recognized sources of technical information on the Soviet space programs were contacted to explore its availability.

Information concerning the materials used in lunar mission payloads may answer questions of identity and quantity of materials sent to the Moon. There remains the question of where on the Moon's surface will the contaminants be located. This study therefore included an evaluation of the availability of information on payload landing locations and the dispersion of material which is expected about those locations.

3. Implementation of an Inventory

Alternative models of inventory systems were structured and approaches for implementing them were evolved so that comparative evaluations of the benefits, limitations, requirements and costs could be made to identify practicable models and approaches. Further analysis of the practicable models was performed to enable comparisons of effectiveness, level-of-effort requirements to establish and maintain, estimated costs, and capability to accommodate changing requirements for future programs.

IV. SUMMARY OF STUDY RESULTS

A detailed and complete inventory of Earth-originated organic constituents placed on the Moon is not feasible at this time, nor in the foreseeable future. The greatest and most foreboding constraint to such an inventory is the complete lack of significant information concerning engineering materials systems used in payloads launched by the USSR. Even in the case of well-documented U. S. programs, the desired level of detail can not be achieved because trace constituents in many components are not now identifiable. There are other significant constraints which are described in this report but none have this order of magnitude nor are they similarly intractable.

The results of this study indicate that a useful estimate of the nature, extent and location of organic material contamination of the lunar surface can be achieved by evaluating the organic materials load of the various U. S. payload configurations, and then extrapolating the results to cover payloads placed on the Moon by the USSR. In this approach, the Soviet payloads would be categorized according to published descriptions of missions, instrumentation, and whether the landings were hard or soft. These payloads could then be equated to U. S. payloads or combinations thereof. The inventory inputs would also include locations of the spacecraft landings and a dispersion model which accounts for the spread of material about the landing site. This approach to treating the problem will not satisfy the desire of the lunar sample investigators for very precise information concerning the contaminants, however, the desired precision is not available with respect to contamination by spacecraft already on the Moon regardless of the approach.

There is a relatively conservative effort that could be undertaken if the decision were made that some positive action must be applied to the problem. The suggested approach for such a case is an "inventory" of lunar landings and the area surrounding each landing site which is expected to contain all of the contamination introduced by the associated payload. It is proposed that this inventory should include as a back-up resource, all of the spacecraft documentation which contains materials information. This provision will preserve the feasibility of extracting material identification and quantity data if a special need occurs to assess the contamination due to particular U. S. spacecraft.

An analysis has been made of the cost elements associated with several practicable inventory models developed in the study. In summary it can be stated that any approach to the problem which entails an assessment of the organic constituents loads carried to the Moon by all, or only representatives of different configurations, of the U. S. spacecraft is very costly. To establish the least-cost model involving such an assessment, would cost in excess of $700,000. At the opposite end of the cost spectrum is the approach described in the preceding paragraph, which could probably be established within a budget of no more than $105,000. or $190,000 if preservation of spacecraft documentation is to be included.

A cost differential between these two concepts for accommodating, at least in part, the Space Science Board recommendation, also exists for the maintenance of the inventories. Any refinement of data on the landing locations or applicable dispersion models will cause adjustment to be made to both types of inventory. However, in the event of new U. S. programs or the availability of data on the Soviet lunar payloads a sizable cost increment is incurred by those systems maintaining processed data on all pertinent spacecraft; the other type of system incurs only a small immediate increment and defers the cost of processing materials data until a specific need occurs, if ever.

V. THE ELEMENTS OF AN INVENTORY

1. Background

1.1 The Space Science Board Recommendation

Discussions were held with staff members of the Space Science Board of the National Academy of Sciences, National Research Council to gain insight concerning the background to the recommendation of the Board for an inventory of all organic constituents of terrestrial origin on the Moon. The recommendation stated that the purpose was to permit the interpretation of analytical results from future collections of lunar material. In making this recommendation, the Board was carrying out one of its responsibilities as established by the Academy which is stated in part, "still another task of the Board, is a program . . . in the prevention of undesirable and unnecessary contamination of Moon and planet surfaces and atmospheres with alien particles of energy and matter introduced from Earth by space vehicles." The recommendation was developed by an ad hoc committee established to consider methods and techniques for achieving logical requirements of space probe sterilization. The committee's primary recommendation dealt with a policy of implementing and funding studies of space probe sterilization requirements, considered as logical from the biologists' viewpoint. Similarly, the recommendation concerning contamination of the lunar surface by organic constituents reflects the biologists' viewpoint. Even though it is unlikely that living forms will be found on the lunar surface due to the hostile environment, the biologists point out that the Moon may carry the residue of previously living forms or possibly material that is in the nature of precursers to life.

Although there is controversy over the validity of this reasoning, biologists point out that, if they should be right, contamination of the lunar surface can destroy a once-in-forever opportunity to make exobiological studies that may have great bearing on an understanding of terrestrial life. At an earlier time the Council of the National Academy of Sciences expressed its deep concern that initial operations might "compromise and make impossible forever after, critical scientific experiments" and agreed to participate in the planning of lunar or planetary experiments so as to prevent contamination of celestial objects in a way that would impair unique scientific opportunities.

In the report of the Summer Study conducted under the auspices of the Space Science Board in June and August 1962, the Working Subgroup on Space Probe Sterilization stated that, "Aside from the presence of viable organisms which might contaminate an extraterrestrial body, the introduction of non-living organic compounds might constitute an unwelcome complication for cosmobiological research, even on the Moon or a planet that is devoid of indigenous life. This complication can be materially lessened if a complete inventory of organic constituents of each spacecraft is maintained. . . . such inventories should be recorded in a form for convenient reference."

