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Space Station Utilization in Lunar Orbit

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SPACE STATION UTILIZATION IN LUNAR ORBIT

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ABSTRACT

An effective lunar exploration system can be created by flying a modified earth-orbit space station in polar lunar orbit as a remote sensor platform and lander deployment base.

Objectives of such a lunar station can be categorized by (1) science, (2) technology and (3) operational experimentation. A plan for orbital investigations and surface exploration is presented.

The lunar environment, as well as interactions with the lunar landers, logistics shuttles, and a propellant depot levy unique requirements for the conversion of an earth station to lunar applications.

It appears feasible and highly economical to use a modified earth-orbit station for major advances in lunar exploration.

INTRODUCTION

The vast regions of the moon can be investigated very efficiently from lunar orbit with a modified earth-orbit station that would incorporate multiple lunar landers, remote sensors, and a field research laboratory. A system of such broad and flexible capability will provide (1) information pertaining to the overall nature and history of the moon and its utility to man, (2) a uniquely advantageous facility for viewing phenomenon such as radio-astronomy and solar-terrestrial emissions, and (3) a way-station for an eventual lunar surface base.

Because the moon is quite remote from earth and there is great interest in investigating widely dispersed regions of the lunar surface, the combination of a station and landers based in lunar orbit provides sustained and repetitious access to the subjects of interest with field laboratory resources.

Figure 1 depicts a lunar-orbit station derived from a 33-foot-diameter earth-orbit space station, with space tugs for lunar landing and backup return to earth orbit, plus auxiliary vehicles. Figure 2 illustrates a lunar station using the 15-foot modular space station concept. Figure 3 outlines the broad array of elements inherent in such a multivehicle system.

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**SCIENTIFIC, TECHNOLOGY/ENGINEERING, AND OPERATIONAL OBJECTIVES**

The broad spectrum of objectives in prospect for a station in lunar orbit is as follows:

1. Efficient investigation of current state and utility of the moon
   a. Remote sensing from orbit
   b. Multiple landings and traverses
   c. Selected surface sample analysis in orbit
2. Simulation of planetary techniques
3. Extra-lunar observations of vantage
4. Lunar surface base activation and support services

**Lunar Exploration**

The most important scientific questions regarding the moon pertain to its origin, development, and current state, particularly as related to the solar system. Although it seems highly unlikely that life ever existed on the moon, a continuing minor search will also be made through sample analysis. These questions and others of secondary scientific importance have been defined in detail in a number of NASA-sponsored studies. The more important exploration objectives relating to the questions of the moon's origin, development, and state are (1) sample collection and analysis, (2) geologic and topographic mapping, and (3) measurement of internal characteristics.

Guidelines for selecting experiment objectives for a station in lunar orbit would be based on (1) the specific need for the desired data, (2) the advantages in conducting the experiment by means of each potential method (rover, orbiter, surface base, etc.), (3) an estimate of the potential availability of the equipment for acquiring such data by the time vehicle installation is required, and (4) the degree of confidence that such potential measurement capabilities can unambiguously provide the desired information.

**Extra-Lunar Exploration**

...lunar orbit observatory also provides some significant advantages over other observation sites, such as earth orbit, for certain astronomical and astrophysical studies. Principal among these are the increased baseline (earth to moon) for studies such as radio interferometry, frequent occultation (by the moon) of radio and other galactic emitters, and utilization of the moon as a shield from earth noise.

**Lunar Resources**

The objective of searching for lunar resources cannot be considered as a purely exploitative endeavor because most means for investigating such resources will be the same as those used to study basic lunar scientific questions. Moreover, much of the scientific information obtained will provide clues as to location and presence of resources.

Until some unique discoveries are made, there is little prospect that lunar resources will be directly applicable to earth usage in the foreseeable future (based on economic considerations). The question of lunar resources is pertinent and conceivably very important to a lunar base; particularly those materials that can be fabricated for base construction, those which can be utilized for base protection, and those which can be used for base consumption (including possible propellant manufacture).

Of greatest interest is surface and subsurface mineral and chemical composition determination and geological and topographical mapping. Attention would be concentrated upon areas of apparent resource potential such as areas of recent volcanism or permanently shadowed areas.

**Technology and Engineering Objectives**

Wherever cost-effective and feasible, a lunar-orbit station should also produce a precursor medium or proving ground for eventual planetary exploration techniques. Extra-terrestrial system maintainability techniques for example should be incorporated wherever possible.

