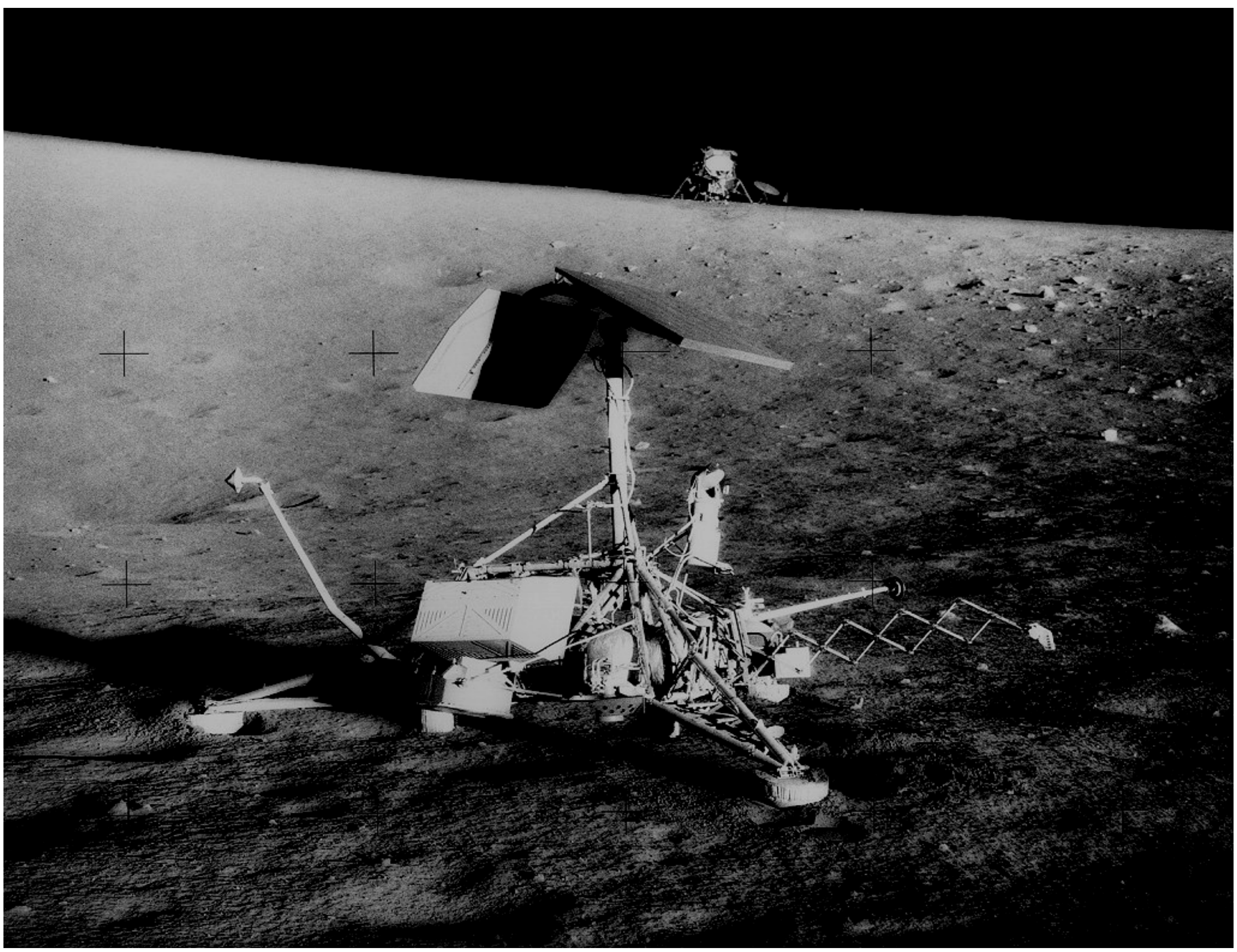
NASA's Recommendations to Space-Faring Entities:
How to Protect and Preserve the Historic and Scientific Value of U.S. Government Lunar Artifacts

Release: July 20, 2011



Revision and History Page

Status	Revision No.	Change No.	Description	Release Date
Baseline	13		Baseline	07/20/2011

HUMAN EXPLORATION & OPERATIONS MISSION DIRECTORATE
STRATEGIC ANALYSIS AND INTEGRATION DIVISION
NASA HEADQUARTERS

NASA'S RECOMMNEDATIONS TO SPACE-FARING ENTITIES: HOW TO PROTECT AND PRESERVE HISTORIC AND SCIENTIFIC VALUE OF U.S. GOVERNMENT ARTIFACTS

THIS DOCUMENT, DATED JULY 20, 2011, CONTAINS THE NASA RECOMMENDATIONS AND ASSOCIATED RATIONALE FOR SPACECRAFT PLANNING TO VISIT U.S. HERITAGE LUNAR SITES.

IT IS REQUESTED THAT ANY ORGANIZATION HAVING COMMENTS, QUESTIONS OR SUGGESTIONS CONCERNING THIS DOCUMENT CONTACT ROBERT M. KELSO, NASA JOHNSON SPACE CENTER, PHONE 713.213.3106 OR EMAIL ROBERT.M.KELSO@NASA.GOV

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SECTION A1 – PREFACE, AUTHORITY, AND DEFINITIONS

PREFACE

NASA recognizes the steadily increasing technical capabilities of space-faring commercial entities and nations throughout the world and further recognizes that many are on the verge of landing spacecraft on the surface of the moon. Representatives of commercial entities have contacted NASA seeking guidance for approaching U.S. Government (USG) space assets on the lunar surface – out of respect for hardware ownership, and a sincere desire to protect general scientific and historic aspects of these sites. Because there is no precedent for this situation throughout nearly 50 years of spaceflight, there are no USG guidelines or requirements for spacecraft visiting the areas of existing USG-owned lunar hardware regardless of condition or location.

Fortunately, there are several lunar experts across NASA and the scientific, historical, legal, materials, and flight-planning communities who can provide some initial guidance for these lunar endeavors. NASA has performed recent propellant/plume and lunar regolith impingement analyses and initiated a science evaluation that examined the risks and concerns of damage to the heritage Apollo landing sites resulting from future spacecraft descent/landing and associated surface and low-altitude flight mobility. From a scientific perspective, many sites are still active (e.g., Apollo retro-reflectors), and continue to produce material, biological, and physical scientific data associated with long-term exposure of human-created systems (e.g., witness plates) to the lunar environment. NASA has also considered impacts to non-Apollo USG lunar artifacts.

Until more formal USG guidance is developed and perhaps a multilateral approach is developed to reflect various nations' views on lunar hardware of scientific and historic value, NASA has assembled this document that contains the collected technical knowledge of its personnel – with advice from external experts and potential space-faring entities – and provides interim recommendations for lunar vehicle design and mission planning teams. As such, this document does not represent mandatory USG or international requirements; rather, it is offered to inform lunar spacecraft mission planners interested in helping preserve and protect lunar historic artifacts and potential science opportunities for future missions.

These recommendations are intended to apply to USG artifacts on the lunar surface – these artifacts include:

A. Apollo lunar surface landing and roving hardware;
B. Unmanned lunar surface landing sites (e.g., Surveyor sites);
C. Impact sites (e.g., Ranger, S-IVB, LCROSS, lunar module [LM] ascent stage);
D. USG experiments left on the lunar surface, tools, equipment, miscellaneous EVA hardware; and
E. Specific indicators of U.S. human, human-robotic lunar presence, including footprints, rover tracks, etc., although not all anthropogenic indicators are protected as identified in the recommendations.

Because of the relevance of these recommendations to current and future lunar elements deposited by other space-faring entities, NASA has begun engaging in dialogue with foreign space agencies, as appropriate.

LEGAL FRAMEWORK

The USG continues to maintain ownership of NASA hardware and other property on the surface of the moon, including the Apollo artifacts. These recommendations are not legal requirements; rather they are technical recommendations for consideration by interested entities. NASA seeks coordination in advance of lunar activities that would impact NASA artifacts of historic and scientific interest to ensure that all appropriate interests are recognized and protected. NASA recognizes that these recommendations may evolve and welcomes the opportunity to work with foreign space agencies and other entities planning robotic lunar missions. As part of the USG, NASA is committed to meetings USG responsibilities under international law.

U.S. law authorizing NASA to make these recommendations include the following:

- *National Aeronautics and Space Administration Act*
- *2010 NASA Authorization Act*
- *United States Constitution --"Property Clause"*
- *Federal Property and Administrative Services Act of 1949, as amended*
- *General Services Administration Regulations*
- *18 U.S.C. 7*

These recommendations are consistent with international law, including the following: *The 1967 U.N. Outer Space Treaty (OST), which provides, in part:*

- That outer space shall be free for exploration and use by all states;
- That there should be freedom of scientific investigation in outer space;
- That outer space is not subject to national appropriation;
- That parties to the treaty retain jurisdiction and control over objects launched into outer space that are listed on their registries, while they are in outer space and that ownership of objects launched into outer space is not affected by their presence in outer space or by their return to Earth;
- That nations be guided by the principle of cooperation and mutual assistance in lunar exploration and use, with due regard to the corresponding interests of other parties to the treaty; and
- That international consultations must take place prior to the commencement of an activity that any party has reason to believe would cause potentially harmful interference with activities of other parties.

APPROACH: NASA is seeking to promote the development and implementation of appropriate recommendations, such as those provided herein, with interested private sector entities and, as appropriate, working within the USG and with foreign governments.

DEFINITIONS

A1-1 DISTURBANCE

The term "disturbance" in this context means: to effect a change or perturbation to the site artifacts resulting in loss of historic and scientific processes and information. Some spacecraft operations, like descent/landing or overflight, can result in significant damage to the site artifacts; while other operations (e.g., a rover traversing an Apollo site) could result in significant loss to the scientific value of the site.

> ***RATIONALE:***
> *Since the completion of the Apollo lunar surface missions in 1972, no missions have returned to visit these historic sites, leaving them in pristine condition and undisturbed by artificial processes (the sites have changed due to normal space weathering). It is anticipated that future spacecraft will have the technology and their operators will have the interest to visit these sites in the coming years. These visits could impose significant disturbance risks to these sites, thus potentially destroying irreplaceable historic, scientific and educational artifacts and materials.*
>
> *A site may include multiple areas of interest, depending upon the specific mission. For example, the Apollo 11 site can be easily included within a single boundary whereas the Apollo 17 site, with additional mobility provided by the lunar rover, may include multiple boundaries around the landing area as well as around each of the traverse sampling sites.*

A1-2 APPROACH PATH

The 'approach path' is defined as the intended path of the spacecraft, plus the width of the three-sigma dispersion for the path.

A1-3 DESCENT/LANDING (D/L) BOUNDARY

The D/L boundary is defined as the outer perimeter that establishes a keep-out radius for the approach path of any lander/spacecraft toward any USG heritage lunar site.

- For heritage lander sites (e.g., Apollo, Surveyor): This boundary thus defines an area beginning at the lunar surface site of interest and extending to a 2.0 km radial distance from the site where no overflight of a landed spacecraft may occur.
- For the heritage impact sites (e.g., Ranger, S-IVB): This boundary thus defines an area beginning at the lunar surface site of interest and extending to a 0.5 km radial distance from the center of the impact site where no overflight of a landed spacecraft may occur.

This boundary prevents the plane of the descent trajectory from crossing into the keep-out radius at any point during the descent, thus remaining tangential to the boundary. It is incumbent on each visiting spacecraft to ensure no intrusion into this boundary during descent and landing, including nominal and off-nominal operations.

> ***RATIONALE:***
> *The 2.0 km keep-out radius applies to the descent/approach path of the visiting vehicle to address three main concerns during descent:*

1. *Overflight – possibility of creating high-velocity particles during descent, directly impinging plume on the heritage site*
2. *Near overflight – exhaust-blown dust onto the site*
3. *System failure during descent – collision potential / dust creation*

The first two scenarios occur near the surface, and the ejecta flux protection of the 2.0 km touchdown keep-out radius will prevent those.

For the third scenario: In case of a complete loss of thrust, the instantaneous impact point (IIP) of the vehicle lies in the plane of the trajectory. Generally the IIP lies downrange of the landing target, but there are some cases in which it is up-range, depending on the descent trajectory. A reasonable constraint would be to require that the plane of the descent trajectory not cross into a similar type of keep-out radius at any point during the descent. This requirement would cover the overflight concerns (1 and 2 above) as well.

With reference to the impact sites, a 0.5 km distance is selected to allow closer D/L targeting than is allowed for the USG heritage lander sites (Apollo, Surveyor). The heritage lander sites have flight hardware that is elevated above the lunar surface, exposing it to high-velocity particle impacts created by the descent engines. However, the impacts sites sit much farther below the surface terrain and are less likely to be damaged by the ejecta particles resultant from the arrival of the visiting vehicle.

A1-4 ARTIFACT BOUNDARY (AB)

The AB will be established to specifically encompass all artifacts at a particular site to prohibit interaction/visitation within that area in order to protect the artifacts of interest: descent stage, lunar rover, flag, Apollo Lunar Surface Experiments Package (ALSEP) experiments, etc.

A1-5 VISITING VEHICLE SURFACE MOBILITY BOUNDARY (VVSMB)

The VVSMB defines the specific areas for each heritage site where surface mobility is recommended to assess/examine the artifacts of the site without disturbing the site/artifact and without directly contacting any of the hardware in the AB. The surface mobility boundary will be determined to allow the maximum recommended access for scientifically assessing the artifacts of the site while ensuring minimal disturbances. These boundary conditions will vary by site, depending on the site's historic value, and will contain the artifacts within the specified artifacts boundary areas.

A1-6 OVERFLIGHT

Overflight is defined as the specific flight path of an entering spacecraft or braking stage that results in a trajectory over the heritage site (D/L boundary).

A1-7 CONTAMINATION

Contamination is the act of depositing chemical, biological or physical material onto artifacts at the heritage site such that the deposition reduces its historical, engineering, or scientific value. Contamination can take on several forms, including surface particulate, non-volatile residue, volatile hydrocarbons, and microbial.

Analysis of returned Surveyor 3 spacecraft parts showed chemical contamination from Apollo 12 LM exhaust compounds (Reference: NASA-SP-284, 1972).

A1-8 REFERENCE SYSTEM

Each lunar spacecraft should have an onboard reference system to identify the physical location description of the D/L, AB and VVSMB. Such a reference system will assist in ensuring that all visiting spacecraft have knowledge of the identified boundaries.

A1-9 KEEP-OUT ZONE

A **keep-out zone** is the recommended boundary areas into which visiting spacecraft should not enter. It is desirable to isolate certain locations relative to the D/L, AB and VVSMB from visiting spacecraft. A particular zone's radius will vary as a function of the artifact and site location.

SECTION A2 – DESCENT AND LANDING (D/L)

Recommendations Format

The recommendations presented in this document are provided in topical sections with indented recommendations and rationale, as applicable. Recommendations are synopses of NASA and subject matter expert opinions; rationales capture explanatory comments supporting the recommendation and any associated analysis.

TARGETING

A2-1 APPROACH PATH

RECOMMENDATION:
The approach path for the D/L trajectory should be tangential to the D/L boundary in order to protect the site from off-nominal descent/landing situations.

***RATIONALE**:*
The 2.0 km keep-out radius applies to the descent/approach path of the visiting vehicle to address three main concerns during descent:

1. *Overflight – possibility of creating high velocity particles from the descent where there could exist direct plume impingement on the heritage site*
2. *Near overflight – exhaust-blown dust onto the site*
3. *System failure during descent – collision potential / dust creation*

The first two scenarios occur near the surface, and the spirit of the 2.0 km touchdown keep-out radius will prevent those.