Various representatives of the scientific community have continued to express concern over the contamination problem as evidenced in the statement of the Bioscience Group report of the 1967 Summer Study of Lunar Science and Exploration: "For post-Apollo missions, as in the early Apollo missions, the sampling requirements for bioscience are more demanding and severe than those for most other groups, excluding geochemistry. Moreover, the Bioscience Working Group predicts that the success of the bioscience research will depend to a great extent on the quality of the sample received, in terms of the lack of biological and organic chemical contamination and of the preservation of possible viable organisms. . . . the collection and return of samples free from microbial and organic chemical contamination is the paramount requirement."

The foregoing indicates that the need for an "inventory" of organic contaminants on the Moon's surface relates to the objective of organic chemical exploration in search of molecules of possible biological or pre-biological origin. Detailed knowledge of the amount, distribution, an exact structure of organic compounds present on the Moon is of extreme importance. Since the organic chemical investigation used in attempts to answer these questions would be on a molecular level, the conclusions would not necessarily be dependent on an assumption of life and life-related processes as they are now known. The need also relates to the objectives for lunar biological exploration which includes the search for life associated macromolecules, stereo configurations and their constituent parts such as amino acids, nucleosides, bases, sugars, lipids, and hydrocarbons, as well as a search for microfossils.

1.2 History of Lunar Surface Contamination

The history of the transfer of organic materials from Earth to the Moon began in 1959 with Luna II,a Soviet payload which delivered a flag of the USSR to the lunar surface. Since that time, 24 additional payloads have been impacted, soft-landed, or placed in orbit about the Moon. Nineteen of these payloads are on the surface of the Moon and those still in orbit can be expected to impact the surface within the next several years.

Each of these spacecraft have carried many thousands of components in addition to its own structure. The organic materials in these components include items such as balsa wood impact absorbers, paper-based phenolic circuit boards, elements of resistors and capacitors, conformal coatings, and a host of polymers and elastomers in gaskets, seals and similar elements. Lubricants, and, in the case of soft landing payloads, the descent engine fuel add to the problem in the forms of the residual content of the payload mechanisms and tanks, and products of combustion. It is evident that a very broad range of organic constituents have been delivered to the Moon by these payloads.

In the U.S. program, there has been an effort to employ those materials which will withstand hostile environments of space and the lunar surface so that materials degradation will not impair the mission. As a result, it is expected that some of the organic materials arrived, and have persisted, on the surface of the Moon in forms comparable to those which were launched. However, our knowledge of the stability of the organic materials in the lunar environment is limited, thus precluding a reliable assessment of the residual contamination due to payloads which have been on the surface for a long period of time. Significant unknowns which will have an effect on the form in which Earth-originated organic materials will be found include the types and rates of chemical processes on the lunar surface, the compounds comprising other extralunar materials accreted from space, and the energy input from space and the Moon's interior.

In most cases, the landing locations of payloads on the Moon's surface are known to within one half of a degree or better in latitude and longitude, the exceptions being the U. S. Lunar Orbiter IV and several of the Soviet vehicles. In these latter cases, it is expected that the definition of the payload impact locations will be improved as the abundant and increasing photographic data on the Moon's surface is more completely analyzed.

2. Information Needs of Lunar Sample Investigators

The purpose of the inventory, as stated in foregoing sections of this report, requires that planning and implementation be sensitive to the information needs of the principal investigators designated to study the first sample of the Moon's surface to be returned to Earth. The particular experiments, methodology, and instrumentation planned by these investigators establish criteria for the format and level of detail to be outlined in the proposed inventory. It is evident that an inventory should provide a record concerning contaminants that will answer the questions of: What organic constituents are present? How much of each constituent is present? And, where are these constituents located? This study has shown that the most difficult question to answer is the one concerning the nature of the contaminants since there are so many thousands of components for each spacecraft and the organic constituents of those components have not generally been specified in detail.

The most direct contamination risk to the lunar sample is due to the Apollo Lunar Excursion Module, the astronauts, and their tools. The question of whether or not the sampling site is pristine prior to the collection effort of the Apollo Mission has little significance if contamination from these sources cannot be identified with exactness that is compatible with the planned investigative procedures. This problem has received considerable attention, and special precautions are being applied in the development of equipment and procedures for the Apollo Mission. A study has been performed concerning lunar surface chemical contamination by LEM Descent Engine and Associated Equipment (ref. Aronowitz et al). It was learned through discussions with personnel of the NASA Manned Spacecraft Center that, the problem of identifying chemical constituents of the materials which may become "contaminants" to the lunar sample is being addressed by keeping a collection of specimens of the materials which will be available for examination by the lunar sample investigators.

The approach to the contamination problem being applied to the Apollo Lunar Landing Mission are of interest to this study for purposes of evaluating the interfaces between this effort and the alternative approaches to an "inventory" of pre-Apollo contamination. It is evident that a collection of specimens cannot be generated for all, or even typical, payloads of pre-Apollo missions to the Moon. The effect of this limitation is that organic materials must be identified as exactly as possible from existing documentation on the pre-Apollo payloads.

A survey of the principal investigators for the biochemical and organic analysis work on the lunar sample reveals that they will be concerned with identification of trace constituents with concentrations as low as the order of a nanogram (10^{-9} grams) in a kilogram (10^{+3} grams) of sample. For an inventory to accommodate this order of exactness, the organic materials should be precisely defined in terms of chemical compounds since the planned methods of analysis are suitable for distinguishing between members of the same homologous series.