There are two potential advantages of providing various interplanetary capabilities in a lunar-orbit station. One is to reduce future modifications to adapt such a station to a planetary role, and the other is to permit the simulation of planetary operations in lunar orbit, where difficulties would not present as serious an emergency-recovery problem as in an interplanetary mission.
Operational Objectives

A station in lunar orbit will initially serve as a central control point for a variety of lunar observations and exploration operations which involves logistics vehicles, a propellant depot, and a data relay satellite. Later, it will be converted to a different mode wherein it serves as a way-station and emergency retreat for a surface base.

SYSTEM FEATURES

Station

The basic core module of the 33-foot-diameter earth-orbit space station, which will be modified for use in lunar orbit, is shown in Figure 4. The core module contains three pressurized compartments (1) the compartment formed by decks 1 and 2, (2) the compartment formed by decks 3 and 4, and (3) the central tunnel. This feature ensures that a habitable environment is available if pressurization system fails in either of the two primary compartments. The tunnel serves as the primary traffic route for men and equipment between decks. The forward end of the core module contains the isotope/Brayton electrical power system in an unpressurized environment and a storage compartment (which may be pressurized for access).

Figure 4. Space Station Core Module

Lunar Application Modifications to Station

The impacts of the lunar mission on the baseline space station are shown in Table 1. As noted they are relatively minor, with the exception of the radiator change. The degradation in the radiator surface coatings (primarily caused by solar flare protons) reduces the thermal capability below that needed for a 25-kw system. The lunar-orbit station radiator surface should therefore be coated with second surface mirrors which have much better degradation characteristics. This modification requires that the dimpled meteoroid bumper be redesigned to a flat cylinder to facilitate the mounting of the mirrors. The size of environmental control/life support (EC/LS) system thermal capacitor must also be increased to accommodate the fluctuations in the thermal environment. Radiator performance in the lunar environment is one example of the unique subsystem characteristics in prospect for a space station in lunar orbit, as compared to the earth-orbit case.

Figure 5 shows typical earth-orbital space station transient radiator performance in the two most critical orbital situations and the application of thermal storage for the base with $\theta=0$ degrees to meet the outlet temperature requirement established for humidity control. Figure 6 presents typical lunar environmental data generated by the MDAC PO33 orbital heating program for a lunar-orbit station; the figure shows greater heat flux excursions and a higher average orbital heat flux than that encountered in earth orbit. Thus the lunar station has a very severe heat rejection problem, requiring some combination of: (1) increased radiator area and radiator segmentation, (2) a phase-change thermal capacitor to damp out the hot transient, and (3) alternate means of humidity control, such as desiccants or heat pumps.
The electrical power system (EPS) appears to be adequate, since 10.1 kw would be available for experiments. The surface coatings of the EPS radiator must be modified as defined for the EC/LS radiator.

The guidance, navigation and control (GNC) system requires additional sensors as indicated in Table 1 to meet the lunar orbit requirements.

The baseline structure subsystem is adequate in terms of radiation and meteoroid protection. An entire deck modification to accommodate a surface sample analysis laboratory is dependent on future emphasis on this experiment support and the possible need for contaminant control. Impact of this possible addition to the basic station module is not included in Table 1.

**Table 1.**

Lunar Mission Space Station Impacts.

<table>
<thead>
<tr>
<th>Item</th>
<th>Baseline Capability</th>
<th>Modification Needed</th>
<th>Disposition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiator coatings</td>
<td>Degradation in solar absorptivity due to lunar conditions</td>
<td>Replace ZnO coating with augmented absorptivity and modify nadir radiator to flat cylinder</td>
<td></td>
</tr>
<tr>
<td>Thermal power</td>
<td>25,000 W</td>
<td>Need 12,500 W</td>
<td>Design change 1, 000 W</td>
</tr>
<tr>
<td>Nuclear Power</td>
<td>Total 25 kw</td>
<td>None, experimental power probably adequate</td>
<td>--</td>
</tr>
<tr>
<td>Thermal power</td>
<td>Intermediate 10 kw</td>
<td>Long core cooling time, high thermal power experimental power to 1 kw</td>
<td></td>
</tr>
<tr>
<td>EPS radiator</td>
<td>Surface coatings degraded no change</td>
<td>Replace ZnO coatings with second surface material</td>
<td>Design change 2, 000 W</td>
</tr>
<tr>
<td>GNC power</td>
<td>Restricted</td>
<td>Horizon scanner Kit addition</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sun sensor Kit addition</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Horizon reimager optical filter Modify</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U/M and support for robotic vehicle</td>
<td>Limited</td>
<td>Increase sensor recovery</td>
<td>Kit addition</td>
</tr>
<tr>
<td>Hexagonal</td>
<td>100 degree mirror (17 one useable)</td>
<td>None</td>
<td>--</td>
</tr>
<tr>
<td>Meteors</td>
<td>0.01 probability of no penetration in 15 years</td>
<td>None</td>
<td>--</td>
</tr>
</tbody>
</table>