For the third scenario: In case of a complete loss of thrust, the instantaneous impact point (IIP) of the vehicle lies in the plane of the trajectory. Generally the IIP lies downrange of the landing target, but there are some cases in which it is up-range, depending on the descent trajectory. A reasonable constraint would be to require that the plane of the descent trajectory not cross into a similar type of keep-out radius at any point during the descent. This requirement would cover the overflight concerns (1 and 2 above) as well.

By specifying a keep-out radius for the approach plane, it would still permit a large number of different approach paths to the site. Mission designers could then design the descent trajectory geometry (inclination and ascending node combination) such that the plane does not cross within this keep-out radius. More specifically, it would be the plane with appropriate error bounds drawn to cover for anticipated dispersions.

A 0.5 km keep-out radius applies to the descent/landing path of the visiting vehicle to any of the USG heritage impact sites. This distance allows closer targeting (versus the heritage lander sites) for both lander/rover and hopper configuration landers.

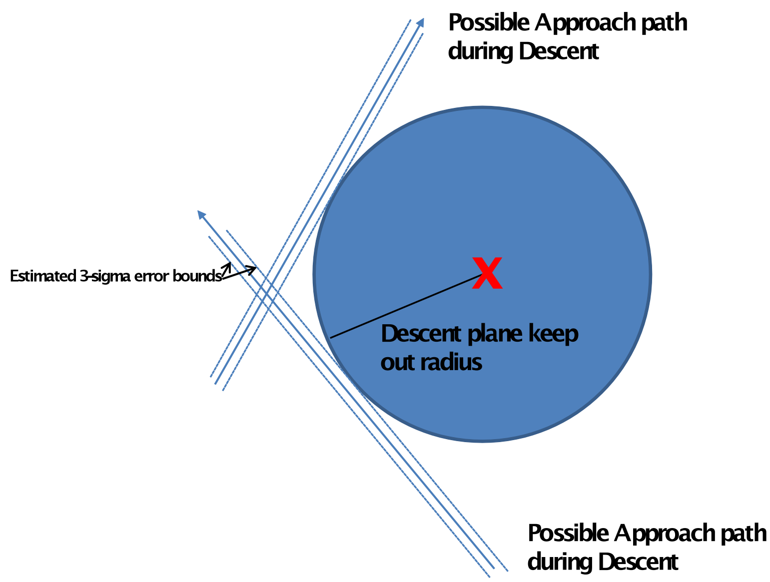

Figure 1: Possible Approach Path Scenarios

A2-2 NO OVERFLIGHT

RECOMMENDATION:
The visiting vehicle trajectory should remain tangential to the D/L boundary to ensure no overflight of the heritage sites as defined by the D/L boundary.

RATIONALE:
Overflights of the USG lunar artifacts could result in unwanted deposition of un-burned propellants and possible collision with the site due to trajectory/navigation errors. Overflight could also create a situation in which unexpected engine failure results in an uncontrolled trajectory into (or too close to) the USG lunar artifacts.

A2-3 TOUCHDOWN TARGETING

RECOMMENDATION:
Touchdown / impact points (IP) should be targeted to a distance of no less than 2.0 km or three-sigma of the landing uncertainty (whichever is greater) from any USG heritage landers in order to avoid intrusion into the sites during landing and to place the landing point “over the lunar horizon”. This should include consideration for ensuring that the maximum dispersion ellipse maintains the no-closer-than 2.0 km distance.

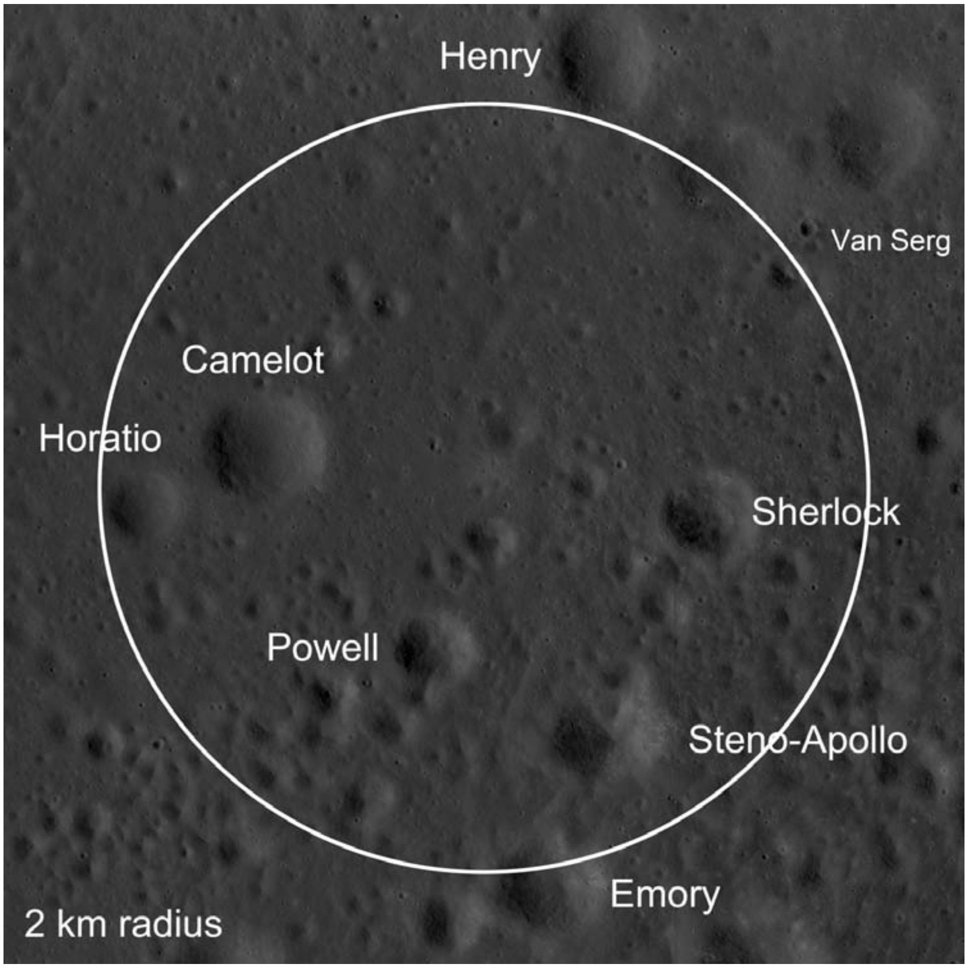

Figure 2: Example of 2.0 km D/L Keep-out Radius at Apollo 17 Taurus-Littrow Landing Site.

RATIONALE:

NASA analysis using gas flow codes has indicated that rocket exhaust plumes from the landing stages can induce high injection velocities of the top layer of the lunar surface; this analysis is further supported by the mathematical analysis performed prior to the Apollo program before such codes were developed. The plume modeling also predicts that the impingement from the descent engine(s) on the loose lunar material creates a nearly flat sheet of blowing material, a broad cone of particulate ejecta that rises at an angle between 1 and 3 degrees elevation above the local terrain on all sides around the landing spacecraft. This predicted ejection angle of 1 to 3 degrees is confirmed by photogrammetric techniques applied to the blowing dust clouds seen in the descent videos of the Apollo landings.

Analysis further indicates that these particles can achieve ejection velocities between 300 and 2000 meters per second (m/s) with the smaller particles generally traveling faster. Because there is negligible ambient lunar atmosphere outside the plume, the particles continue at that velocity until striking the lunar surface far away. Some particles travel almost all the way around the moon before impact. The smallest, dust-sized particles achieve near-lunar escape velocity, 2.37 km/s, and even exceed it by a significant margin, sending them into solar orbit, according to some plume simulations. These conclusions are corroborated by the observations of the Apollo crews. Several *crew members reported that the blowing material was a flat sheet close to the surface, so that rocks could be seen through the sheet and/or protruding through the top of it. During Apollo 11, Buzz Aldrin reported that while this material was blowing, the lunar horizon became "obscured by a tan haze," which indicates that the ejected particles were moving fast enough to travel over and beyond the horizon. For the dust-sized particles, the highest velocity achieved is equal to the plume gas velocity, which depends on its combustion temperature and thus chemical composition and, to a lesser degree, the vehicle's thrust. Thus, a smaller landing vehicle (with comparable propellants) can eject dust-sized particles at comparable velocities, although in lower quantities (mass) per second.*

Careful review of the landing videos, and comparison to plume modeling, shows that gravel and rocks 1 cm to 10 cm in diameter were also ejected by the plume at speeds between 5 and 50 m/s. Ballistic calculation indicates that these rocks impacted the lunar surface up to 1.5 km from the LM. It is the inertia of these larger particles (in contrast to the low inertia of dust-sized particles) that prevents them from achieving velocities comparable to the plume gas before they run out of the plume into lunar vacuum. Thus, for a smaller lander with less thrust (lower plume gas density), the rocks and gravel will achieve an even smaller fraction of the plume gas velocity and will travel a shorter distance from the landing site. Vehicles larger than the LM could eject rocks a greater distance.

Experiments have shown that lunar soil is highly abrasive and effective as a sandblasting medium. The Apollo 12 LM landed 155 m from the Surveyor 3 spacecraft and retrieved material samples from the spacecraft for later analysis. Even though Surveyor was in a crater and below the horizontal plane by 4.3 m and thus "under" the main sheet of material blown from the LM, the Surveyor spacecraft received significant sandblasting and pitting from the Apollo landing. This suggests that collisions between the ejected particles within the main dust sheet scattered them out of that sheet into a much broader but lower-density spray than described above, and it was the scattered particles that impinged on the Surveyor. Comparison with the optical density of the blowing soil indicates that if the Surveyor had been directly impinged by the main sheet, it would have sustained several orders of magnitude greater surface damage, including dust implantation, scouring, pitting, cracking, and microscopic crushing of the surface materials. Thus, the Surveyor's damage under-represents the degree of damage that could have occurred from an LM-sized vehicle's plume at that distance. Also, the damage to the Surveyor would have been greater if any of the ejected gravel pieces or rocks had struck it (the odds of such an occurrence have not yet been quantified).

Other cases of plume impingement effects have been documented in addition to the Surveyor damage. These include two cases (Apollo 15 and 16) where the launch of the Apollo LM Ascent Stage (AS) blew blankets that had been left on the surface, and the blankets almost impacted and damaged the deployed scientific instruments. O'Brien reported that when the AS lifted off in both Apollo 11 and Apollo 12, the solar cells in the Dust Detector Experiments (DDE) had an immediate change in their received sunlight – sometimes less and sometimes more – attributable to dust being delivered to or knocked off the cells, respectively. In Apollo 11, the DDE was 17 m away from the LM, and in Apollo 12 it was 130 m away. At the latter distance, the plume gas would be too rarefied to have much effect, so the observed removal of dust from the DDE was due to the impingement of high-velocity ejecta.

At every distance from a spacecraft landing on the Moon, there will be ejected particles that impact at that distance. At large distances the impingement flux becomes small and eventually negligible. However, requiring large distances to protect the Apollo sites could make it impractical for missions to visit them. A landing distance that is specified as a means to protect the sites while still enabling access must be a compromise that reduces the impingement effects without entirely eliminating them. The lunar horizon is roughly 1.8 km from any given point on the lunar surface. By targeting the landing point at 2.0 km from the closest lunar artifact, the main sheet of high-velocity dust-sized particles – which constitutes the largest fraction of the lunar soil – will fly over the top of the artifact site and thus minimize direct impingement. Larger rock or gravel-sized ejecta, which will travel at lower velocities, will impact the lunar surface well short of the horizon, thus also missing the artifact site. The intermediate range of particle sizes (larger, sand-sized particles), which will travel over the horizon but with sufficient downward curvature to strike the artifact site, are a minority fraction of the lunar soil and will have a much lower flux density at impingement from that distance than if the spacecraft were landing closer, thus reducing damage.

A2-4 DISPOSAL OF BRAKING STAGE(s)

RECOMMENDATION:
The disposal of all deorbit braking stages should be targeted tangential to the D/L boundary to ensure no overflight of a heritage site and to ensure that the IP is greater than 2.0 km from the heritage site (0.5 km for impact sites).

RATIONALE:
Minimize collision potential and the creation of dust clouds within the historic and scientific sites.

A2-5 USE OF NATURAL TERRAIN BARRIERS

RECOMMENDATION:
If possible, natural lunar terrain barriers such as hills, crater rims, ridges, or terrain slopes should be used to block the spray of the landing spacecraft. Note that use of natural terrain barriers does not change the D/L boundary recommendations.

RATIONALE:
The recommended 2.0 km landing distance reduces but does not entirely eliminate impingement of high-velocity particles. Degradation of the lunar artifacts by ejecta impingement is a cumulative and irreversible effect. It is expected that with increasing access to the lunar surface these sites may be visited frequently, which over time will significantly multiply the effect. Therefore, it is desirable to further reduce impingement to as low as reasonably achievable (ALARA) by taking advantage of natural barriers to block the spray. Changes in terrain slope can "ramp" the ejecta into a higher ejection angle so that a larger fraction will fly over the top of the protected site. Natural barriers

can block the direct flux of larger particles that curve downward as they cross the horizon, preventing them from reaching the site. It should be noted that the barriers will absorb the momentum of larger impinging particles, but in lunar vacuum, barriers will simply scatter the dust-sized particles without significantly reducing their velocity. It may be possible that using a barrier to scatter the main dust sheet could result in more dust-sized material raining down onto the protected site than if the 2.0 km distance were the only method of mitigation. Dust-sized particles that scatter and then rain down on the site will impinge with no significant reduction in velocity. Further analysis could determine in particular cases of various terrain features whether they reduce or increase the dust impingement at the site, and if they increase the impingement, it could be determined whether that increase is outweighed by the barrier's blockage and absorption of the larger-sized particles that would have otherwise curved over the horizon and hit the protected site.

A2-6 COLLISION AVOIDANCE WINDOWS

RECOMMENDATION:
An analysis specific to the landing vehicle should be performed prior to selecting the landing time and location, in order to determine whether its ejected soil and dust will reach altitudes where it may damage lunar orbiting spacecraft; if so, collision avoidance (COLA) windows should be implemented to prevent landing with the precise timing that could damage those spacecraft.

RATIONALE:
From a hypervelocity impact perspective, there may be a concern for damage to sensitive satellite surfaces such as optics (e.g., camera lenses, star trackers, windows, solar cells), and thin materials that should not be perforated in order to function (e.g., light-tight enclosures, thermal insulation). The level of concern would depend on the specific hardware component function, impact sensitivity, and failure criteria.

Analysis shows that, depending on the specifics of the lander's propulsion system, ejected dust may exceed altitudes typical of lunar orbiting spacecraft, and perhaps even exceed lunar escape velocity. Analysis further shows that the density of this ejecta, when it reaches orbital altitudes, is still sufficient to cause numerous impacts on a passing spacecraft. These impacts will be in the hypervelocity regime due to the high relative velocity of the ejecta and the spacecraft. The effects of such impacts are unknown at this time, but might cause significant harm to sensitive features of the spacecraft such as scientific optical instruments. Therefore, to avoid causing damage, an analysis using the particular propulsion system characteristics should be performed to determine the ejecta velocity and the time it will take the ejecta to reach and then pass through the orbital trajectories of each spacecraft in lunar orbit at that time. The particular times that those spacecraft also pass through those intersection points, minus the travel time of the ejecta to get there, determines the landing times that should be avoided. The COLAs will be defined as the windows of time with adequate margin (typically only a few minutes) to avoid landing at that particular location on the moon on that date. NASA has developed software tools to perform this analysis.