Several alternative approaches to the format for the output of an inventory listing have been investigated. In all cases, it was found necessary to use a system of precise names for identifying organic compounds in order to avoid ambiguity concerning the exact composition and structure of the constituents. Probably the most acceptable system of nomenclature is that established by the International Union of Chemistry. The names in this system uniquely describe chemical compounds and could be used as the basis for a thesaurus relating to an alpha-numeric code used in the inventory listing. Alternatively the names for all compounds of possible interest could be listed to catalog the information concerning quantities and locations of the contaminants. Categorizations of organic compounds may be simply an alphabetical listing of the compounds, or perhaps a listing similar to that which is used in the Handbook of Chemistry and Physics, which is alphabetical according to the parent compound in the case of derivatives (e.g., 1-Methyl-1-phenyl-hydrazine is listed as Hydrazine, 1-methyl-1-phenyl-). Another variation of the alphabetical listing would be to cross-reference the compounds according to major functional groups or structural features (e.g., 4-Chloro-4-methyl-2-pentenal would be cross-referenced to chlorine, alkenes, and aldehydes).

Carrying the functional group approach further, it is feasible to classify the compounds according to the presence of the specified functional group in the molecule. A compound which contains more than one functional group would be listed under each functional group which it possesses (this is the system used in the Eastman Organic Chemicals Catalog classified by functional groups No. 2 F, where 4, 4-Dimethoxybenzophenone is listed under both alkyl-aryl ethers and aromatic ketones).

Another suitable method of classification is by empirical formula, using a system such as that employed by Chemical Abstracts. In this system the compounds are listed by atomic composition with carbon and hydrogen taking precedence and the other elements following in alphabetical order. Of course, several compounds might have the same empirical formula so that I. U. C. names would have to be listed along with the empirical formula. An example, is the Eastman Organic Chemicals Catalog, List No. 44, in which the empirical formula C_4H_7NO is shown to include methacrylamide, 3-methoxypropionitrile, and 2-pyrrolidinone.

These indexing systems are only available, however, if the exact chemical composition of the organic constituents is known, so that the I. U. C. names can be applied. The common nomenclature applied to many materials in engineering specifications does not relate to exact atomic composition and/or structural relationships. Unless the analysts have exact identities of the organic materials delivered by the payloads, they can only make a guess, albeit an educated guess, as to whether compounds found by the analysis were Earth-originated or indigenous to the Moon.

Although methods are at hand to formulate a clear and concise categorization of organic constituents, and further, to index an inventory for ready reference, major problems will confront any effort to transform information gleaned from space vehicle and payload documentation. These problems relate to the precise identification of the organic constituents in components of spacecraft systems. Components such as electrical resistors number in the thousands for typical configurations and are generally the products of several manufacturers. The organic material content may range from only a protective coating to practically everything but the wire. Specifications for such components generally do not precisely define the composition of all organic constituents. Furthermore in many cases the formulations used are safeguarded proprietary information or else involve indeterminant reactions during processing so that the chemical identity of the end product is not fully known. Finally there are many occasions for the entry of trace quantities of impurities into organic constituents which comprise components of acceptable quality to meet design and quality assurance criteria. Such impurities preclude a complete chemical description of the component even when all materials and processes involved in manufacturing the component are fully documented.

3. Sources of "As Launched" Spacecraft Materials Information

Extensive records have been maintained by the NASA and/or prime contractors for U.S. spacecraft landed on the Moon. On the other hand, no documentation is available concerning materials comprising those spacecraft launched by the Soviet Union. The programs for which documentation is available are Ranger, Lunar Orbiter, Surveyor, and Explorer/AIMP. The later programs were more fully and carefully documented than the Ranger program, and so are more susceptible to detailed study and evaluation of the organic materials load. For this reason, more accurate estimates can be made of the types and amounts of organic compounds carried on the payloads of the more recent programs.

Documentation includes detailed drawings, specifications and parts lists which cover the "as launched" configuration. A survey was made to determine the availability of spacecraft materials information for each spacecraft that has landed on, or is in orbit about, the Moon. Cooperation of the managers and other team members of each of the U.S. programs has enhanced this study by providing for assessments of availability and format of existing data and the effort that would be necessary to extract it from spacecraft documentation.

The Ranger Program, being the first U.S. effort in lunar exploration, was not as thoroughly documented as the later programs. However, there is a vast amount of information from which data on organic materials can be gleaned according to H.M. Shurmeier and Gordon Kautz of the Jet Propulsion Laboratory. In this program five spacecraft impacted the Moon. Each of these spacecraft experienced a single impact onto the Moon's surface at velocities of 2.6 to 2.7 kilometers per second. The locations of the impact points are known to within 0.1° in latitude and longitude. Although there were five spacecraft, they represent only two configurations. It is reasoned therefore, that only two spacecraft, one of each configuration, would need be evaluated to develop the inputs from the Ranger Program to an organic constituents inventory. The people best qualified to undertake such a task are those who by association with the program are most familiar with the design and materials applications in the spacecraft, its systems and components, and the experiments flown on it. Because of the time that has elapsed since the last flight in this program, it would be very difficult to obtain any of these people to perform this task. However, the data could be developed by a small team of capable people, even though not as familiar as the Ranger team with the two spacecraft configurations. The level of effort required to accomplish this task is estimated to be 20 to 24 man-months over a scheduled interval of possibly five months. The estimated cost of this work is approximately $120,000.