**3. Other considerations**

1. Optional locations
   a. Lunar surface
   b. Station

c. Experiment
d. Module

2. Selection criteria
   a. Vibration
   b. Sensitivity
c. Attitude
d. Control
e. Crew time
f. Weight
g. Volume
h. Transportation cost
i. Utility services

3. Other considerations
   a. Experiment procedure
   b. Duration
c. Interaction
d. Equipment
e. Time sensitivity
f. Specimen condition
g. Program cost
h. Program schedule
i. Base experiment plans
j. Decision support

These selections must be made early in the program to insure proper accommodation planning and effective integration.

**EXPERIMENTATION**

As the selection of candidate experiments has been accomplished by separate NASA activities, only the integration of such experiments is addressed here. Selecting the location of various experiment activities involves a number of factors as follows:

1. Optional locations
   a. Lunar surface
   b. Station

Lunar Surface

Manned and unmanned landers and rovers can make significant contributions to lunar exploration. A realistic analysis of the impact of lunar surface vehicles on the orbiting station requires the postulation of a candidate exploration program to provide not only system and support sizing but sensitivity data. Table 2 depicts an example of one type of program and the associated rationale. Note that the regions north and south of the prior Apollo equatorial landing areas are emphasized.
Every lander or rover taxes the resources of the orbiting station substantially. Rendezvousing, servicing during the docked mode, monitoring during ascent/descent and surface operations, and sample specimen and data handling all compound to place substantial crew, configuration, and subsystem requirements on the station.

Typical functions that might be performed by the landers and rovers are:

1. Sample collection
2. Observation, photography, and description of geologic features and lithologic types.
3. Compositional mapping.
4. Topographic measurements.
5. Gravimetric and magnetic traverses.
6. Temperature and heat flow measurements.
7. Seismic measurements.
8. Earth-produced tides.

Table 3 describes the experiment vehicle characteristics of a representative Space Tug lander payload which must be integrated into the experiment and operational functions prescribed for the station system.

On-Orbit Experiments

On board the station, experiment activities will consist of remote sensing, surface sample analysis and conceivably free-flyer experiment module support.

Surface Sample Analysis

The sizing of the laboratory is important as is potential bio-isolation of lunar samples. An example of a minimum-sized laboratory is shown in Figure 7, where one-half of a 33-foot-diameter floor provides segregated laboratory facilities located adjacent to docking airlocks and the remote sensor installation. This laboratory would require two specialists who would also participate in some of the surface sortie missions. Figure 8 illustrates a candidate layout and contents of a constituent analysis compartment in particular.

The sample laboratory could include local analysis of lunar material and preparation of same for shipment to earth. A flexible onboard analysis capability could be provided for these functions to accommodate a broad range of potential experiments. However, care must be exercised to preclude the incorporation of functions which are not really time-critical or those which are really done better and more economically on earth. Onboard analysis can provide compositional information to aid in the exploration program in regard to choice of sample collection sites, choice of areas for detailed study by remote sensing techniques, and providing ground truth information for the remote sensors. Onboard preliminary analysis can also aid in the selection of samples worth return to earth. This could involve returning only portions of selected rocks, with the remaining being stored onboard until earth analysis confirms the crew’s judgment. Onboard analysis also permits study of highly time-sensitive characteristics of the samples such as absorption isotherms for initially pristine surfaces and short-lived radionuclides.

A candidate priority list for the functions of a sample analysis laboratory might include:

1. Mineral and major element analysis.
2. Trace element, isotope, and trapped gas analysis.
3. Support of remote sensing program.
4. Study gas adsorption behavior of pristine surfaces.
5. Study of paleomagnetism.

Remote Sensing
Candidate sensor functions for lunar orbit have been defined in many studies. Some of the more pertinent of these as applicable to the orbiting station are given in Table 5.