A2-7 LANDER ORIENTATION FOR FINAL APPROACH/LANDING RELATIVE TO THE U.S.HERITAGE SITE (multi-engines descent case)

RECOMMENDATION:
Given a multi-engine lander, a reference system is defined to place an axis through engines 1 and 3 and another axis through engines 2 and 4. The lander should be placed in an orientation for final approach/landing such that either of the two-engine axes is directly aligned with the USG lunar heritage site (green arrows in Figure 3). Thus, during low-altitude trajectories, the plume reflection planes would be pointed away from the lunar heritage site.

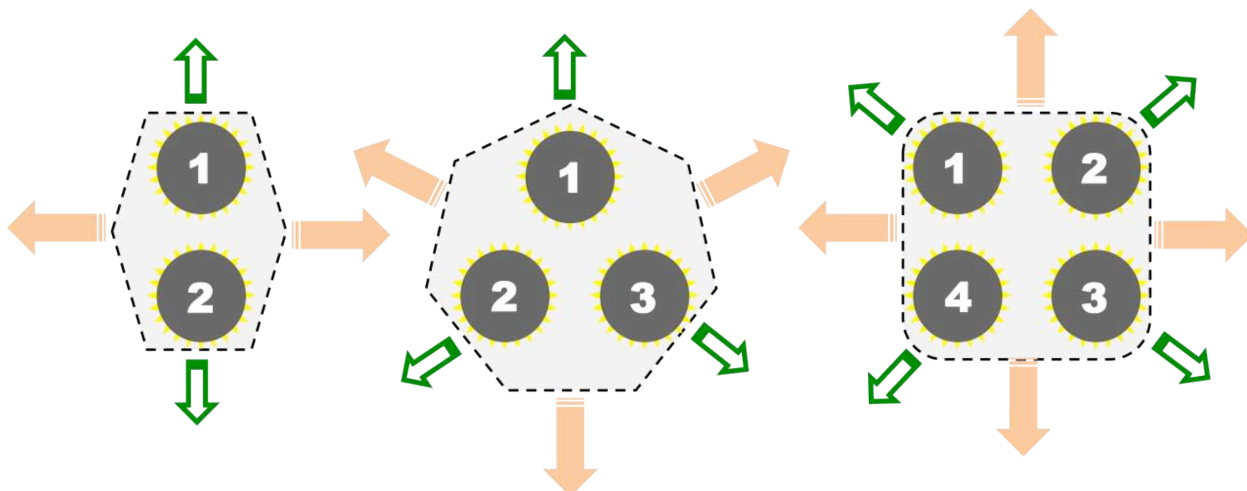

Figure 3: Diagram of multiple engine spacecraft ejecta paths – orange (solid) arrow denotes direction of maximum ejecta flux 'rooster tail' along plume reflection planes. Open (green) arrow identifies direction of minimum ejecta flux.

RATIONALE:
Recent analysis has indicated that the multi-engine lander case creates an exaggerated effect on the lunar soil. The plume interaction between the multiple descent engines creates a "rooster-tail" of blown particles unlike the single engine case. This rooster tail thus produces particle trajectories in multiple angle trajectories rather than the particle sheet of 1 to 3 degrees from the local horizontal as seen in the single engine case.

Numerical simulations show that soil erosion is ejected at a much higher flux, much higher angles above horizontal, and at much higher velocities along these planes than compared to the ejection of particles form a single engine lander. The particles ejected along these planes travel much longer distances and would strike the Apollo sites with higher impingement flux and higher impact velocities, causing much greater damage than would occur in the single-engine case. Further analysis is required to quantify this effect, but the safe landing distance limit and safe flyby altitude limit are based on the single-engine case, and therefore the flux along the plume reflection planes will significantly exceed the intent of those limits. Keeping the vehicle oriented so that Apollo site is always midway between its plume reflection planes will ensure the least amount of damage to the site.

SECTION A3 – MOBILITY

ROVERS/HOPPERS/KEEP-OUT ZONES

MOBILITY

A3-1 GENERAL OVERVIEW – HISTORICAL PERSPECTIVE PER APOLLO SITE

RECOMMENDATION:
While all the Apollo sites represent significant historical/heritage value in material culture, the Apollo 11 and 17 landing sites carry special historical and cultural significance. It is recommended that the sites for Apollo 11 and 17 be treated as unique by prohibiting visits to any part of the site and that all visiting vehicles remain beyond the artifact boundaries (AB) of the entire site.

RATIONALE:
Apollo 11 was a pivotal event in human exploration and technology history. Apollo 11 marked the first human flight to the lunar surface; Apollo 17 represented the last within the Apollo Program. Project Apollo in general, and the flight of Apollo 11 in particular, should be viewed as a watershed in human history and humanity. It was the first instance in human history in which emissaries from this planet visited another body in the solar system. It represented the culmination of years of effort, the significant expenditure of life and resources, and the opening of a new age in human history. The site of that first landing requires preservation; only one misstep could forever damage this priceless human treasure.

A3-2 KEEP-OUT ZONE – APOLLO 11 & 17 SITES

RECOMMENDATION:
It is recommended that the Apollo 11 and 17 sites be protected by ABs, and thus restricted from close inspection by visiting robotic systems. The visiting vehicle mobility exclusion boundary will encompass all artifacts (hardware, footprints, etc.) for these sites.

A. For the Apollo 11 site, the keep-out zone extends 75 m from the lunar module descent stage to encompass all hardware and human activity (Figure 4).
B. For the Apollo 17 site, the keep-out zone extends 225 meters from the lunar module descent stage (Figure 5).

RATIONALE:
It is desired to maintain the integrity of the Apollo 11 and Apollo 17 sites. Since the Apollo 11 site is of great historic significance and yet is fairly contained for the hardware and footprints, landers may touch down over the horizon to protect the site from damage, and mobility systems can approach the site as long as they remain outside the larger mobility exclusion zone. The 75 m radius for Apollo 11 ensures that all human activities for that flight are contained within the keep-out zone.

It is desirable to also isolate an Apollo J-mission site. Since Apollo 11 was the first site and Apollo 17 the last site, this recommendation preserves and protects each site for future scientific investigations.

Also note that the Apollo 11 ALSEP retro-reflector continues to be an active scientific experiment and can be easily degraded by particulate and chemical contamination.

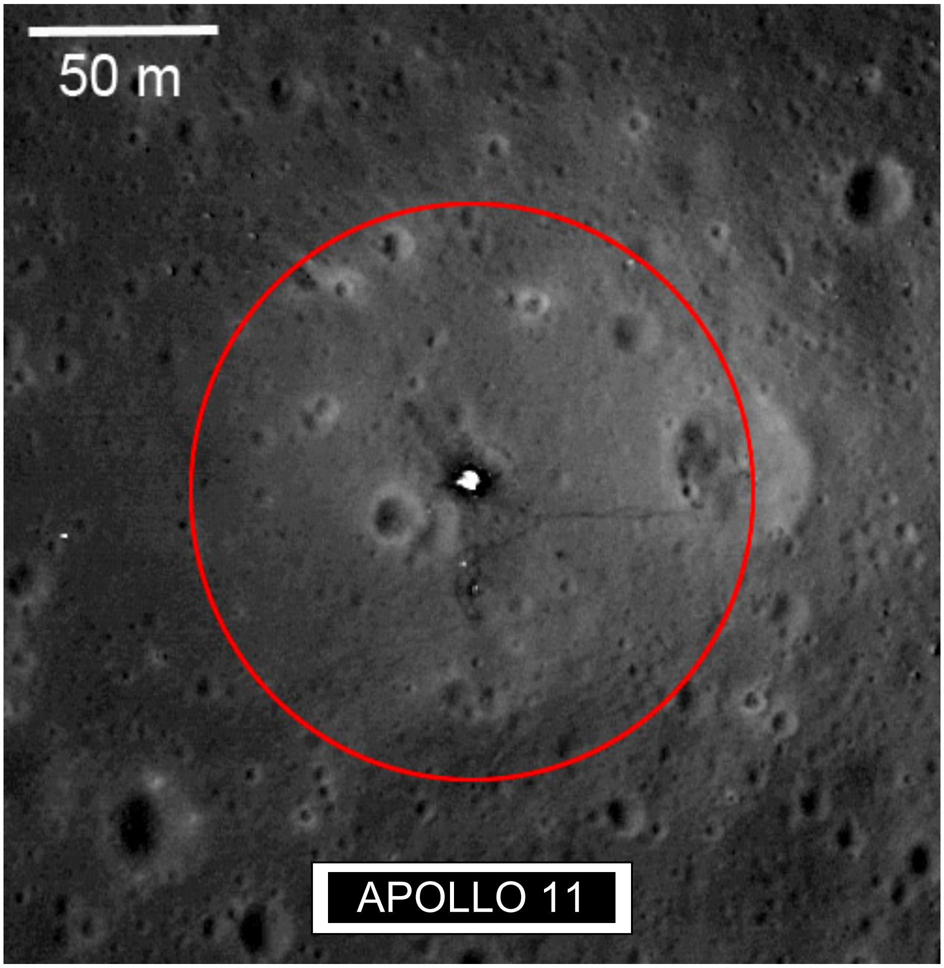

Figure 4: Apollo 11 AB extends 75 m from the LM descent stage.

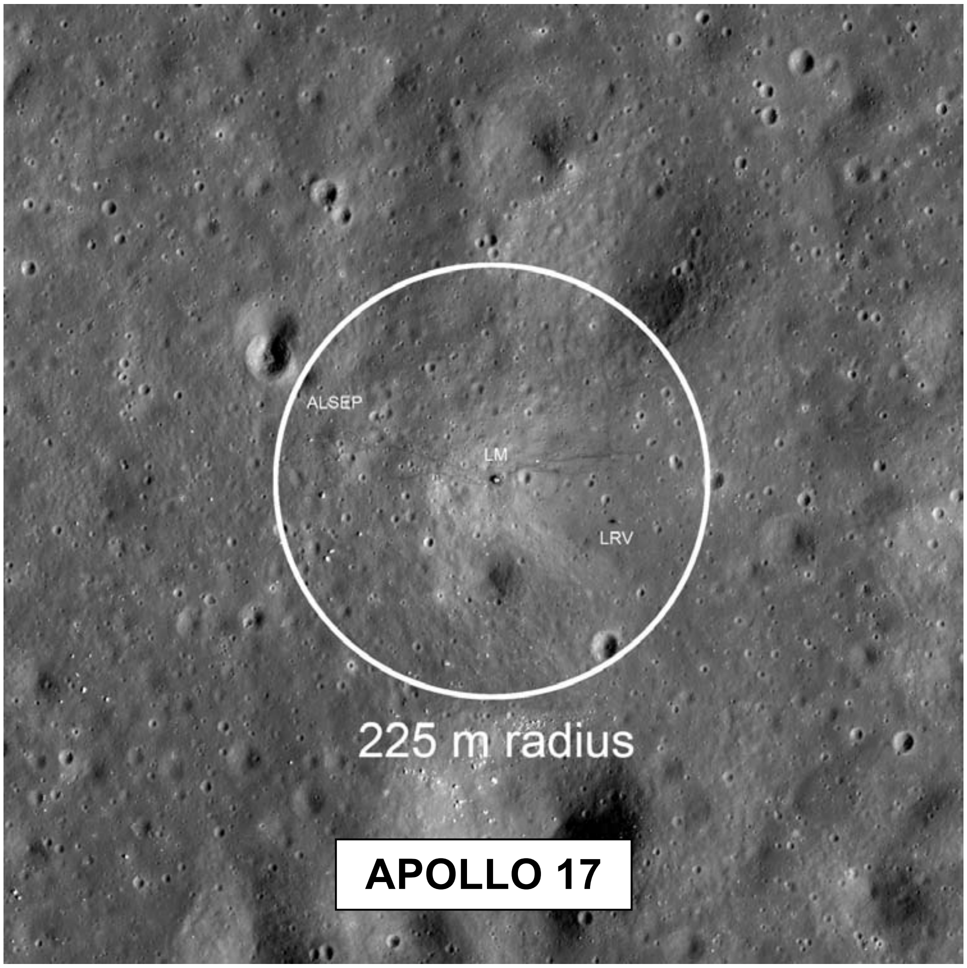

Figure 5: Apollo 17 AB extends 225 m from the LM descent stage.

<u>*A3-3 KEEP-OUT ZONE – APOLLO 12, 14-16 SITES*</u>

RECOMMENDATION:

A. More access should be provided to individual components/artifacts at the Apollo 12, 14-16 sites in order to allow for enhanced scientific and exploration-based assessments. The following keep-out zones have been identified by component/type:
- Descent stage – 3 meters buffer distance
- Lunar rover (LRV) – 1 meter buffer distance
- ALSEP experiments – 1 meter buffer distance
- Sampling sites – 1 meter buffer distance
- All other artifacts (flag, tools, storage bags, etc.) – 1 meter buffer distance
- No restrictions on footprints/LRV tracks outside the indentified keep-out zones.

RATIONALE:

The Apollo lunar artifacts are still considered ongoing experiments in space weathering. The identified keep-out zones allow for close inspection of the artifacts while still preserving their scientific integrity. Also note that the Apollo ALSEP retro-reflectors continue to be active scientific experiments and can be easily degraded by particulate and chemical contamination.

RECOMMENDATION:

B. The laser ranging retro-reflectors (LRRRs) should be carefully preserved (See Section A2). LRRR experiments are found at the Apollo 11, 14, and 15 sites (as well as the Soviet Lunokhod 1 and 2 rover sites). The LRRRs should be treated as special cases with approach mobility being tangential to the site. Once within a 10 m radius zone of the LRRR, mobility can only proceed at speeds that do not propel regolith particles in front of the rover (see Section A3-7) up to the total exclusion zone of 1 m radius around the retroreflector. Direct approach to the LRRR is not recommended.

RATIONALE:

While all landing/artificial impact sites have historical value, it should be recognized that the Apollo-era lunar Laser Retro-Reflector Ranging (LRRR) experiment is still ongoing, with laser ranging to passive retroreflectors placed on the lunar surface.

The lunar LRRR experiment measures the distance between the Earth and the moon using laser ranging. Since these are active experimental stations, NASA prefers to not risk compromising or contaminating these activities through robotic visits. It should be noted that a physical disturbance would affect 40 years of LRRR data continuity. The stability of the reflectors is critical to a variety of geophysical and relativistic physics problems. It is essential that these sites not be disturbed, however, careful observations of their current state would allow scientists a better idea of what is causing the degradation in the laser return signal, but also help in designing the next generation of LRRRs.

Five lunar sites contain LRRRs: Apollo 11, 14, and 15; and two Soviet Lunokhod Rovers deployed by Luna 17 and 21. Accidental deposition of dust on the surfaces of these LRRRs or sandblasting of the retroreflector surfaces would seriously diminish the science return because, as noted by Williams and Dickey (2003)[1], many of the science parameters derived from laser-ranging data are very sensitive to time span (i.e., the longer time that data are gathered, the better the science return). However, science can be enabled by close-range (<10 m) of the current LRRRs because over the 40 years that they have been on the lunar surface, degradation of the return signal has been observed (Murphy et al., 2010)[2]. Close-range observations of the retroreflectors could determine if this is due to increased dust deposition or radiation damage because of the long-term exposure to the space environment (see Section A3). However, the descent and landing of any visiting spacecraft to these sites should not disturb the retroreflector equipment to preserve the existing data integrity.

1 Williams J.G. and Dickey J.O. (2003) Lunar geophysics, geodesy, and dynamics. 13th International Workshop on Laser Ranging.