The Lunar Orbiter Program included five spacecraft each of which was impacted onto the Moon following completion of its mission. The locations of these impact points are known to an accuracy of at least 0.1° in latitude and longitude except in the case of Lunar Orbiter IV. Contact with Lunar Orbiter IV was lost on 17 July 1967 with the spacecraft on a trajectory to impact the Moon. The general area of impact has been identified and Messrs W. Watson and L. Daspit of the NASA Langley Research Center advise that analysis is continuing to further identify its exact impact location. Information is also available from that Center on the amounts of fuel on board each spacecraft at the time of impact. The Boeing Company was prime contractor for these spacecraft and the documentation from which the materials inventory can be obtained is located in that firm's Kent, Washington facility in a section managed by Mr. William Vernon. The effort that would be required to develop a complete organic materials inventory from the documentation available at the Boeing Company and at a variety of subcontractors is estimated to be of the order of 20 to 25 man-months, and at best would take from 4 to 6 months to complete. The cost of such an effort would be approximately $100,000.

The Surveyor Program adds seven more spacecraft to the inventory problem. Five of these spacecraft soft landed on the Moon and so add complexity to the inventory problem due to exhaust products of the landing engines. Most of the information resources that can be applied to the inventory problem are located at the Hughes Company, the prime contractor for the Surveyor spacecraft. During the course of this study discussions were held with Mr. Robert Sears and

Mr. Horace Maxey of the Hughes Company to gain insight concerning the effort required to extract the desired information from the existing documentation. Most of the desired information would have to be extracted from drawings which are now in storage on microfilm. Selected drawings covering the vehicle and twelve sub-systems would have to be reproduced and then studied to identify those components and materials of interest to the organic constituents inventory. It is considered that detailed study of records for a single spacecraft in each of the two configurations used in the Surveyor Program would be sufficient to evaluate the organic materials load carried to the Moon. If, in the case of spacecraft which soft landed on the lunar surface, it is acceptable to assume that all components in hermetically sealed containers can be excluded from the inventory and that information on the formulations of organic material obtained from the suppliers of those materials would be acceptable without requiring extensive verification or proof, then the level of effort required to accomplish this task is estimated at 30 to 35 man-months. The cost for such an effort would be approximately $150,000 to $180,000.

The locations of these spacecraft on the lunar surface are known to accuracy of better than 0.1° in latitude and longitude.

Explorers 33 and 35 are AIMP vehicles both of which are presently in flight. Explorer 35 (AIMP-E) is in an eliptical lunar orbit with an expected life extending far beyond the initially predicted three years. Explorer 33 (AIMP-D) missed lunar orbit and is now in an Earth orbit which carries beyond the Moon's orbit at apogee; it may eventually impact on the lunar surface. These spacecraft were built at the NASA Goddard Space Flight Center and the documentation necessary to establish an organic materials inventory is largely available from there.

Carefully developed documentation exists at the Goddard Space Flight Center for the Anchored Interplanetary Monitoring platform vehicles. Every component of the vehicles sub-systems are accounted for in tabulated records which have been updated to reflect the "as-flown" configuration. Detailed drawings of the vehicle and all sub-systems are also available as sources of the information needed for an organic constituents inventory. Mr. Frank LeDoux, Head, Structural and Mechanical Applications Section, Mechanical Systems Branch at the Goddard Space Flight Center cooperated with the Exotech Staff in estimating the level of effort that would be required to complete an organic constituents inventory of the AIMP vehicles. In spite of the excellent documentation which includes detailed specification of many components and coatings, there are items such as the approximately 12,000 resistors aboard one vehicle which could not be assessed for constituent materials without inquiry being made to the several suppliers of those items. It is estimated that, at the minimum, 3 man-years of effort would be required to prepare the inventory in exhaustive detail. The related cost would be in excess of $150,000. Mr. LeDoux indicated that an expensive part of the effort would be the investigative work necessary to assess the material constituents of components used in the experiments flown aboard the spacecraft, and also the great number of small components such as resistors and capacitors which are supplied by a variety of manufacturers.

The foregoing discussion of the sources of materials information and the large effort that would be required to develop that information into an organic constituents inventory, indicates a set of problems which are common to all attempts at studying past programs to fully identify the material constituents carried to the lunar surface. These problems center about the fact that the extensive documentation in each program was undertaken to meet a variety of objectives, but did not include an exact record of all organic material formulations carried aboard the payloads. Thus, much investigative work would be required to trace back each small component suspected of containing organic materials to obtain such an assessment from its manufacturer. It is practically assured that even with the most exhaustive investigation, the results would not be free of considerable uncertainty. The constraint to completeness of the inventory is the fact that the manufacturers of small components often have no occassion to maintain very close control over all constituents going into their product unless such control is required to meet performance or quality control specifications. In the formulation of coatings and potting compounds, those constituents considered controlling of the required characteristics of the compound are specified. However, slight variations in formulation occur in the processing of various batches of the material; these are seldom documented and are more of the nature of accepted variations in the product. These are but a few examples of the many sources of uncertainty which confront an investigator who would attempt to search out a complete organic constituents inventory from the documentation of past lunar mission programs. In summary there is no evidence of recognition of a requirement for maintaining a detailed account of organic constituents. Since an inventory was not recognized as a requirement in the programs discussed above, the existing documentation does not facilitate the development of an inventory by direct extraction. It is evident that an attempt to prepare a complete inventory of all organic constituents carried to the Moon by U. S. spacecraft would require a significant effort by each of the prime contractors and/or NASA Centers responsible for the spacecraft and involve costs that would probably exceed 1.3 million dollars if the inventory were to have information in the form most useful to the investigators of the lunar surface sample.