Table 5.
Characteristics of Selected Candidate Instruments.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Spectral Range</th>
<th>Weight (lb)</th>
<th>Size (inches)</th>
<th>Power (watt)</th>
<th>Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metric camera</td>
<td>0.4 - 6.7µ</td>
<td>369</td>
<td>61 x 24 x 20</td>
<td>350</td>
<td>Understressed, close view (with or without windows) for terrain and atmosphere. Sensitivity to sun elevation &lt;75⁰. Film change accessibility can be outside station.</td>
</tr>
<tr>
<td>Panoramic camera</td>
<td>0.37 - 6.0µ</td>
<td>224</td>
<td>24 x 64 x 18</td>
<td>15</td>
<td>Same as for metric terrain camera</td>
</tr>
<tr>
<td>Multispectral camera</td>
<td>0.37 - 6.0µ</td>
<td>50</td>
<td>12 x 12 x 24</td>
<td>25</td>
<td>No windows, close and direct view of surface</td>
</tr>
<tr>
<td>Gamma and x-ray spectrometers</td>
<td>0.37 - 2.2µ</td>
<td>100</td>
<td>2 x 24 x 20</td>
<td>25</td>
<td>No windows, close and direct view of surface</td>
</tr>
<tr>
<td>Hy and Lyman a telescope</td>
<td>0.128µ - 0.131µ</td>
<td>100</td>
<td>2 x 6 x 5</td>
<td>2</td>
<td>No windows, close and direct view of surface and less extinction</td>
</tr>
<tr>
<td>UV-visible spectrometer (active/passive)</td>
<td>0.160µ - 1.6µ</td>
<td>100</td>
<td>2 x 12 x 10</td>
<td>45</td>
<td>Absorbed through windows/counter. Essential for active/passive measurements during night and day</td>
</tr>
</tbody>
</table>
| IR spectrometer (active/passive) | 6.4 - 6.4µ | 219 | 57.5 x 16.5 x 16 | 167 | No windows, close and direct view of surface, 6.4 - 2.4µ
| Microwave multipeak irradiation | 15, 22, 22, 22, 5, 5, 5, 4 GHz | 150 | 70 x 65 x 30 | 150 | Antenna outside, with close view of active/passive instruments |
| Microwave radar      | 8 - 18 GHz     | 520         | 108 x 6 x 4   | 2090       | Antenna outside, electronic range depends |
| VLF radiometer      | 1 - 18 KHz     | 1000        | 130 x 50 x 40 | 12000      | Antenna outside, electronic range depends |
| Laser range/          | 0.684µ        | 171         | 77 x 48 x 55  | 63        | Laser fired through or out through windows. Laser beam cut through over high targets |
| altimeter            |               |             |               |            |             |
| Argon ion laser      | Visu: 1.164µ, 5.164µ, 4.696µ, 0.469µ, 0.479µ | 600 | 10 x 9 x 3 | 2500 | Optically aligned with all range gates for interferometric use. Optional bias beam transmitted and reflected through windows. Laser fired through over high target |
| (Horace model)       | Meas: 0.163µ, 0.355µ | 600 | 12 x 12 x 10 | 4000 | Same as preceding |
| Wall laser (induced)| Visu: 1.19µ, 5.19µ | 500 | 12 x 12 x 10 | 4000 | Same as preceding |
| Mid IR: 0.355µ    |               |             |               |            |             |

Note: Electronic lasers provide lines adaptable over broad bands, or in a narrow common mode, ultimately have application here as active sources.

Some of the functions are not currently conventional in that a new, proposed mode involves the use of lasers as irradiation sources. This mode provides a number of advantages such as:

1. Full-time use of the spectrometers throughout every orbit or optionally at any time in orbit, day or night.
2. Optimum capability of obtaining sensing signature information by maximizing intensity and purity of spectral irradiation and minimizing background noise (particularly at night).
3. Optimization of spatial resolution by control of the irradiation beam cross-section and the irradiated target area. Feasibility of such an approach is being investigated.

Extra-Lunar Research

The accommodation of functions, such as radio astronomy, simultaneous solar and terrestrial emissions must be closely scrutinized as to location and resource allocation. The nature of the objectives and considerations of the astronomical experiments involved is as follows:

1. Objectives
   a. Faint radio object detection (lunar shielding of earth noise)
   b. Integrated optical emission of earth-sun (bolometry)
   c. High angular resolution radio interferometry (38 x advantage to earth)
   d. Broad-sky radio occultation (versus small lunar disc from earth)

2. Sensors and location
   a. Interferometry, occultation bolometry
   b. Lunar surface-detection (parabola, dipole, spiral, long-wire, yagi, mill cross)

3. Key location criteria
   a. Sensor size
   b. Observation period
   c. Crew involvement
   d. Lander duty cycle

OPERATIONAL ELEMENTS

The various operational functions of the orbiting station are depicted in Figure 9.