2 Murphy T.W. Jr., Adelberger E.G., Battat J.B.R., Hoyle C.D., McMillan R.J., Michelsen E.L., Samad R.L., Stubbs C.W., and Swanson H.E. (2010) Long-term degradation of optical devices on the Moon. Icarus 208, 31-35.

A3-4 KEEP-OUT ZONE – SURVEYOR SITE

RECOMMENDATION:
A 1 m buffer keep-out zone should be in effect around all Surveyor spacecraft hardware.

A3-5 KEEP-OUT ZONE – IMPACT SITES

RECOMMENDATION:
While rovers may drive to the rim of the impact crater and observe, it is recommended entry into the impact crater not occur without prior NASA coordination.

RATIONALE:
It is common practice for the Mars Exploration Rovers (MER) Spirit and Opportunity to rove up to a crater rim, and track around the rim prior to entering a given crater. For the Ranger and S-IVB impact craters, an important scientific objective is to examine in the crater and observe the morphology (because they look different from natural impact craters) and to map out the distribution of debris.

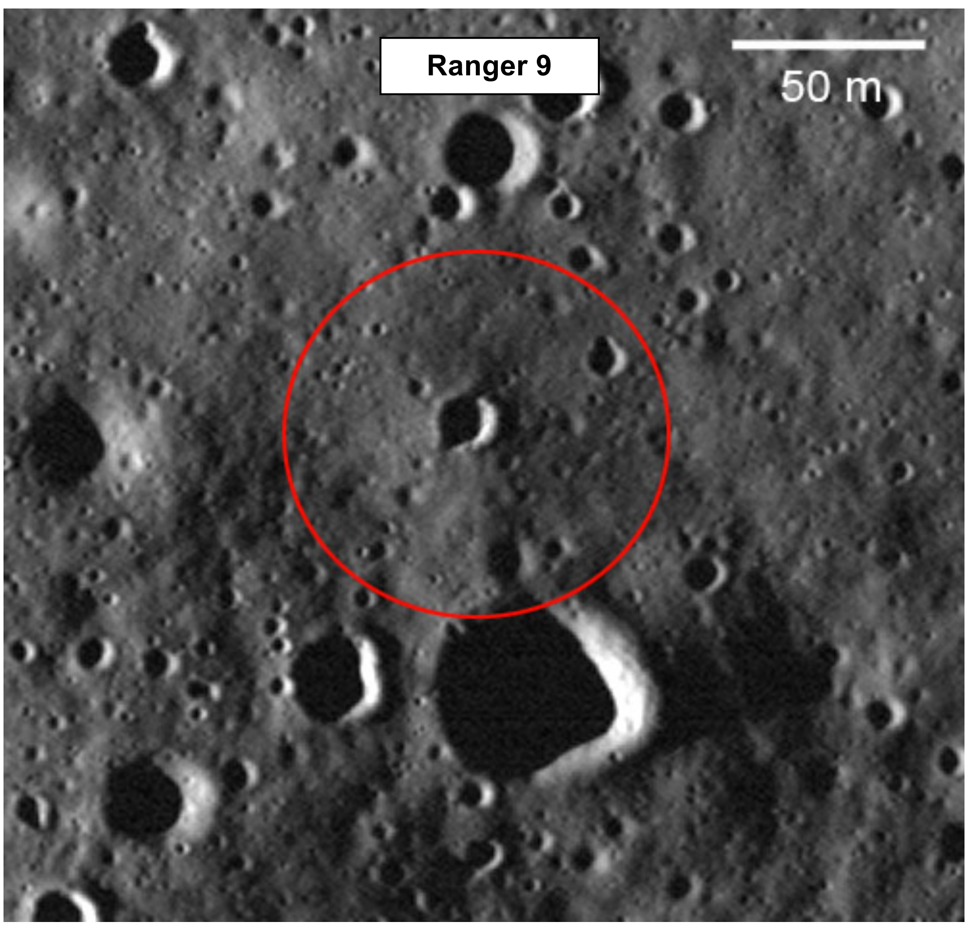

Figure 6: The Ranger 9 impact site. Note: red circle only denotes the location of the Ranger impact site, rather than designating a keep-out zone)

A3-6 KEEP-OUT ZONE – ROVERS AT APOLLO SITES

RECOMMENDATION:

A. With the exception of the Apollo 11 and 17 sites, rovers should observe the keep-out zones of individual artifacts at the Apollo 12, 14, 15 and 16 sites.

RATIONALE:

In general, slow-moving rovers will not create dust/deposits in and around the site (see section A3-7 below).

RECOMMENDATION:

B. For rovers that enter the AB for Apollo site visits, the rover should be removed from the site boundary prior to lunar sunset and end-of-mission (EOM); and not be left within the site boundary.

RATIONALE:

NASA prefers that rovers do not remain parked within the AB at end-of-life. The effects of a severe lunar environment on unattended/uncontrolled space and surface vehicles could lead to containment failures, energetic events or other potential uncontrolled events (e.g., battery venting) that could later contaminate the site.

RECOMMENDATION:

C. Tangential approach – rather than allowing a direct-approach to any given artifact, it is recommended that aim points be selected that are tangential to the artifact.

RATIONALE:

As recommended in Section A2-1 that all trajectory D/L paths be tangential to the landing sites, it is suggested that a similar philosophy be used in the approach to any heritage artifact. Currently, rovers can take pathways that could aim directly at the artifacts, then stop within the prescribed buffer distance. But this approach doesn't necessarily protect for "delay-to-stop" cases or failure modes in which the stop command is not properly received or executed. By selecting aim points that are tangential to each artifact, rovers can still gain close access to the target, but minimize contact in the event of "fail-to-stop" cases.

A3-7 LINEAR WHEEL SPEED OF ROBOTIC ROVERS

RECOMMENDATION:

No part of the approaching (roving) vehicle should be capable of propelling particles more than half way to an artifact. This sets a limit on speeds of all components of a rover in the neighborhood of artifacts. Specifically, the linear (exterior) wheel speeds of robotic rovers should not exceed the meters/second listed below while traversing within the site in order to avoid casting/throwing dust and particles. Rover designs should consider containment/deflection of casting particles.

Table 1: Rover wheel speed versus debris cast distance.

Distance dust can be thrown (m)	Velocity (m/s)
3	2
5	2.8
10	4
15	5
30	7
75	11
80	11.4
200	18

RATIONALE:
Excessive speed around the AB could result in dust contamination on the heritage flight hardware within the site.

A3-8 BACK-TRACKING

RECOMMENDATION:
The approach path prior to reaching an AB, D/L, or VVSMB is not restricted, but once the boundary is crossed, the traverse should be the most direct approach to the desired site location. However, once the visit is completed, the exit path(s) should be back along the same path used for the site approach, as much as possible.

RATIONALE:
Entering and exiting along the same location is highly recommended to minimize disturbance and contamination of site. This should apply to the first visit to that site and all subsequent visits so the same entry and exit "paths" would be used as much as possible.

A3-9 HOPPERS AT APOLLO SITES

RECOMMENDATION:
Landers of the hopper configuration (as with lander/rover configurations) should not land within the 2.0 km radius defining the D/L boundary of a USG heritage lander site. While hoppers can launch/land outside the D/L boundary, they can also perform site inspections via an altitude-flyby per section A3-10 (see below).

RATIONALE:
Some landers employ a "hopper configuration" for their mobility – reusing descent engines to achieve flight and translation across the lunar terrain. The engines of the hopping configuration create an upwelling of fresh regolith as it ascends from its current location and lands in new regions, which in turn produces additional amounts of dust and debris within the area. Despite the lack of a large, central crater beneath the LMs in the Apollo landings, the amount of ejected soil has been calculated by several methods (optical density, damage to Surveyor, experiments, theory, and shape of the surface beneath the LM) and has been found to be on the order of 1 mt (metric ton) or more. The amount of soil disturbed by a smaller lander is expected to be less, scaling approximately with vehicle thrust, but this can still be a significant quantity for any lunar lander. This dust and resultant high-velocity particles could impart significant damage to a protected site, and damage the site's historical record (e.g. crew's footprints and tracks in the case of Apollo landings). Propellant exhaust and ejecta could also affect loose materials like the Modularized Equipment Stowage Assembly (MESA) blanket or other blankets on the Descent Stage and lunar surface.

A3-10 LOW-ALTITUDE FLY-BY OF APOLLO SITES

RECOMMENDATION:
It is recommended, for hopper configuration landers, to perform "low-altitude"/ tangential fly-bys of the lunar heritage sites by translating outside of the Apollo hardware's AB, using a minimum of 40 m altitude to the local surface and a tangential distance from the outer hardware AB perimeter consistent with section A4-3 (unburned or residual propellant, see below).

RATIONALE:
The low-altitude, tangential fly-by approach allows hopper-configuration landers to provide imagery of lunar heritage sites with minimal risk to the site.

Plume impingement: the top layer of the lunar surface is primarily loose particles and dust. During lander translations over the surface, rocket engine exhaust will induce radial ejection of the surface material at high velocities and create dust clouds. These dust/particle streams can result in both contamination and degradation of the protected site.

Altitudes of great than 40 m for translations should ensure negligible plume interactions at the surface.

In the Apollo landings, the crews reported the incipient erosion altitude (the altitude at which dust blowing first occurred during descent) based on naked-eye observations and varied between missions. It was usually between 20 m and 50 m. On Apollo 12 it was reported as 100 m. This was a statistical outlier, but is consistent with modeling. It may be that the dust movement was more easily seen at lower quantities on that mission due to the much lower sun angle. The modeling is difficult because little is known about lunar soil's cohesion. Best estimates so far indicate that "fine sand" particles (around 100 µm) are more easily blown than other particle sizes, and that their motion begins when the LM descends to near 85 m as shown in Figure 7. At that altitude, although the fine-sand sized particles do begin to move, they do not *experience sufficient lift and will not travel any appreciable distance before falling back to the surface. Also, these particles do not have enough optical density to be seen moving. Only clouds of particles smaller than about 10 µm should be visible to the crew from any appreciable height. The saltating motion of those fine-sand sized particles, however, mechanically disturbs the dust particles (<10 µm), which can overcome the cohesion that had held them to the surface. Once knocked loose, the dust can then be lifted by the plume, accelerated to high velocity, and seen as a dust sheet by the crew. Without the saltating disturbance of fine-sand sized particles, the plume could not directly move the dust-size particles until the LM is below about 25m. The saltating disturbance may explain why the Apollo 12 crew saw dust blowing from such a high altitude.*

With a spacecraft that has much smaller thrust than the LM, the altitude of initial dust blowing will be lower than these reported values, but it is difficult to predict analytically. Forty meters is chosen as a reasonable estimate until further analysis is performed.

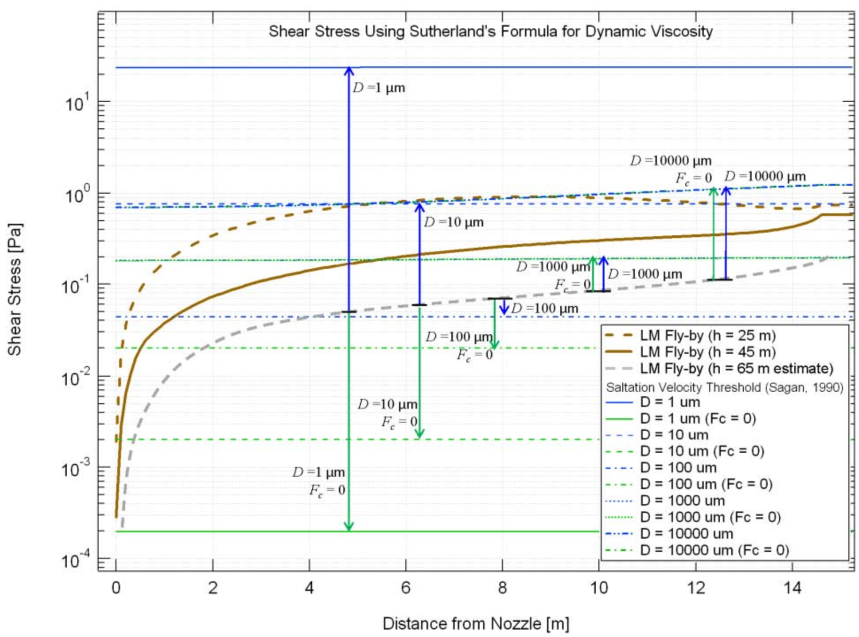

Figure 7: Shear stress generated by a rocket exhaust plume and shear stress levels required to mobilize various sizes of lunar soil particles.

Recently, O'Brien (2009) showed that the plume of the LM ascent stage removed dust from the Dust Detection Experiment at a distance of 130 m during Apollo 12.

SECTION A4 – CONTAMINATION

A4-1 PHYSICAL CONTACT

RECOMMENDATION:
Visiting spacecraft should not physically contact any USG lunar hardware. Exceptions should be pre-coordinated with NASA.

RATIONALE:
Lunar dust and potential biological contamination may be transferred from the visiting spacecraft onto the historical assets, degrading the historical site and/or impacting the science value of the site. However, physical contact with USG hardware and/or impact debris may provide additional scientific value, which should be balanced with the potential for damage. Coordination with NASA is recommended to ensure acceptance and understanding of all risks and benefits.

A4-2 DUST

RECOMMENDATION:
Visiting spacecraft should always adhere to the altitude and tangential distance constraints given in section A3-10 “Low-altitude Fly-by of Apollo Sites”

RATIONALE:
Spacecraft rocket plumes are known to disturb soil on the lunar surface and create sheets/clouds of flying dust. The distances cited in section A3-10 will protect the Apollo site from both dust contamination and degradation from dust abrasion. All mission phases, including low-altitude fly-by, should adhere to the recommended distances.

A4-3 UN-BURNED/RESIDUAL PROPELLANTS

RECOMMENDATION:
When within 200 m of the lunar surface, visiting spacecraft should maintain a main engine orientation such that a cone with a half angle of 45 degrees that is centered on the engine axis does not intersect any portion of the keep-out zones defined in Sections A3-2 through A3-6.

RATIONALE:
The purpose of this recommendation is to keep the lunar heritage sites from being contaminated with propellant residue that is potentially toxic to humans and/or damaging to Apollo hardware (e.g., corrosive). Studies have shown that droplets large enough to be of consequence (larger than one micron in diameter) of unburned/residual propellant from spacecraft rocket motors are confined to within 45 degrees of the engine thrust axis when the rocket is operated in a vacuum environment. Therefore, adherence to this constraint will ensure that adverse effects from the deposition of propellant droplets upon the Apollo artifacts will not occur.

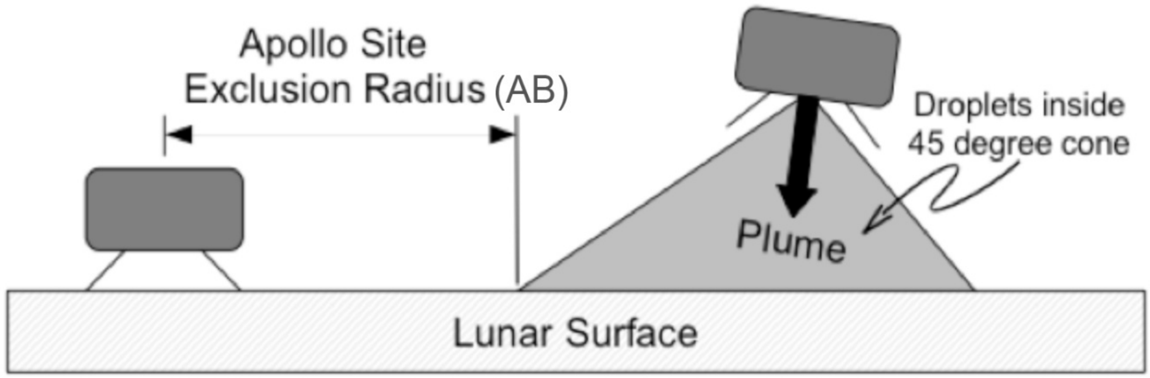

Figure 8: Illustration of plume droplet cone.