Existing records of spacecraft materials are generally in terms of generic, proprietary, or engineering names rather than precise chemical names of chemical compounds. All materials identification developed as inputs to the inventory should be translated into names of compounds and functional groups according to the recommended nomenclature described in an earlier section of this report. This requirement establishes the level of detail required from component manufacturers regarding the constituents which are introduced in their processes. From the standpoint of the lunar sample investigator, a detailed inventory losses much of its usefulness if the constituents are not fully described in terms of chemical compounds and functional groups.

4. Dispersion Mechanisms

The spread of Earth-originated organic materials over the surface of the Moon is an important element of an inventory which will enhance the interpretation of analytical results from studies of lunar surface samples. Two classes of dispersion mechanisms can be considered: (1) The spread of materials due to the payloads landing maneuver and impact; and (2) the spread of materials from the original landing sight due to dispersive forces of the lunar surface environment. Present knowledge of the Moon's surface environment is sufficiently limited that dispersion by related mechanisms cannot be reliably estimated. However, the displacement of materials from a payload landing site by these mechanisms is expected to be at least an order of magnitude less than dispersions due to the landing itself. The mode of dispersion from the payload relates to whether the vehicle experienced a high velocity impact or was gradually decelerated to a relatively soft landing. In the case of high velocity impact, the payload would break up and the fragments would be displaced through ballistic trajectories along with debris from the crater formed at the original impact point. There are both analytical models and empirical methods which enable dispersion patterns to be estimated provided the mass, velocity, and the payload's angle of incidence to the lunar surface are known. Suitable methods for this type of analysis derive from the extensive analytical and experimental work concerning high velocity impact of projectiles into a variety of semi-infinite targets including basalt and other materials which are considered similar to the lunar surface. When applying these methods to impacts on the lunar surface, scaling factors and other adjustments are applied to account for the weaker gravitational field of the Moon, the lack of a sensible gaseous atmosphere, etc. As knowledge of surface conditions increases these methods can be further refined to yield better dispersion models.

The dispersion of contaminants from a soft landing payload relates almost entirely to the products of combustion and nozzle erosion which impinge on the Moon surface during the spacecraft's controlled descent. This subject and appropriate methods for calculating the expected area of dispersion have recently been treated in a NASA-sponsored study at Grumman Aircraft Engineering Corporation. This research was concerned with problems due to the Lunar Module exhaust, and reports by L. Aronowitz et. al. describe the level and extent of the lunar surface contamination that will be caused by rocket exhaust gas during the Apollo mission landing. Their findings indicate that water, N_2, H_2, and CO will constitute over 90 mole percent of the exhaust, with CO_2, H, and OH also present. Organic compounds may appear in trace quantities due to thermal decomposition of phenolic materials of the rocket liner. Their treatment of exhaust gas dynamics and the adsorption and desorption of contaminant molecules on the lunar surface has enabled the preparation of maps which show the distribution of these contaminants in the vicinity of the touchdown site. The methods of analysis employed in the Grumman study are suitable for adaptation to treat the problems of contaminant dispersion from the Surveyor vehicles and the Soviet soft landing payloads.

VI. METHODS FOR IMPLEMENTING AN INVENTORY

1. Models of an Inventory

The following paragraphs present brief descriptions of the inventory models examined during the search for practicable alternatives which would meet the objectives of the Space Science Board's recommendation.

a. The inventory could be a very detailed listing of all organic compounds known to have been launched on lunar payloads, including the amount of each constituent that was present. This approach to the inventory is feasible only for the U. S. spacecraft, since sources do not presently exist for obtaining this information on the Soviet spacecraft.

   The development of such a detailed listing would include identification of the various constituents and the amounts on board each spacecraft, the location of the payload landing, and application of a reasonable dispersion model to each landing site. The results would provide for an estimate of the fraction of the total organic materials load carried by any payload which would fall within given radii from the point of landing or impact. Such an inventory would be grossly incomplete pending the eventual development of a source of detailed information on the organic materials carried by Soviet payloads. If information on the Soviet payloads comparable to that presently available for U. S. payloads were obtained, a comprehensive inventory could be developed which would describe all known Earth-originated organic material contaminants, indicate the amounts of each delivered to the Moon, and define bounds within which dispersion of these constituents is expected to have been limited.

   The remaining obstacle to completeness of the inventory, which is unquestionably permanent, derives because the documentation and other sources of identification of materials on past missions will not include any of the trace constituents which were not intentionally added. However, if the Soviet information were available so that this model could be achieved it would probably be the most desirable inventory from the standpoint of the lunar sample investigators.

b. The foregoing model requires that a detailed accounting be be made of all organic materials present on board payloads which have landed on the Moon. A practical constraint to the achievement of this model is the enormity of the task of extracting the detailed information concerning organic materials from the documentation that has been compiled on the various lunar payloads.

A less exact, but more practical model of the inventory has all the elements of model (a), just described, but limits the materials information requirement by including a detailed accounting of materials for only one spacecraft of each configuration employed in the various series of missions in the U. S. and the USSR programs. The detailed descriptions and amounts of organic materials ascertained for each configuration would then be assumed to apply at each lunar surface location where a payload of that configuration has landed.

This model is subject to the same constraints, relating to inadequacies of data sources, as were described for model (a).