Interfaces

The orbiting station configurations and operations will be determined substantially by the interfaces with related systems. Figure 10 illustrates the direct and indirect relationships of the system complex.

Delivery Systems

A prime candidate for earth-to-earth-orbit delivery of the 33-foot-diameter station is the Saturn INT-21. The 15-foot diameter station modules would be delivered into earth orbit by the winged shuttle, and assembled there for subsequent cis-lunar transit. Delivery of the station from earth orbit to lunar orbit may be by nuclear shuttle, which involves unique support systems. For example, a propellant depot in orbit approximately 10 miles behind the station could initially serve as a refueling point for delivery of a heavy station and later as a primary rendezvous point for all logistics, with crew and cargo modules being subsequently shuttled to the station with their own propulsion on a space tug.

An intense radiation environment exists around the nuclear shuttle long after engine shutdown. It therefore appears that the shuttle should loiter no closer than 7 to 10 miles from the station unless relative orientation is very closely controlled. The nuclear shuttle power maneuvers, as in arrival at and departure from the station, must be controlled to preclude excessive radiation exposure.
Once the station is established in lunar orbit, logistics services will be provided by the winged shuttle for earth to earth orbit, and nuclear shuttle from earth orbit to lunar orbit.

Lunar Lander

The potential number, complexity, and relatively large size of the lunar lander tugs that operate from the station involve considerable interactions between the two systems. The tug will alternately rendezvous, park, and deploy from the station imposing numerous mutual requirements for configuration and operational features. Special controls and accommodations must be incorporated in the station for space tug rendezvous and docking. Access, monitoring, and checkout instrumentation, power and environmental provisions, and quiescent controls must be furnished by the station for the tug. Before deployment to the lunar surface, a formal pre-launch preparation and countdown for the space tug will consume considerable station crew time and checkout equipment, particularly for the second and subsequent launches, to ensure readiness and reliability. During descent and stay on the lunar surface, a considerable communications function will be exercised between the station and the tug. The flight mechanics and potential relationships between the two systems are particularly critical for communications contact and the staging of return ascent trajectories.

Since each tug will be reused a number of times, the servicing and maintenance for the space tug and its experiments are envisioned as consuming considerable crew time. One space tug crew capsule will also, in all probability, be parked continually at the station for emergency return to earth.

Figure 11 depicts the interactions between station and the Space Tug lander.

Data Relay Satellite

Since approximately one-half of the lunar-orbit station operation will take place behind the moon with respect to earth and thus out of communication contact, a data relay satellite system will probably be required for basic status monitoring. Additionally, the relative infrequency of logistics flights creates a heavy accumulation of experiment data during interim periods. A data relay satellite will not only help to relieve this data load, but it will also enhance the coordination time between investigators on the ground and the crew performing their experiments in the station.

Surface Base

The lunar-orbit station will perform many functions in support of buildup and operation of the lunar surface base which may be established approximately three years after station deployment. Initially the modules which constitute the lunar surface base will be deployed to the surface from the station, where they would have been docked after delivery from earth, checked out, and prepared for the landing. The lunar surface base crews in transit between the translunar shuttle and the base may utilize the orbit station as a way-station for transfer to and from the lander spacecraft. In operation the station will have communication links with the lunar surface base in support of information management, experiment support, crew safety, etc. The station will also serve a "shepherding" function for rovers which are deployed from the base. The station may also deploy unmanned "logistics drops" to extended traverse expeditions from the base or space tugs to rescue rover crews who are stranded at great distances from the base. Even after establishment of a lunar surface base, the station may still deploy landers to those areas which lie beyond the reach of base rovers (see Figure 12).

Thus, orbit station functions in support of this objective include: (1) select and prepare lunar surface base site, (2) perform surface base module landing operations, (3) support surface base logistics, and (4) support surface base operations.

Unaccessible from first base rovers, thus, remains station-based lander territory. Station will "shepherd" base rovers during traverses.
Crew Activities

An example of the 12-man crew activity profile and related crew skills is shown in Figure 13. The number of onboard experimenters is decreased when the lander vehicle is away from the station. Since the landing sorties are of very high priority, this manpower situation indicates the need for caution in forecasting the amount of experimenting performed on the station itself.