A4-4 PLANETARY PROTECTION

RECOMMENDATION:

To address planetary protection concerns, mission documentation should be prepared consistent with the Committee on Space Research (COSPAR) Planetary Protection Category II Guidelines, and, when available, under the guidelines of the lunar mission's nation's appropriate authority. The COSPAR Guidelines involve documentation including an inventory of organic compounds carried on or produced by the spacecraft (e.g., trace organics released in thruster exhaust).

RATIONALE

COSPAR Planetary Protection Policy specifies that robotic missions to the moon be designated as Planetary Protection Category II. As such, Category II missions require documentation to be provided to the Planetary Protection Officer or other appropriate authority of the lunar mission's national scientific organization that participates in COSPAR, or the COSPAR Planetary Protection Panel, which provide guidelines and policies for implementation. For missions in which NASA participates, Category II missions to the moon require documentation to be provided to the NASA Planetary Protection Officer based on COSPAR policy and requirements outlined in NASA NPR 8020.12 and NASA NPD 8020.7.

A4-5 BIOLOGICAL

RECOMMENDATION:

To address concerns about microbial and biological contamination at historic and scientific sites, visiting spacecraft should follow all recommended keep-out zones, boundaries and restrictions outlined in these recommendations.

RATIONALE

Remnant detectable microbial levels and biological contamination, if any, at historical lunar mission sites represent valuable, irreplaceable data of scientific interest. Concerns about microbial and biological contamination at historical sites will be sufficiently addressed by following all recommended keep-out zones, boundaries and restrictions outlined in these recommendations.

APPENDIX A – ACRONYMS

Acronym	Meaning
AB	Artifacts Boundary
ALARA	As low as reasonably achievable
ALSEP	Apollo Lunar Surface Experiments Package
AS	Ascent Stage
COLA	Collision avoidance
COSPAR	Committee on Space Research
D/L	Descent/Landing
DDE	Dust Detector Experiments
EOM	End of Mission
IIP	Instantaneous Impact Point
IP	Impact Point
km/s	Kilometers per second
LCROSS	Lunar Crater Observation and Sensing Satellite
LM	Lunar Module
LRRR	Laser ranging retro-reflector
LRV	Lunar Roving Vehicle
MER	Mars Exploration Rover
m/s	Meters per second
mt	metric ton
OST	Outer Space Treaty
PI	Principal Investigator
USG	U.S. Government
VVSMB	Visiting Vehicle Mobility Boundary

APPENDIX B – NASA Engineering / Safety Center (NESC) Evaluation of Apollo Artifacts as Witness Plates

Future visits to the Moon's surface, such as those anticipated by participants in the Google Lunar X-Prize (GLXP) competition, offer a unique opportunity to study the effects of exposure to the lunar environment on materials and articles left behind by previous lunar missions. Very little data exist that describe what effect temperature extremes, lunar dust, micrometeoroids, solar radiation, etc. have on man-made material, and *no* data exist for time frames approaching the 4 decades elapsed since the Apollo missions. Some of the hardware on the Moon was designed to remain operable and transmit telemetered scientific data back to the Earth, but much of what is there was meant to be used during the Apollo mission time frame and then abandoned with no expectation of further survivability. How these artifacts and their constituent materials have survived and been altered while on the lunar surface is of great interest to engineers and scientists. The Apollo artifacts are, in essence, witness plates to 38+ years on the Moon.

The NASA Engineering and Safety Center (NESC) was asked to consider these possible effects of the lunar environment on man-made artifacts and suggest which artifacts would be the most enticing targets for imaging or investigation by future visiting vehicles. The NESC team used Apollo 15 as a representative landing site. The Apollo 15 crew left 189 individually cataloged items on the lunar surface, including the descent stage of the Lunar Module, the Lunar Roving Vehicle (LRV), the Apollo Lunar Surface Experiments Package (ALSEP), and a wide variety of miscellaneous items that were offloaded by the astronauts to save weight prior to departure. The locations of many of these items are well documented, and numerous photographs are available to establish their appearance and condition at the time they were left behind.

The NESC team formed for this activity consisted of several NASA Technical Fellows and members of technical discipline teams (TDT) with expertise in thermal control, materials, mechanical systems, lunar environment, nondestructive evaluation, and environmental control and life support (see Table B1).

Table B1: NESC Team Members

Neil Dennehy	Guidance, Navigation and Control Technical Fellow
Jared Dervan	NESC Resident Engineer
Michael Dube	Mechanical Systems TDT
William Prosser	Nondestructive Evaluation Technical Fellow
Steven Rickman	Passive Thermal Technical Fellow
Henry Rotter	Life Support and Active Thermal Technical Fellow (Apollo Veteran)
Donald Shockey	Materials TDT
Michael Sims	Robotics TDT/Center for Collaboration Science and Applications
Michael Squire	NESC Principal Engineers Office

Input was also received from members of the original Bendix Corporation team that designed and built the ALSEP instruments. Specific thanks go to Mr. Lynn Lewis, who provided much of the information in Table B2 and additional observations in this appendix.

The task for the NESC team was to determine which artifacts were accessible and evaluate what benefits might be realized by taking high definition images of each one. Accordingly, the ground rules set for this NESC activity were to assume that the only scientific equipment available will be high definition cameras, and no physical contact with the artifacts is allowed. The NESC team's conclusions are presented in Table B2 where they are categorized as follows:

Materials: One of the primary objectives in looking at the artifacts is to gauge the effect of the lunar environment on different materials. Conditions on the lunar surface vary in temperature from +250° F to -300° F and include exposure to ultraviolet and other forms of radiation, so material surfaces after 40 years of exposure to this environment could be discolored, faded, dulled, flaked, rumpled, pitted, mud-cracked, scratched, and/or covered with dust.

Structural/mechanical: The temperature extremes may have caused some artifacts to exhibit thermal effects, and the 500-plus day-night thermal cycles may have caused thermal fatigue damage or deformation due to dissimilar metals being in contact with each other. In addition, micrometeoroid impacts may have produced craters whose number, size, and appearance may be useful in updating current models. Radially symmetric objects with several impacts may be able to give some rough directional information as well.

Thermal: Most of the Apollo hardware received some form of thermal protection. This included multilayer insulation (MLI), radiators/reflectors, and/or thermal paint. There is interest is seeing how these different systems may have degraded.

Dust: Much has been documented on the characteristics of lunar dust and the deleterious effect it has on equipment. There is also interest in dust transportation and deposition from human activities and natural processes. Flat surfaces (especially horizontal) and artifacts that appear pristine in Apollo photographs would be optimum targets to look for dust deposition.

Blast Effects: Observations of how blast effects from nearby rocket engines vary as a function of distance may be possible by looking at some affected artifacts.

Miscellaneous: Captured here are observations not easily grouped in any of the above categories.

Table B2: Apollo Artifacts Targeted Observations (referenced figures can be found on pages 38-40)

Artifact	Materials	Structural/ Mechanical	Thermal	Dust	Blast Effects	Miscellaneous
ALSEP Central Station (Fig. B1) [Apollo 12, 14-17]			Look for cause of operational temperature increases.			
cables	material degradation[i]	Are cables lying flat?[ii]		Compare areas of ribbon cable that appeared pristine in Apollo photographs.		
antenna		thermal cycling warpage/ damage	evidence of delamination of thermal coating			
antenna mast		thermal cycling warpage/ damage	evidence of delamination of thermal coating			
painted structure			evidence of delamination of thermal coating			
specular thermal reflector			Condition of aluminum coating	any dust deposition		
side and rear curtains			damage to MLI		Compare side facing descent stage to protected sides.	
tubular extenders		Inspect spring-loaded extending mechanism.				
S-band aiming mechanism			evidence of delamination of thermal coating			Read set points on dials and sun compass heading – has orientation changed?
crew interfaces		Look at 5 switches – do they still look operable?				Does the power indicator on top of the unit indicate power to the unit?
dust detector		visible changes or damage		visible dust accumulation to correlate with data		
Radioisotope Thermal Generator (RTG) (Fig. B2) [Apollo 12, 14-17]						
radiator fins	material degradation	Compare the fins with each other to estimate micrometeoroid directionality.		dust accumulation on fins	Compare fins facing descent stage to protected fins.	
fuel cask	material degradation					

Artifact	Materials	Structural/ Mechanical	Thermal	Dust	Blast Effects	Miscellaneous
Passive Seismic Experiment (PSE) (Fig. B3) [Apollo 12, 14-16]						
thermal shroud	discoloration, delamination, cracking		discoloration, delamination, cracking Are there wrinkles in the shroud; is it evenly deployed?	dust deposition	Did blast disrupt the thermal shroud placement?	Is the shroud displaced from its last photographed position?
bubble level indicator	material degradation, cracking					Is the device still level (has it shifted)?
sun compass	material degradation			dust deposition	dust deposition	Has the device shifted?
Lunar Surface Magnetometer (LSM) (Fig. B4) [Apollo 12, 15-16]						
sunshield	discoloration, delamination, cracking		discoloration, delamination, cracking	dust deposition		
magnet booms	material degradation	thermal cycling warpage/ damage	discoloration, delamination, cracking of insulation			
magnetic sensors	material degradation		evidence of delamination of thermal coating on top of sensor discoloration, delamination, cracking of insulation			
radiator	material degradation	damage to specular reflectors		dust deposition (protected from above by sunshield)		
bubble level indicator	material degradation					Is the device still level (has it shifted)
sun compass	material degradation			dust deposition	dust deposition	Has the device shifted?
Solar-wind Spectrometer (Fig. B5) [Apollo 12, 15]			evidence of delamination of thermal coating			
Faraday cups/dust covers – 6 faces of the collector are set at 60 degrees from vertical, with a horizontal face on top.	material degradation	Compare the cups with each other to estimate micrometeoroid directionality.	evidence of delamination of thermal coating	dust deposition on dust covers and faces – possibly showing a directional component	6 faces could provide comparison	
support legs	material degradation	structural or mechanical damage				
radiators/sun shade	material degradation	structural or mechanical damage	Observe any damage.	dust deposition	effects from ascent stage[iii]	
electronics assembly housing	material degradation		evidence of delamination or damage to MLI			

Artifact	Materials	Structural/ Mechanical	Thermal	Dust	Blast Effects	Miscellaneous
Suprathermal Ion Detector Experiment (SIDE)/Cold Cathode Ion Gauge (CCIG) (Fig. B6) [Apollo 12, 14-15]				dust deposition on flat top of main unit		
SIDE housing	material degradation		evidence of delamination of thermal coating			
cable	material degradation	Are cables lying flat?		Compare areas of ribbon cable that appeared pristine in Apollo photographs.		
cable reel		condition of mechanism				
CCIG	material degradation	visual damage				
bubble level indicator	material degradation, cracking					Is the device still level (has it shifted)?
Heat Flow Experiment (HFE) (Fig. B7) [Apollo 15, 17]						
electronics housing	material degradation		evidence of delamination of thermal coating	Dust deposition on flat top		
cable	material degradation	Are cables lying flat?		Compare areas of ribbon cable that appeared pristine in Apollo photographs.		
probes/borestems	material degradation	thermal cycling warpage/ damage to probes				
sun shield	discoloration, delamination, cracking		discoloration, delamination, cracking	dust deposition		
lunar surface drill		visual damage				
Laser Ranging Retroreflector (LRRR) (Fig. B8) [Apollo 12, 14-16]						
reflective array	degradation, possibly causing performance degradation	may display meteoroid impacts		Correlate dust deposition with observed change in performance. Any dust accumulated in recessed portions or vertical and angled surfaces?		
thermal blankets	material degradation		visible degradation			
Solar Wind Composition (Fig. B9) [Apollo 11, 12, 14-16]						
pole	material degradation.	thermal cycling warpage/ damage to pole				

Artifact	Materials	Structural/ Mechanical	Thermal	Dust	Blast Effects	Miscellaneous
Hammer and Feather (gravity demonstration experiment) (Fig. B10) [Apollo 15]	effect of lunar environment on biological material (feather)				Did the blast move the feather?	
Lunar Rover Vehicle (LRV) (Fig. B13) [Apollo 15-17]		Look at structural joints for evidence of thermal fatigue or cracking.				
seats	degradation of nylon strips			Higher elevation of the seats may allow comparison with lower level artifacts; depending on orientation relative to descent stage, the seats may have received some blast protection.		
seat belts	degradation of nylon					
structure		areas where dissimilar metals are joined to look for thermal cycling effects	evidence of delamination of thermal coating			
fenders	degradation/ discoloring of fiberglass					
radiators			if dust cover removed – discoloration, visible degradation, look for dust accumulation			
high-gain antenna		thermal cycling warpage/ damage to mast				
low-gain antenna		thermal cycling warpage/ damage to mast				
video camera		visible degradation of the optics				
crew interfaces		degradation in switches and gauges Try to read values on gauges.		Are the gauges obscured with dust?	Are the gauges obscured with dust or blasted?	

Artifact	Materials	Structural/ Mechanical	Thermal	Dust	Blast Effects	Miscellaneous
Lunar Module (Descent Stage) (Fig. B14)				dust deposition on the top surface	blast damage on top of LM	
engine nozzle extension	degradation					
thermal/MMOD shield			damage from ascent plume heating		See if insulation integrity was compromised by ascent stage blast.	
footpads	discoloration					
RTG fuel cask thermal shield		visible evidence of radiation leakage during flight				
US flag (Fig. B11)	degradation of nylon flag	thermal cycling warpage/ damage to pole				
clothing		discoloration – compare to ground samples/ pictures				
food/waste						visible effect of lunar environment on biological material
gnomon (Fig. B12)						How have the colors changed on the color standard?
Lunar Surface				changes in tire/foot prints such as smoothing, collapsing into the track	size and shape of ascent stage excavations	
				new meteorite craters or linear features recorded by the PSE		

As reflected in Table B2, the ALSEP experiments and the LRV are highly prized targets of opportunity. The LRV in particular should be considered a priority because it contains a wide variety of different materials and does not have the "tripping" hazard that may be associated with cables lying about on the surface. In situ observations on the lunar surface will help determine the most interesting and relevant artifacts to investigate next, and a supporting "back room" as was used in Apollo will encourage success and make the best use of the time spent in that vicinity. Any mission to the lunar surface should have a support team of engineers and scientists to evaluate incoming data and help with real-time mission decisions.

One primary area of interest regarding lunar artifacts is to observe the effect of the lunar environment on different materials. Table B3 lists some of the materials at the Apollo 15 site and examples of where they can be found.

Table B3: Materials on Lunar Surface

Aluminum	Various structural components
Aluminized Mylar®	Insulation and reflectors
Graphite/beryllium	RTG fuel cask
Fiberglass	LSM support arms/LRV fenders
Fused silica glass	LRRR mirrors, LRV radiators
Nylon	LRV seats and seat belts, flag
Zinc	LRV tires
Titanium	LRV tires
Stainless steel	Plaque on LM, ALSEP fasteners/clips/latches
Beryllium	RTG radiators
S-13 G and Z-93 white paint	Solar reflectors
Gold	Infrared reflectors
Aluminized Kapton®	Insulation
Aluminized Teflon®	ALSEP shroud material
Magnesium	LRV batteries
Chromel® R metal fabric	Boots, gloves
Niobium	Descent stage engine nozzle extension

In addition, points of reference and comparison are important in evaluating levels of damage or change to the lunar hardware. Any standards or baselines in the form of Earth-based existing materials, spares, or test data that can be used as comparisons to lunar observations would provide enhanced scientific and material value.