The economy of this approach is evident in the case of U. S. programs since only five spacecraft would be analyzed to obtain a detailed accounting of organic materials rather than sixteen spacecraft. Similar economy would be expected with respect to the Soviet programs if information on their payloads was made available.

c. The model just described can be modified to accommodate the lack of information concerning the Soviet payloads, and still offer an estimate of the lunar surface contamination that may be useful to the investigators who will perform biochemical and organic analyses.

In this approach the information developed by analysis of U. S. payload configurations would be applied to the Soviet payloads according to the recognizable similarities of the Soviet mission objectives and their counterparts in the U. S. program. In this inventory model then, the Soviet payloads would be simulated by combinations of systems and subsystems of U. S. payloads which in turn would have been carefully analyzed to assess the organic constituent loads. Each landing site for the Soviet payload would then be assigned a contamination load according to an estimate of equivalency with components of U. S. payloads.

A dispersion function would be assigned to each contamination load in accordance with whether the payload experienced a soft landing or hard impact. The inventory according to this model would cover all payloads placed on the Moon, provide an estimate of organic constituent contamination according to an assigned equivalence to typical U. S. payloads, an estimate of contaminant spread according to dispersion models for hard and soft landings, and would be suitable for upgrading if and when information concerning the Soviet payloads is made available.

d. Each of the foregoing inventory models requires a very substantial data collection effort to enable the answering of the questions of what constituents and how much of each has been delivered to the lunar surface. It is estimated that more than eight man-years of effort would be required to develop a detailed assessment of the organic materials load carried on the "typical" configurations of U. S. spacecraft required in the last model described above. In spite of this level of effort an inventory developed according to these models would either ignore the significant input due to Soviet payloads or treat them in such a way that substantial errors could be introduced due to the method of estimating on the basis of assumed similarities to U. S. payloads. In response to this predicament another inventory model is suggested which ignores questions concerning the identity and quantity of organic constituents and rather would accommodate inquiries concerning identification of those regions of the lunar surface contaminated by any organic materials of terrestrial origin.

This model treats the minimum undertaking that is considered a constructive response to the Space Science Board recommendation for an "inventory." The approach in this case is to identify each landing site for the lunar payloads, both U. S. and Soviet, and then apply a dispersion function according to whether the payload experienced a soft landing or a hard impact. The most significant input to this model is a reliable estimate of the area surrounding the landing site which will contain practically all of the contamination. This should be a conservative estimate based upon dispersion models recently developed for both hard and soft landings on the lunar surface. The result of such undertaking is visualized as a series of charts of the lunar surface which would designate those areas which are expected to be contaminated by organic materials of terrestrial origin. Obviously the most direct application of this type of information would be to the planning of lunar surface sampling missions. Those areas where such contaminants, at least in solid or liquid phase, are not expected to be present would be immediately identified for consideration in the planning.

The objective of the Space Science Board would be better served if the presently available documentation on spacecraft systems and constituent materials were preserved. Then, in the event that a sample was drawn from an area where the risk of contamination induced a particular requirement for detailed information on the nature and quantity of contaminants, this data could be developed to meet the needs of the individual case.

No estimate of the nature and amount of the organic constituents in the contaminated zones would be prepared in anticipation of the needs of the investigators. However, it is evident from the discussions of the other models of the inventory that such estimates are replete with uncertainties due to the lack of information concerning the Soviet programs and the materials involved.

e. The last model to be presented is identical to the foregoing except that no provision is included to safeguard spacecraft documentation from either past or future programs. This simplest of "inventory" models would definitely be limited to the identification of payload landing sites and appropriate dispersion patterns. Since it does not allow for identification of organic constituents by type and amount, this model provides little more than a nominal response to the recommendation of the Space Science Board.

   It is recognized that part, if not all, of the documentation for lunar mission payloads may be retained indefinitely for purposes other than an organic constituents inventory program. However, the limitation stated above for this model of the inventory is assumed to apply unless assurance is obtained that all materials information will be available on a continuing basis. In the event of such assurance, this model would then have the same benefits as model (d) but with a slower response to demand for detailed information.

Table I presents the foregoing models in summary form for purposes of comparison.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE I: INVENTORY MODELS

(Described in Section VI. 1)

	Data Inputs		Estimated Cost (Thousand $)		Benefits	Limitations & Comments
	Organic Materials	Locations & Distributions	Establish	Maintain		
Model (a)	Compounds identified & quantities determined from program documentation and from records of component manufacturers for all lunar payloads	Obtain best available fix on locations; assign dispersion model as appropriate for hard or soft landing	1380	50 per new spacecraft	Most complete inventory possible from existing documentation - full service available when established - avoids further loss of detail which component suppliers may add to present documentation	Data limited to U. S. programs only - detail accuracy limited by existing documentation - large cost for incomplete inventory - output limited to organic compounds
Model (b)	Same as (a) but only for typical payloads of different configurations in lunar programs	Same as (a)	710	50 per new spacecraft	Provides reasonably accurate estimate of contaminants delivered by each U. S. payload	Same as (a) but less expensive-output indicative rather than exact
Model (c)	Same as (b) plus estimate of USSR inputs by approximation to comparable U. S. configuration	Same as (a)	805	50 per new spacecraft	Provides estimate as in (b) plus an approximation of input due to USSR payloads	Uncertainty of making good estimate for USSR payloads - output indicative rather than exact
Model (d)	Existing documentation stored for safekeeping. Analyzed only for particular cases when need occurs.	Same as (a)	190	10 per new spacecraft and 190 - 240 to respond to a demand for detailed data	Economical "inventory" to indicate - gives maps of contaminated zones - can be expanded if and when need for details occurs. Accommodates changing requirements & adapts to "collected specimens" approach.	No ready service regarding identification & quantity of contaminants. Loses information now available but not in program documentation.
Model (e)	None	Same as (a)	105	1 per new spacecraft	Most economical "inventory" - gives useful maps of contaminated zones	No provision for materials information