Figure 13. Crew Activity Profile

Propellant Depot

The weight of propellant in lunar-orbit storage at any time will depend upon the requirements for the nuclear shuttle, safety reserves, the tug and the propellant resupply timeline. This peak storage requirement could range from 60,000 to 220,000 pounds.

Greater flexibility of nuclear shuttle operation can be achieved by providing LH2 storage in lunar orbit. This allows variation in logistics payloads as the nuclear shuttle carries more or less propellant than it needs for its return to earth orbit. Expending all propellant on the outboard leg approximately doubles the payload delivery capacity of the nuclear shuttle. Any infrequent, especially large, payload can thus be delivered via this technique. For this mode, storage for about 100,000 pounds of LH2 might be required, i.e., 70,000 pounds for zero-payload return to earth orbit, plus safety reserves.

Current thoughts from nuclear stage studies are that propellant transfer would be low-g, with acceleration of the propellant supply module and the coupled nuclear stage in a direction perpendicular to the orbit plane, for a few orbit revolutions. Objectives and system approach candidates for this facility are summarized in Table 6. An example of a propellant management depot is shown in Figure 14.

Table 6

<table>
<thead>
<tr>
<th>Objectives</th>
<th>System Candidates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common terminal for nuclear and lunar lander shuttles</td>
<td>Discrete bipropellant tank farm</td>
</tr>
<tr>
<td>Decouple lunar lander from nuclear shuttle flights</td>
<td>Preferred propellant transfer mode—low g with pump (reliability and time)</td>
</tr>
<tr>
<td>Service lunar shuttle</td>
<td>Free-flying—separate from lunar-orbit station</td>
</tr>
<tr>
<td>Propellant resupply</td>
<td>Use elements common to other systems</td>
</tr>
<tr>
<td>Maintenance and replenishment</td>
<td>Lunar shuttle</td>
</tr>
<tr>
<td>Potential service to nuclear shuttle</td>
<td>Nuclear shuttle</td>
</tr>
<tr>
<td>Propellant depot—operational flexibility</td>
<td>Earth-orbit tank farm</td>
</tr>
<tr>
<td>Maintenance—reliability impact</td>
<td>Replacement tankage</td>
</tr>
<tr>
<td></td>
<td>(Lunar shuttle concept)</td>
</tr>
<tr>
<td></td>
<td>Dependent</td>
</tr>
<tr>
<td></td>
<td>Jettison tanks on lunar surface</td>
</tr>
<tr>
<td></td>
<td>Auxiliary tankage (run, and strap-on tanks increase flexibility)</td>
</tr>
<tr>
<td></td>
<td>Use extra lunar shuttle(s)</td>
</tr>
</tbody>
</table>

Effect of Environment on the Lunar-Orbit Station

Although the natural lunar environment is not expected to greatly affect orbit selection, the problem must be studied to ensure the application of comprehensive orbit selection criteria. The lunar-orbit station is exposed to various locally induced environments. For example, many vehicles will be docked at different times and operated within the general vicinity, creating various mass concentrations and collision hazards and, in the case of the nuclear shuttle, radiation hazards. The propellant depot also created potential explosive hazards.
The principal natural environment hazards will be galactic and solar cosmic radiation. The former comprises radiations sufficiently energetic that they cannot reasonably be shielded, and they will contribute 4 to 8 REM/year. The latter presents a significant problem chiefly at solar maximum, where the combination of a low dose criterion (25 REM to the blood-forming organs over a 6-month period) and low risk levels (i.e., 1 percent of missions will exceed the criterion) result in relatively large shield thickness requirements. These are of the order of 20 g/cm² of aluminum, assuming the vehicle shielding to be worth 12 g/cm² (similar to present Space Station studies). Recognition of the 25-REM blood-forming organ criterion as conservative could permit acceptance of higher risks of exceeding the criterion (i.e., no supplementary shielding is required if the risk is 10 percent); at higher risk levels a mission abort capability would suffice to protect astronauts against exposures exceeding the maximum acceptable level (i.e., 75 REM in 6 months).

CONCLUSION

Man's knowledge of the moon can be extended substantially and efficiently with a lunar-orbit space station which deploys surface landers. Although some of the operations of such a station are substantially different from those of an earth-orbiting station, a modified version of the latter will perform the mission effectively and provide many of the cost benefits inherent in the common usage of a vehicle in two programs.

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