Finally, several ALSEP experiments recorded failures that were not completely explained by data available. It may be possible to see visible contributors to the anomalies in images taken by future visiting vehicles. Table B4 lists several ALSEP instruments where failures were recorded prior to the end of service life.

Table B4: ALSEP Failures Occurring that May Be Influenced by Environmental Causes

Site	Experiment	Failure	Comments
Apollo 14	Central Station	Intermittent loss of signal (LOS)	LOS for up to 2 months at a time before returning.
Apollo 15	Solar Wind Spectrometer	Loss of all data, suspected high-voltage arcing in electronics	
Apollo 15	Heat Flow Experiment	Intermittent operation and anomalous data	
Apollo 15	Lunar Surface Magnetometer	y-axis total failure, then complete loss of data	
Apollo 16	Lunar Surface Magnetometer	z-axis intermittent failure	
Apollo 16	Passive Seismic Experiment	Inadequate thermal control causing high daylight temperatures	Possibly due to raised thermal shroud, dust on shroud, lift-off debris, or experiment contact with lunar surface.
All	Central Station	Steady increase in temperature over time	May be due to thermal protection degradation.
All	Laser Ranging Retroreflector	Gradual performance degradation	Also witnessed on the Russian Lunakhod reflector

The GLXP roving vehicles are only required to have high definition visible-light cameras, but some additional suggestions are presented here in case additional scientific equipment is on board, or if the ability (and authorization) to make physical contact with the artifacts is available.

- Take infrared (IR) measurements of the RTG fins to determine how much energy is being produced.
- Measure nuclear radiation levels around the RTG vicinity.
- Take IR measurements of the power dump panel (rear side of Central Station).
- Attempt to move crew interface knobs, switches, dials, etc. and if they are frozen, try to determine the cause.
- Investigate the state of biological material in waste containers and food.
- Take up-close, high-magnification photos showing details of material degradation on artifact surfaces.
- Use cameras located on a separate lander to take video of the rover as it maneuvers away from the landing site – to collect data for use in future mobility designs.

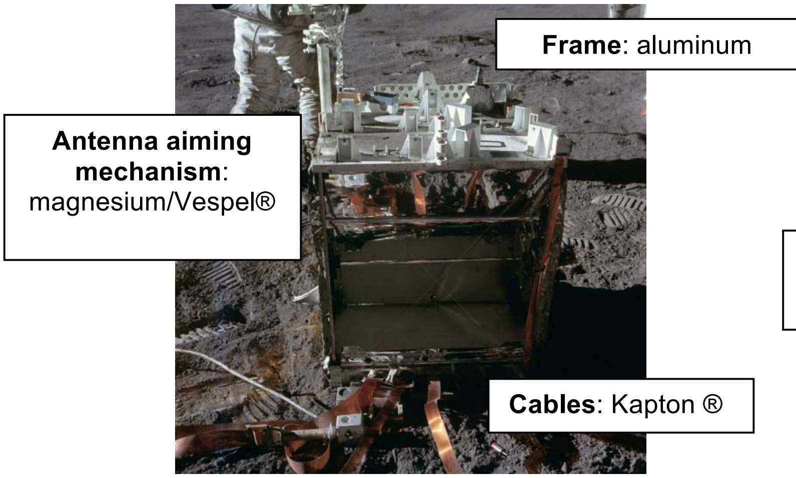

Figure B1 – ALSEP Central Station

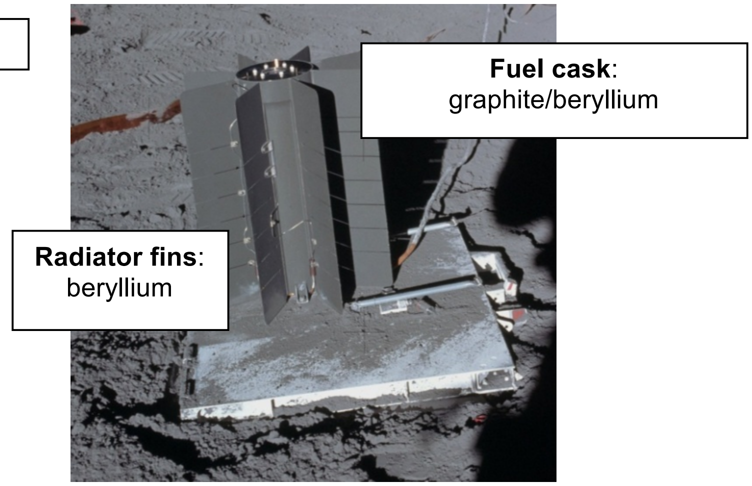

Figure B2 – RTG

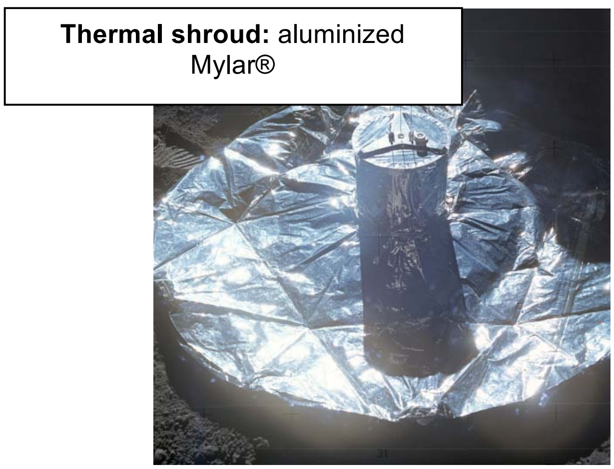

Figure B3 – Passive Seismic Experiment

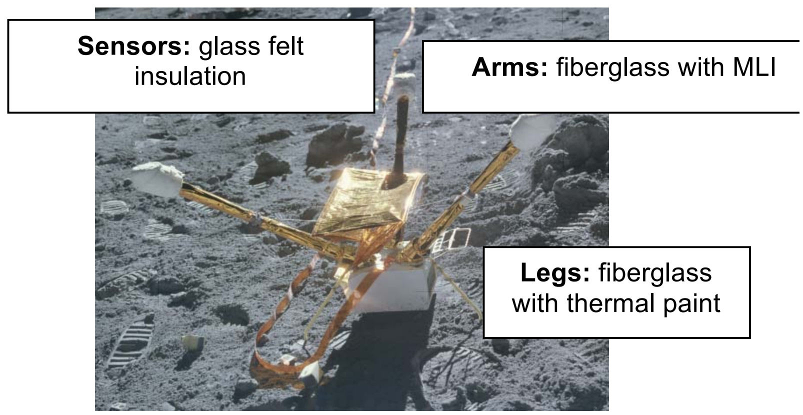

Figure B4 – Lunar Surface Magnetometer

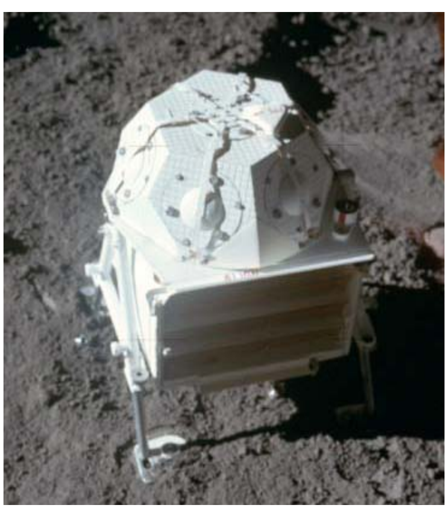

Figure B5 – Solar Wind Spectrometer

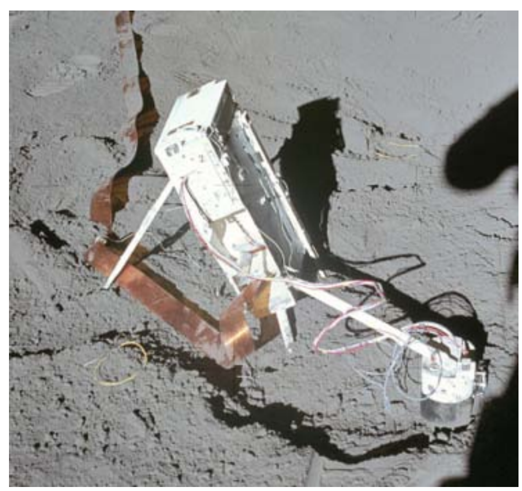

Figure B6 – Suprathermal Ion Detector/Cold Cathode Ion Gage

Representative Apollo Artifacts

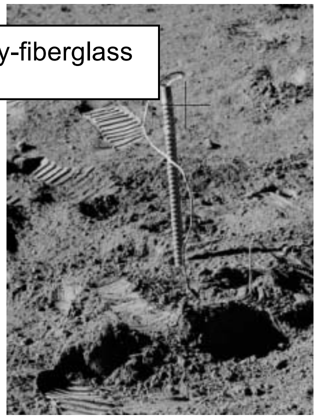

Figure B7 – Heat Flow Experiment

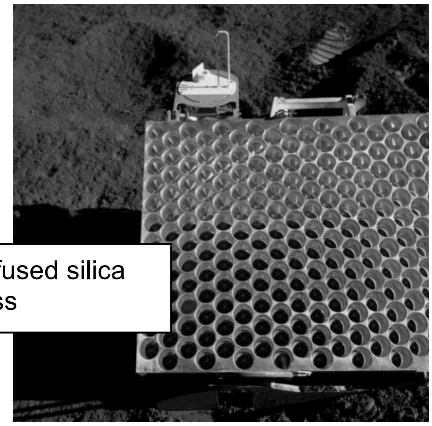

Figure B8 – Laser Ranging Retroreflector

Figure B9 – Solar Wind Composition Experiment (Only Support Pole Remained on Moon)

Figure B10 – Hammer and Feather Demonstration

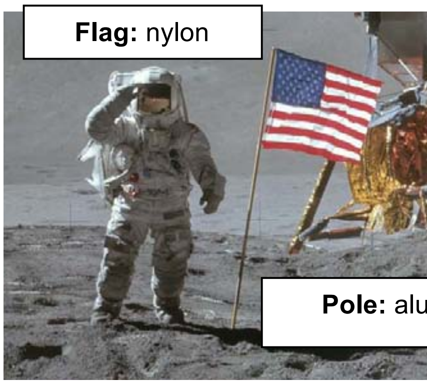

Figure B11 – U.S. Flag

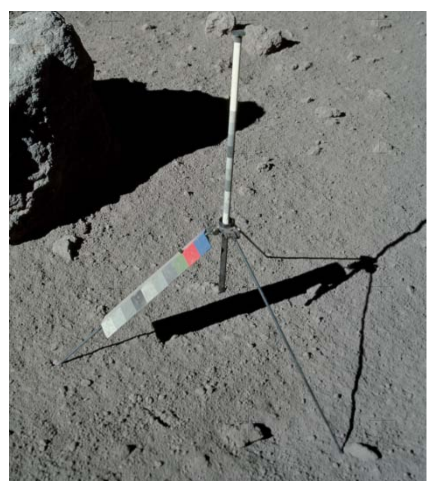

Figure B12 – Gnomon

Representative Apollo Artifacts

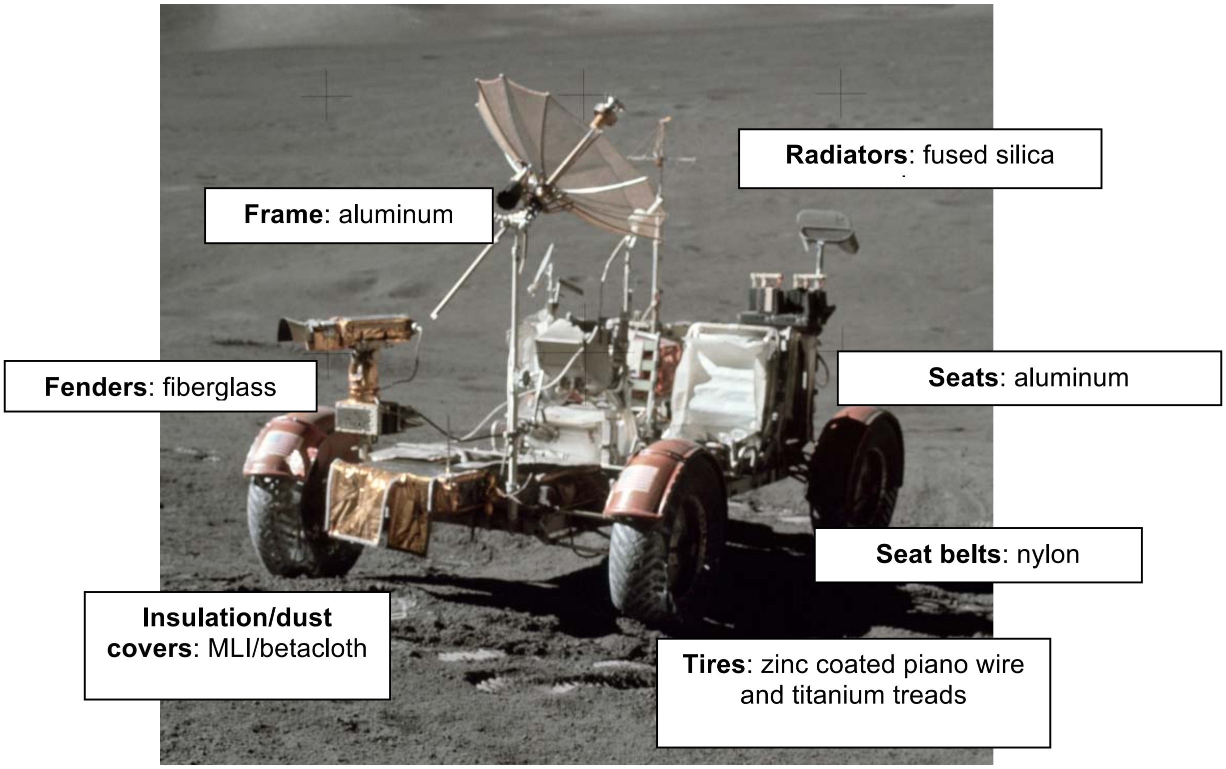

Figure B13 – Lunar Roving Vehicle

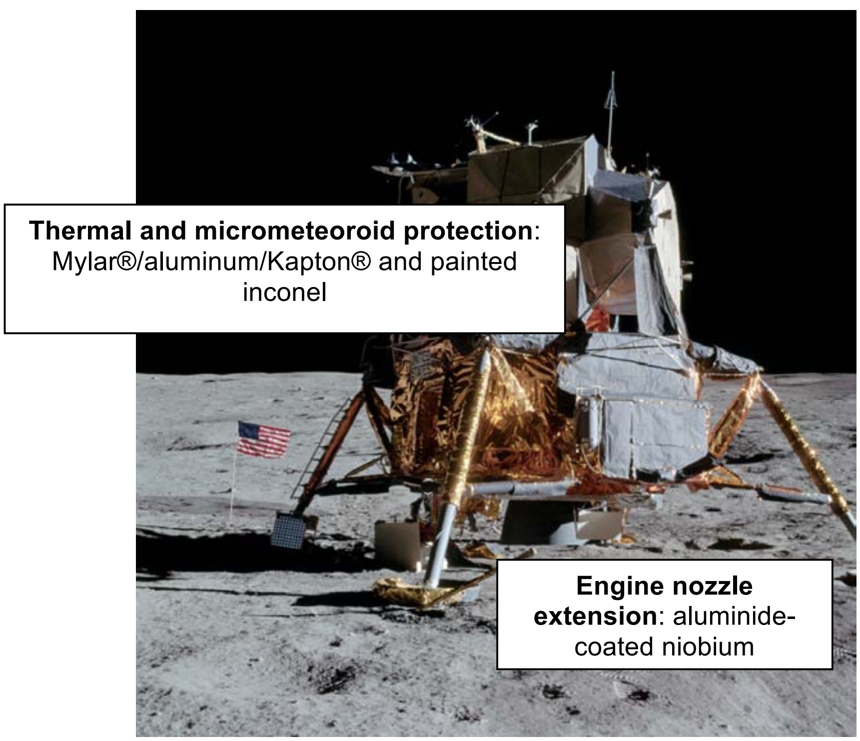

Figure B14 – Lunar Module Descent Stage (Shown with Ascent Stage)

Representative Apollo Artifacts

The following references were used to provide information for this appendix.