2. Requirements of Implementing the Models

The models described above can be classified as: (1) including treatment of spacecraft materials data at the time of establishing the inventory, (2) deferring analysis of payload materials until a specific need for such information occurs, or, (3) not including materials data in any form. The third class is simply an abbreviated version of the second, so that two approaches for implementing an inventory will cover all the alternatives developed in this study; these are described in the following paragraphs.

a. Pre-processed Inventories

For each of the alternatives which include detailed assessment of the organic material load aboard all or several of the payloads, the first step is to establish a team or teams of people who will carefully sift through all drawings and parts lists and other forms of material specifications to determine the identity and quantity of each such constituent. Discussions with managers at several levels within the U. S. programs have corroborated the evident conclusion that this job could best be done by persons who have gained a good familiarity with the materials included in the payloads as they were developed and readied for flight. However, it is also evident that for the earlier programs, particularly Ranger, the best qualified people have moved on to new assignments in programs that are current. Certainly it would be difficult, as well as costly to on-going programs, to attempt to reassign key people for a period of from 4 to 6 months to contribute to an inventory effort. However, significant penalties would also attach to an effort which employed people who were technically qualified but unfamiliar with the payloads. Discussions of this problem with program managers revealed the concensus that any effort to develop the needed information with "outsiders" performing the study would greatly lengthen the time required to complete the task and hence inflate the cost.

The data collection task described above would be a one-time undertaking for each program. When it was completed according to the requirements of the inventory model selected, it would provide the essential element of classes and amounts of organic constituents delivered to the Moon by past programs. Additional requirements would be the best available description of the spacecraft landing points on the Moon and a selection of an appropriate dispersion model for each case. Concurrent with this effort to obtain the needed information from historical records,a program should be implemented which would insure that for on-going and future programs for exploring the Moon, all data requirements for the inventory would be developed as the programs progressed.

b. Demand-processed Inventories

A different approach is appropriate for that model of the inventory which does not require an assessment of the organic constituents load of the various payloads until the need for that information is demonstrated. The first requirement for this approach would be to provide for the safe keeping of all drawings and parts lists and other record material essential to an evaluation of the types and quantities of materials aboard each payload. The only data that would be physically entered into the inventory would be the most precise available description of the location of each payload on the Moon's surface, and to each payload a reference indicating the most appropriate dispersion model to be applied. A series of charts of the Moon's surface would then be prepared showing the location which is expected to contain all the associated contamination. The inventory would be maintained by refining the plot of payload loactions as may be warranted by developing information, and applying improved dispersion models which may be developed as more knowledge is acquired concerning the lunar environment.

3. Estimate of the Costs

The various tasks involved in implementing the inventory models must be defined so that comparative evaluations can be made of associated requirements and costs. This is most conveniently done in an outline form which is keyed to the presentation of estimated costs in Table II.

A. Information Collection

1. Review in detail, and extract identities and quantities of all organic materials from drawings, parts lists and specifications for payloads placed on, or in orbit about, the Moon in Ranger, Lunar Orbiter, Surveyor, and AIMP programs. If complete chemical descriptions cannot be determined from documentation, trace components back to producers as may be necessary to obtain "best available" information. Alternatively, provide for safeguarding existing documentation for possible review at a later time.

2. For new U. S. programs, establish accounting requirements and reporting procedures. Alternatively, establish requirements for collecting and maintaining specimens of all organic constituents.

3. For lunar missions of the USSR:
   a. Endeavor to develop source of the needed information.
   b. Gather all available information which may be useful for relating Soviet payloads to U. S. spacecraft configurations.

4. Obtain the most accurate information available on landing locations of all payloads delivered to the lunar surface. Continue efforts to obtain refined data.

5. Survey analytical methods for evaluation of contaminant dispersion on lunar surface and establish appropriate models for both hard impact and soft landing.

B. Establishing and Maintaining the Inventory

1. Establish system of nomenclature and prepare thesaurus for the inventory.

2. Translate organic constituents information into inventory language and format as contaminant matrix for each payload on the Moon.

3. Develop an estimated contaminants matrix for each Soviet payload on the Moon.

4. Identify each payload landing site by latitude and longitude on the Moon's surface.

5. Assign an appropriate dispersion function or model to each landing site.

6. Store the inventory information to accommodate efficient search and retrieval procedures. In the case of organic material specimens, storage facilities should accommodate preservation of the samples and thorough cross-referencing should be applied to relate the samples to the appropriate payload identification and other information maintained in the inventory.

C. Output from the Inventory

1. Establish procedures for responding to requests for information and/or material specimens.

2. Prepare inventory "read-out" in form useful to the scientific community.

Most of the inventory models described in Section VI of this report do not require the performance of all of the tasks listed above. For example, an inventory effort according to model (d) would not require tasks B 1, B 2, B 3 nor the primary task described in A 1. Similarly the primary task described in A 1 involves the study of documentation for all U. S. payloads landed on the Moon in the case of inventory model (a), but only one spacecraft of each different configuration on models (b) and (c). These differences are accounted for in Table II.