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APPENDIX C – NASA LUNAR SCIENCE ASSESSMENT OF APOLLO SITES AS WITNESS PLATES

I. Introduction

Soft landings on the Moon, both robotic and crewed (Apollo) resulted in scientific investigations of the surrounding region. For Surveyor, the investigation was largely photographic although some manipulation of the soil near the spacecraft was photographed in order to evaluate the geotechnical characteristics of the surface material. Some of the landed Surveyors had an alpha particle backscattering experiment and a magnet to learn about the mineralogical properties of the regolith.

The Soviet Lunokhod rover successfully ranged over significant distances before failing. Of course, the Apollo astronauts explored and sampled areas around the landed Lunar Module, extensive areas in the case of the 'J' Missions (A15, A16, and A17).

In this section we discuss special locations, usually small in area, where preservation of the extant surface environment has value for understanding more completely the scientific findings from that special location. We also discuss photographs that could add to our understanding of scientific and technological issues related to the lunar surface. (We assume herein that no measurements other than high-resolution images can be available.) More information on any Apollo experiments discussed below can be found at http://www.hq.nasa.gov/alsj/RP-1994-1317.pdf.

II. Science hardware

A. Lunar Laser Ranging Retroreflectors (LRRR) [A11, A14, A15, Lunokhods 1 & 2]

The Lunar Laser Ranging Retroreflectors were emplaced at A11, A14, and A15. The Soviet Lunokhod rovers also carried retroreflector arrays. All of these arrays are currently being used for research into lunar motion, dynamics, and internal structure. The corner cube reflectors comprising each array MUST not be degraded by dust deposition or other contamination from visits.

We cannot emphasize enough the importance of NOT doing anything to degrade the performance of the arrays. In general, this concern leads to establishment of a buffer distance for any active device approaching the arrays. On the other hand, the current state of the reflector surfaces are of great interest to determine, in particular, whether fine-grained lunar surface material coats the surfaces. The strength of the return signal was not measured on Earth when the surfaces were known to be pristine. However, data that does exist suggests some loss of performance has occurred for reasons that are only be speculative. A clear, relatively high-resolution image of an array surface would be very valuable. A picture from the farthest distance compatible with zoom capability of the camera is greatly preferred.

B. Heat Flow Probes [A15, A17]

One of the most important geophysical experiments left on the Moon by the Apollo astronauts (A15, A16, and A17) is the Heat Flow Experiment (HFE). A probe consisting of thermocouples and other instrumentation was inserted into a bore hole drilled by the astronauts. The A16 instrument was inadvertently damaged during deployment and never operated. At A15, one probe could not be installed properly; and the other probe could not be inserted to its fully intended depth, resulting in some thermocouples lying on the upper surface.

Post-mission data analysis from telemetry of temperature readings showed that accurate modeling of the local and regional environments was necessary to properly interpret the data. The configuration of the probes, including the string of thermocouples lying on the surface at A15, should not be disturbed. However, photographic documentation of the configuration would be useful.

C. Soviet Luna missions

Of note and for completeness, the Soviet Union successfully landed robotic spacecraft on the lunar surface 7 times. Lunas 9 and 13 returned photographs of their landing sites along with some measurements of the lunar surface environment. Lunas 16, 20, and 24 returned lunar surface samples to Earth. The geologic setting of the samples are not well known, although the Lunar Reconnaissance Orbiter Camera has located the spacecraft on the lunar surface. A photographic survey of these landing sites would provide context for the geochemical and mineralogical analyses of the returned samples.

Lunas 17 and 21 delivered rovers to the surface under the name Lunokhod. Lunokhod 1 traveled over 10 km and survived 11 lunar day-night cycles. Lunokhod 2 traveled 37 km and survived 4 months. One Lunokhod rover is the property of Russia, and the other has been sold to a private individual. Consequently, NASA has no authority to set conditions on their sites and these USG recommendations do not apply. Nevertheless, the LRRR arrays on each rover are invaluable tools for continuing studies of the Moon and of General Relativity.

D. Lunar Ejecta & Meteorites Expt. (LEAM) [A17]

The LEAM was designed to detect micrometeorite impacts and ejecta from possible somewhat distant lunar surface impacts. The experiment did not operate properly but did send odd signals that were later interpreted as low-velocity strikes from mobilized surface dust at local dawn as the terminator passed. The mobilization of surface dust particles at the terminator is controversial. Therefore, the immediate surroundings of the LEAM and its surface condition are important to preserve and document.

E. Lunar Dust Detector [A12, A14, A15]

The Dust, Thermal, & Radiation Engineering Measurements Package (a.k.a. Lunar Dust Detector) consisted of three solar cells whose power output was transmitted to Earth during the lunar day. The intent was to measure degradation due to dust buildup on the surface. Data from the sensors at A14 and A15 were recorded for 5 years. Documentation of the current state of the surface would be interesting. Therefore, effort should be made to avoid disturbing the surface accumulation until it is documented.

III. Terrain surrounding site

A. Sampling stations (if not in keep-out zone)

The scientific integrity of the returned Apollo samples has been maintained by the Curator of Lunar Samples for the past 40 years. The curation process begins when the sample is collected. A scientific investigator may want to know precise information about the geologic setting of the sample and may have questions about the procedure used in the collection and transport of a lunar sample. The Curator still uses video and photography of the collection of certain samples to be able to answer these questions.

In a few cases, samples were acquired by knocking off a piece from a much larger rock or outcrop. A good example is the sampling from the huge boulder at A17 Station 6 by Harrison Schmitt. Schmitt, a trained geologist, photographed the surface of the boulder both before and after the removal of the sample. A photograph of the same surface on the boulder, looking for changes, would hold some scientific interest.

If a visit to a sample station from an Apollo site is planned, the scientific community should be queried as to whether any information is desired about specific sample locations.

B. Orange soil discovery site [A17]

The discovery by Apollo 17 astronaut Harrison Schmitt seemed to the public to be a ‘Eureka Moment’ in the exploration of the Moon. The colorful volcanic glass deposit has been the object of several important investigations striving to understand the history of lunar eruptions. Most recently, scientists studying a number of the individual glass beads have been able to tease out evidence for the existence of water in the lunar interior in quantities not previously thought possible.

The site of the orange glass deposit signifies an example of opportunistic serendipity that humans bring to space exploration. Although the site should not be disturbed, documentation of the extent and depth of the deposit would add to the scientific value of the discovery.

C. Close-up camera picture targets [A11, A12, A14]

The Lunar Surface Stereo Closeup Camera was touched to the surface by the astronauts to take each stereo pair of a field about 75 mm on a side with a resolution of 80µm. On missions A11 and A12, the pictures were taken in the vicinity of the Lunar Module. On mission A14, some pictures were taken along a traverse to a sampling station. The exact locations of the images are not known.

Consequently, no determination can be made of a keep-out zone for the locations. Similarly, documenting the current state of the surface at the locations would be problematic.

D. Sites of impact by spacecraft

A number of spacecraft have been deliberately crashed into the lunar surface. During the Apollo Era, these included the Saturn IVB upper stages, the Ranger spacecraft, and the Lunar Excursion Modules (LEM). Given the impact velocity, no trace of these spacecraft should survive. However, the impact generates a fresh lunar crater, whose age is known exactly. The scientific community would be interested in the morphology of the crater (depth, diameter, shape, etc.), the nature of the ejecta blanket as a function of distance from the crater (depth, continuity, size distribution, rays, etc.), and the nature of the target material. With that kind of information, models of impact physics could be improved. All of the above properties are ‘extensive’ (as opposed to ‘intensive’) and should not be compromised in any way by a rover trekking around among the debris. It would also be interesting (and surprising) if anything recognizable from the impactor still exists. High-resolution images from the Lunar Reconnaissance Orbiter Narrow Angle Camera could be used to plan a scientifically useful route at the impact site.

IV. Science opportunities (assuming photo capability only)

A. Document surface state of LRRR

The reflecting surfaces of the LRRR arrays have degraded since their installation. A debate rages over the nature of the degradation, some of which must be due to a covering of dust. A good photograph of the LRRR surface would contribute a great deal to the understanding of the processes involved. However, the risk of further degrading the optical surface during the approach must be weighed.

B. Document dust levitation at terminator crossing

Surveyor photographs and the enigmatic LEAM signals have been interpreted as evidence for the levitation and/or movement of dust by means of electrostatic fields generated during the passage of the sunrise and sunset terminator. Direct observation of the terminator passage would be a very desirable product of a landed rover.

C. Document changes on lunar visiting vehicle equipment surfaces at terminator

If electrostatic fields are generated at terminator passage, equipment surfaces on a rover or hopper may acquire or lose dust. Monitoring surfaces would be interesting data. Incorporation of an electric field measurement (e.g., Langmuir probe) would be wonderful.

D. Small-scale surface dust movement as shadow boundaries change

Dust levitation at the sunset terminator passage is thought to be associated with changing surface electric potentials as solar illumination decreases and ultimately disappears. A similar phenomenon is thought to occur at the sunrise terminator. If this hypothesis is correct, small-scale electric fields might occur at shadow boundaries. Some investigators believe that the fields at the submillimeter level could be quite strong, causing small particles to suddenly accelerate and impact neighboring particles. This phenomenon might be detectable by monitoring as small a surface area as possible at a shadow boundary, watching as the shadow grows or shrinks.

E. Document micrometeorite impacts on heritage equipment surfaces

The scientific community believes that good data exists on the micrometeorite flux at the distance of the Earth from the Sun. However, any estimate of the flux on the surface of the Moon must take into account certain perturbing effects such as the gravitational fields of the Earth and the Moon as well as shielding by the physical presence of the Earth and the Moon. If a good photograph allows measurement of the number of impacts on surfaces that were pristine 40 years ago, the models in use could be validated. The surface to be photographed is preferred to be one that is not shielded by other nearby surfaces. This kind of information would be similar to that collected from study of exposed surfaces on the Long Duration Exposure Facility (LDEF) after its return to Earth from orbit by the Space Shuttle.

F. Document weathering processes on footprints & vehicle tracks

The upper millimeter or so of the regolith is thought to be ‘gardened’ over short times in a geological context. It is expected that some weathering through micrometeorite impacts will be observable on features at the Apollo sites. Footprints and rover tracks are possible targets for weathering surveys.

G. Document ejecta & rays at artificial impact sites

Impact processes dominate the surface evolution of the Moon and other airless bodies such as Mercury or asteroids. The general theory for impact physics has been developed through a combination of laboratory experiments (at small scales) and study of crater morphology from orbital images (large scale). Data on very young craters with fresh features has been scarce. The artificial impact sites on the Moon offer unique opportunities to see unweathered features related to the impact process. A combination of new high-resolution imagery from the Lunar Reconnaissance Orbiter with directed photographic surveys on the surface has the potential to greatly increase our understanding of this important planetary phenomenon.

H. Rover wheel interaction with regolith

The geotechnical properties of the upper layer of the regolith have been inferred from observations of footprints and tire tracks laid down during the Apollo missions. These observations consist simply of photographs that were studied after the mission by specialists. A few dedicated geotechnical experiments were performed during the missions. A structured study of wheel interactions with the surface in real time could add to our understanding for future lunar exploration. Of particular importance is the difference in surface structure near the rims of craters, where softer accumulation of fine material is found.

I. Hopper rocket exhaust interaction with regolith

The environmental considerations in this document are largely based on limited study of photographic and video records from Apollo landings and from study of the Surveyor spacecraft visited by the A12 astronauts. Computational models and some experimental work have helped interpret the effects seen in the imagery. Our understanding of surface effects during lunar landings could be advanced significantly if observations were made of regolith movement due to known inputs of rocket engine exhaust. Future lunar landers and hoppers will be in a position to supply such information.

J. Push biggest possible rock over edge of crater or rille

Tracks of boulders rolling down slopes have been used to infer geotechnical properties of the surface layer. The large boulder at A17 was sampled because a track implied that it had been part of an outcrop much higher up on the massif. A17 is also the site of an avalanche that is thought to be the result of an (hypothetical) impact on the far side of the massif. Soils that develop on slopes may well be metastable such that avalanches could be easily triggered. Also, it would be fun to push a big rock over a cliff. It is a question whether a rover could push a rock and also observe the descent, but it is worth thinking about.

APPENDIX D – APOLLO MISSIONS LUNAR ASSETS

This appendix contains a list of additional assets left on the lunar surface or within the flight hardware for the Apollo missions 11, 12, and 14-17.