TABLE II: ESTIMATED COSTS* FOR MODEL INVENTORIES

(In Thousands of Dollars)

	Tasks (Coded as Outlined in Section VI. 2)											Cost to Establish	Cost to Maintain
	A 1	A 2	A 3	A 4	A 5	B 1 + B 2	B 3	B 4	B 5	B 6	C 1 + C 2		
Model (a)	1105	40	5	a/	30	100	-	a/	60	10	30	1380	50/new spacecraft
Model (b)	475	40	5	a/	30	80	-	a/	60	5	15	710	50/new configuration
Model (c)	475	40	20	a/	30	80	60	a/	60	10	30	805	50/new U.S. or USSR configuration
Model (d) (basic)	40	25	20	b/	30			3	60	2	10	190	10/new spacecraft
Demand Response c/			10			80					20		110 c/
U. S. d/		80											80 d/
USSR d/							130						130 d/
Model (e)				b/	30			3	60	2	10	105	1/new spacecraft

a/Cost is included in A 1.

b/Cost for A 4 is included in B 4.

c/ Initial set-up cost when first demand is made for detailed data.

d/Costs to fully describe contaminants due to one payload (U. S. or USSR) over and above set-up cost.

*Note: Estimates based on Ranger, Lunar Orbiter, and Surveyor missions plus AIMP-D. Costs for information collection tasks are based on estimates provided by NASA Centers and prime contractors responsible for past lunar exploration programs. Costs for processing new data are based on Exotech Incorporated estimates for the tasks involved.

VII. CONCLUSIONS OF THE STUDY

Analysis of the constraints, implications and requirements attendant to the alternative models presented in this report leads to the conclusion that a detailed and complete inventory of all organic constituents of terrestrial origin delivered to the Moon is not feasible. This situation is due principally to the unavailability of information needed to assess the organic constituents transported to the Moon by Soviet spacecraft. Furthermore, a requirement for data collection in support of such an inventory was not recognized in the development of documentation for the relevant U. S. programs. Consequently, a very large effort would be required to obtain the exact identities and quantities of all organic materials included in the lunar payloads. Even then, the results would probably be incomplete for the intended purpose of enhancing the interpretation of analytical results from studies of lunar surface samples. The sensitivity of some of the analytical procedures which will be applied to the lunar sample enables detection of a nanogram (10^{-9} g) of organic constituent in a kilogram (10^{-3} g) of sample. This level of sensitivity causes trace constituents or unidentified impurities in the spacecraft components to be significant, although surely beyond detection through analysis of existing records.

In view of the limitations on the expected benefits, and the large effort which would be required to evaluate inventory inputs from existing documentation of past missions, it is concluded that the most detailed inventory that can be considered practicable is one in which the available information for only one space vehicle of each configuration that has landed on the Moon would be completely reviewed to assess the organic constituents load. This approach is common to inventory models (b) and (c) presented in Section VI of this report. Both of these models establish an "inventory" with large areas of uncertainty in the output which would be more appropriately classified as a reasonable estimate of the contamination to be expected due to the lunar mission programs considered. If an estimate is considered an acceptable result of the effort required to develop either of these models, then, model (c) is considered preferable since it covers both U. S. and USSR payloads. Since the unknowns regarding Soviet spacecraft hardware, lubricants, fuels, etc. are gross, it may be no less effective but less costly to treat those payloads as equivalent to the "worst case" contamination due to a U. S. payload.

Only limited benefits can be obtained at rather large costs in any effort that includes initial inputs being developed from existing documentation of past programs. Therefore it is considered that the most practicable approach, if any effort is to be undertaken, is an inventory according to model (d). The initial effort in this approach is to provide for the retention and safeguarding of all existing documentation because of its potential worth to future analytical work. The only data concerning past programs which must be processed and formalized to initiate the inventory is that relating to the locations of all spacecraft which have landed on the Moon and appropriate models of the expected dispersion of materials from the landing sites.

If an inventory effort is to be made, the recommended approach is the least costly of all the alternatives developed in this study. Its benefits compare favorably with those of the other alternatives and furthermore retains a flexibility which will enhance the accommodation of data concerning the Soviet payloads which may become available at a later time. Furthermore, rather than requiring a comprehensive study of all available information on lunar payload materials, this approach permits selective studies to be made of individual payloads which are deemed to be significant to particular lunar-sampling missions. Even if the constraint due to a lack of information on Soviet payloads were overcome, present limits of our knowledge of the lunar surface environment tends to make uncertain the usefulness of a comprehensive study to categorize and quantize all organic material contaminants. Surely not all of the organic compounds which have been delivered to the Moon are so stable in that environment that they have remained in the same form as they were at the time of launching from Earth. The most reasonable approach would appear to be to defer the detailed study of the organic materials loads until a particular scientific mission provides both the motivation and the criteria for an exact inventory of a particular payload.

Consideration was given in this study to the capacity of each of the inventory models to accommodate revised requirements for changing needs for information on the part of the investigators of samples returned from the Moon or possibly from the planets. The model (d) approach provides the greatest flexibility because of its limited commitment to formalizing a data collection, and similarly, has the greater capacity for accommodating revised requirements. For example, the retention of all record material rather than reducing it to an assessment of organic constituents would enable accommodation of a requirement to assess contaminants other than organic materials if such a need were to develop. However, this approach, by not requiring the assessment of all organic materials at the earliest practicable time, will allow certain information sources to diminish and disappear as time passes on. The reference is to information concerning organic materials formulations which are not contained in the present documentation of the various programs. This disadvantage however would apply only to past programs since the requirements for documentation of on-going and future programs should be identical regardless of the approach taken in establishing the inventory. The treatment afforded current and future programs should require that detailed information concerning organic constituents be made a part of the program documentation and would reside there in a readily extractable form until a particular need occurred for its assessment.

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