Mission ID: Apollo 11	Earth Launch Date 7/16/69	Lunar Depart Date 07/21/69 1 of 1
Landing Location: o 41N 23 26E		Lunar Landing Date 7/20/69
Part Number	Nomenclature	Quantity
SEB33100113-301	Filter, Polarizing	1
SV706100-6	Portable Life Support System(PLSS)	2
SV721783-6	Remote Control Unit (PISS)	2
14-0111-01	Defecation Collection Device	4
A7L-106015-01/02	Overshoes , Lunar	2
A7L-201009-01	Covers, pga Gas Connector	2
SJB33100199-304	Kit, Electric waist, Tether	1
SEB33100198-301	Bag, Assy, Lunar equip. conveyor & waist teth	1
SEB33100191-304	Conveyor assy., Lunar Equipment	1
SEB33100214-301	Bag , Deployment, Life Line	1
SEB33100214-302	Bag, Deployment, Lunar equip. conveyor	1
SEB33100191-303	Life Line, lightweight	1
SEB33100192-301	Tether waist, EVA	2
SEB33100192-302	Tether waist, EVA	2
14-0121	Food Assembly, LM (4 man days)	1
SEB16100823-303	TV subsystem, Lunar	1
607B962	Camera , Lunar TV	1
618B377	Lens, TV wide angle	1
618B376	Lens, TV Lunar, day	1
513B464	Cable assembly, TV (100 ft .)	1
LDW340-54013-7	Adapter, SRC/OPS	2
LS0330-122-3-9	Cannister, ECS LIOR	2
LSC340-201-529-1	Urine collection assembly, small	2
LSC340-201-527-1	Urine collection assembly, large	2
MB901-0736-0003	Bag, Emisis	4
LDW340-54227-47	container assembly , Disposal	1
ISC330-325-3	Filter, Oxygen bacterial	1
LDW340-54309-7	Container, PLSS Condensate	1
LSC380-00370-51	Antenna, S-Band	1
LDW390-21543-5	Cable, S-Band antenna	1
LDW340-55054	Bag, Lunar Equipment Transfer	1
TBD	Pallet assembly #1	1

Representative Apollo Artifacts

Mission ID: Apollo 11	Earth Launch Date 7/16/69	Lunar Depart Date 07/21/69	1 of 1
Landing Location: o 41N 23 26E		Lunar Landing Date 7/20/69	

Part Number	Nomenclature	Quantity
TBD	Passive seismic experiment	1
TBD	Central Station	1
TBD	Pallet Assembly #2	1
TBD	Lunar retroranging reflector experiment	1
TBD	Primary structure assembly	1
SEB39100319	Hammer	1
SEB39103122	Scoop, Lunar sample-large	1
SEB39l003l4	Extension handle	1
SEB39100340	Tongs	1
SEV39100317	Gnomon (Excludes mount)	1

Mission ID Apollo 12	Earth Launch Date 11/14/69	Lunar Landing Date 11/19/69	1 of 2
Landing Location 3 11S 23 23W		Lunar Depart Date 11/21/69	

Part Number	Nomenclature	Quantity
SEB33100040-304	Camera, Lunar Surface, Electric Hassa1b1ad	2
SEB33100048-303	Lens , 60mm	2
SEB33100277-303	Adapter. Rt. Ang1e,16mm camera	1
SEB33100020-303	Cable, Remote Control, 16mm camera	1
SEB33100046-301	Protective cover, Reseau	2
SEB33100294-301	Trigger, Electric Hassa1b1ad Camera	2
SEB33100293-302	Handle, Electric Hassa1b1ad Camera	2
SEB33100291-301	Tether , EVA Retractable	2
SEB33100301-301	cutter, Surveyor	1
SV742170-8	Remote Control Unit-PLSS	2
SV742170-2	Bracket, Camera mount	2
SV718783-7	cartridge/ Canister, PLSS LIOH	2
SV701900-18	Battery, PLSS	2
14-0111-01	Defecation Collection Device	4
A7L-106043-05/06	Overshoes, Lunar (PR)	2
SJB33100199-313	Kit, Lec - Waist tether (a)	1
SEB33100191-311	Conveyor assembly, Lunar equipment	1
SOB33100214-304	Deployment Bag, Lunar equipment conveyor	1
SEB11100066-335	PLSS/EVCS Assembly (b)	1
SEB11100066-336	PLSS/EVCS Assembly (c)	1
BW1C80-001	Collection bag, Calibrated, PLSS Feedwater w/sca1e	1
BW1080-001	Collection bag, Ca1ib. PLSS Feedwater w/o scale	3
SEB33100290-301	Safety Line, Lunar Surface	1
14-0112-01	Towels, LM utility (Red)	2
14-0112-01	Towels,LM utility (Blue)	2
SEB16101076-303	TV System, LM Color	1

Representative Apollo Artifacts

Mission ID Apollo 12	Earth Launch Date 11/14/69	Lunar Landing Date 11/19/69	1 of 2
Landing Location 3 11S 23 23W		Lunar Depart Date 11/21/69	

Part Number	Nomenclature	Quantity
SEB16101076-701	Camera, LM Color TV	1
SEB16101076-703	Zoom lens, LM TV	1
SEB16101076	Cable, LM TV Adapter	1
SEB42100104-004	Earplugs	2
LDW340-56013-3	Adapter, SRC/OPS	2
LDW340-56303-1-3	Interim Stowage Assembly	1
LSC330-122-3 - l1	Canister, ECS LIOH	1
LSC340-20l-529-B	Urine Collection Assembly (Small)	used of 1
60-0074-001	Bag, Emesis	4
LDW340-56227-l	Container Assembly, Disposal	1
LOW340-56227-3-l	Container assembly, Disposal	1
LDW340-54301-1- 3	Container, PISS Condensate	1
LDW380-54201-5-1	Antenna, S-Band	1
LDW340-55500-1-1	Tripod, TV	1
LDW340-52261-27	Strap, ECS LIOH Canister	1
LDW340-55404-35	Bag, Camera Mount Bracket	1
LDW340-56272-1&3	Hammock Assembly	1
LDW340-56110-1-1	Bracket, Installation Color TV Camera	1
2338660REV.N	Mounting Assembly RTG Fuel Cask	1
47E301l34-G2REVN	Fuel Cask	1
47D300400 PEV K	Fuel Capsule assembly	1
2334848 REV R	Prime ALSEP Pallet assembly #1 (d)	1
2334849-2 REV AC	Prime ALSEP pallet assembly #2 (e)	1
SEB39100319 - 202	Hammer	1
SEB39103122 - 301	Scoop, Lunar Sample	1
SEB39100314 - 205	Extension Handle	1
SEB39100340 - 203	Tongs	1
SEB39100317-202	Gnomon	1
SEB3100200- 309	Hook, Tether	2
2501-122-K	Camera, Close-up stereo	1
SDB39104308-301	Contrast Target	3
SDB39104503-301	Color Chart	1
2330657	(d)LS Magnetometer experiment	1
2338460-2	(d) Passive seismic experiment	1
2330658	(d) Solar wind experiment	1
47E300779	(e) Radioisotope thermoelectric gen. expo	1
2330660	(e) Subtherma1 ion detector/COGE expo	1
2335945	(e) PSE leveling stool	1
SGB39101165-203	(e) Lunar geological hand tool carrier w/tools	1
SEB3310013-303	Filter, polarizing	1
SEB33100198-3010	(a) Bag, assembly, Lec+ Wt.*303	1

Representative Apollo Artifacts

Mission ID Apollo 12	Earth Launch Date 11/14/69	Lunar Landing Date 11/19/69	1 of 2
Landing Location 3 11S 23 23W		Lunar Depart Date 11/21/69	

Part Number	Nomenclature	Quantity
SV706100-6-22	(b)PLSS	1
8358750-503	(b)EVCS-1	1
SV706100-6-22	(c)PLSS	1
8358751-503	(c)EVCS-2	1

Representative Apollo Artifacts

Mission ID Apollo 14	Earth Launch Date 01/31/71 Lunar Landing Date 02/05/71	1 of 3
Landing Location 3 40S 17 28W	Lunar Depart Date 02/06/71	
Part Number	**Nomenclature**	**Quantity**
SEB 33100113-304	Filter, Polarizing	1
SEB3100277-304	Adapter, Bracket, Rt. Angle, 16mm Camera	1
SEB3100040-305	Camera, Lunar Surface, Electric Hasselblad	1
SEB33100048-304	Lens, 60mm	1
SEB33100020- 303	Cable, Remote control, 16mm camera	1
SEB33100046-301	Protective cover, Reseau	2
SEB3100294-302	Trigger, Electric Hasselblad camera	1
SEB33100293-302A	Handle, Electric Hasselblad camera	1
SEB33100291-301	Tether, EVA retractable	2
SEB33100302-302	Checklist, EVA cuff	2
SEB33100402-301	Brush, lens	1
SEB33100295-307	Camera/Power pack Assy., 16mm L.S.	1
SEB33100100.-213	Camera , 16mm, battery operated	1
SEB33100056-208	5mm lens, 16mm battery operated camera	1
SEB33100303-302	Handle , 16mm battery operated camera	1
SEB33100304-303	Power pack, 16mm battery operated camera	1
SEB33100396:-301	RCU bracket, 16mm battery operated camera	1
SV721783-9	Remote control unit- PLSS (-6)	2
SV742170-2	Bracket, Camera mount (-6)	1
SV718783-9	Cartridge/Canister, PLSS/LIOH (-6)	2
SV701900-22	Battery, PLSS (-6)	:2
14-0111-01	Defecation Collection Device	4
A7L-106043-05/06	Boots, Lunar, pro	2
SEB11100066-359	PLSS/EVCS assembly	1
SEB11100066-360	PLSS/EVCS assembly	1
BW1080-002	Collection bag, calibrated, PLSS feedwater	1
BW1080-002	Collection bag, Calibr., PLSS feedwater w/o scale	1
SEB1310013 4-301	Bag, Jettison stowage	3
SEB33100290-302	Safety line , Lunar surface (100 feet)	1
14-0112-01	Towels, LM utility (Red)	2
14-0112-03	Towels, LM utility (Blue)	2
SEB39105185-301	Brush , Lunar dust	1
SOB33100214-306	Bag, Lunar surface safety line	1
14-0145-01	Device, in-suit, drinking	2
SV729602-4	Buddy SLSS Assembly	1
SEB16100823-305	TV subsystem, Lunar (subsystem includes (a))	1
SEB16101207-303	TV System, LM color (system includes (b))	1
2501-122-M	Camera, Close-up stereo	1
SEB39105177-301	Flag kit, Lunar surface	1
5EB33100361-309	Transporter, Mobile equipment (MET)	1

Representative Apollo Artifacts

Mission ID Apollo 14	Earth Launch Date 01/31/71 Lunar Landing Date 02/05/71	1 of 3
Landing Location 3 40S 17 28W	Lunar Depart Date 02/06/71	
Part Number	Nomenclature	Quantity
3EB42100104-4/5	Earplugs	1 pair
LOW340-56013-3-1	Adapter, SRC/Ops	2
LSC3 3 0-122-3-12	Canister, ECS LIOH	1
LSC340-201-529-8	urine collection assembly, small	6 less ?
S0-0074-001	Bag, Emisis	4
LDW340-58480-1	container assembly, Disposal	2
LDW3 4 0 - 54301-1-3	Container, PLSS condensate	1
LDW380-54201-5-2	Antenna, S-band	1
LDW340-55500- 1-1	Tripod , TV	1
LDW340- 52261-27	strap, ECS LIOH canister	1
LDW340- 55404-35	Bag, Camera mount bracket	1
LDW340-56272-1-3	Hammock assembly	1
LDW340-56272- 3-1	Hammock assembly	1
LDW340-58464-3	Container , Buddy SLSS assembly-stowage	1
LDW340-58484-1-1	Bag , 16mm camera- stowage	1
LDW340-11976-1	Foam side	1
LDW340-11976-15	Foam side	1
Ldw340-11977-1	Strap assembly	1
LDW340-57303-39	Webbing, Tiedown-contingency	1
LDW340-58466-1-2	Pallet assembly, magnetometer	1
LDW340-11977-3	strap assembly	1
2338660 REV R	Mounting assembly Rtg. fuel cask	1
47E301134-G2 REV	Fuel cask	1
47D300400-G1 REV	Fuel capsule assembly	1
2334845 REV.AE	Pallet assembly No.1 (includes (c))	1
2334849-3 REV.AJ	Pallet assembly No.2 (includes (d))	1
SEB39100319-206	Hammer	1
SEB39103122-301	Scoop, lunar sample (Large)	1
SEB39105248-302	Tool , extension	1
SEB39100340-203	Tongs	1
SEB39100317-202	Gnomon	1
SEB39106130-302	Tool assembly, Trenching-Adjustable	1
SEB39105200-301	Scale, sample	1
A13581-D1 REV.B	Magnetometer, Lunar portable	1
2345711-501 REV	Reflect or, Laser ranging retro	1
SEB39105115-302	ASE cable anchor (Apollo simple penetrometer)	1
607R962	(a) Camera, Lunar TV	1
618R376-G01	(a) Lens, TV lunar day)	1
SDB15100061-002	(a) Cover, dust , lens	1
2RC1883H01	(a) Cover, connector, dust	1
SEB16101207-701	(b) Camera, LM color TV	1

Representative Apollo Artifacts

Mission ID Apollo 14	Earth Launch Date 01/31/71	Lunar Landing Date 02/05/71	1 of 3
Landing Location 3 40S 17 28W		Lunar Depart Date 02/06/71	

Part Number	Nomenclature	Quantity
SEB16101207-703	(b) Zoom lens , LM color TV	1
SEB16101207-705	(b) Cable, LM color TV	1
SEB16101207-707	(b) Cover, LM TV lens	1
2330750-6	(c) Active seismic experiment	1
2338460-7 REV F	(c) Passive seismic experiment	1
2338975REV B	(c) Charged particle lunar environment exp.	1
47E300779-G9F	(d) Radioisotope thermoelectric gener. exp.	1
2338104 REV A	(d) Suprthml ion detect ./cold cathode gageexp	1
2334723-501P	(d) PSE leveling stool	1
SGB39101165-208	(d) Lunar geol. expo tool carrier w/tools	1
N/A	(d) ALSEP deployment tools	1
SJB3 3100199	Kit, LEC- waist tether	1
SEB33100198-303	Bag assy., Lunar equip. conveyor & waist teth	1
SEB33100191-313	Conveyor assy., lunar equipment	1
SDB33100214-304	Bag, deployment, lunar equipment conveyor	1

Representative Apollo Artifacts

Mission ID Apollo 15	Earth Launch Date 07/26/71	Lunar Landing Date 07/30/71	1 of 4
Landing Location 26 6N 3 39E		Lunar Depart Date 08/02/71	

Part Number	Nomenclature	Quantity
SEB3100113-304	Filter, Polarizing	1
SEB3100040-307	Camera , Hasselblad- Electric Data	1
SEB3100048-305	Lens, 60mm	2
SEB3100046-301	Protective Cover, Reseau	3
SEB33100294-302	Trigger, Hasselblad Electric Data	3
SEB33100293-302A	Handle, Hasselblad- Electric Data	3
SEB33100291-301	Tether, EVA retractable (CDR)	1
SEB33100402- 301	Brush, Lens	2
SEB33100255	Camera/Power Pack Assembly, 16mm L.S.	1
SEB33100100-215	Camera, 16mm battery operated	1
SEB33100010-303	Lens, 10mm 16mm battery operated camera	1
SEB33100303-J02	Handle, 16mm battery operated camera	1
SEB33100304-30J	Power Pack, 16mm battery operated camera	1
SEB33100396-301	RCU Bracket, 16mm battery operated camera	1
SEB33100291-J03	Tether, EVA Retractable (LMP)	1
SEB3310040-309	Camera, L.S. Electric	1
SEB33100284-302	Lens, 500mm	1
SEB331000Jl-204	Ringsight	1
SEB13100061-209	Garment , Constant wear	2
A6L-400000-16	Garment , Liquid cooled	2
SV721783-14	Remote Control Unit-PLSS (-7)	2
SV742170-3	Bracket, Camera mount (-7)	3
SEB1l100112-301	Cartridge Container assembly, PLSS/LIOH	4
SV723240-1	container assy., protective-PLSS LIOH	4
SV710854	Cartridge, PLSS LIOH	4
SV722862	Battery , PLSS (-7)	4
A7L8106062-03/04	Boots, Lunar-pr	2
SEB33100198-303	Bag Assembly, LEC+WT	1
SEB3310019l-315	Conveyor assembly, Lunar equipment	1
SDB33100214-304	Bag, Deployment, LEC	1
SEB11100066-129	PLSS/EVCS Assembly (wet) (includes (a))	1
SEB11100066-130	PLSS/EVCS Assembly (wet) (includes (b))	1
SEB1J100134-301	Bag, Jettison stowage	4
A7LB-l09042-02	LCG Adapter	2
BW1060-003	Jacket, Assembly, ICG	2
BW1061-002	Trouser Assembly, ICG	2
BW1062-002	Boot, Right ICG	2
BW1062-001	Boot, Left, ICG	2
SEB33100290-J02	Safety Line, Lunar Surface (100 ft .)	1
14-0112-01	Towels, LM utility (Red)	2
14-0112-03	Towels, LM utility (Blue)	2

Representative Apollo Artifacts

Mission ID Apollo 15	Earth Launch Date 07/26/71	Lunar Landing Date 07/30/71	1 of 4
Landing Location 26 6N 3 39E		Lunar Depart Date 08/02/71	

Part Number	Nomenclature	Quantity
SEB39105185-302	Brush, Lunar Dust	1
SOB3J100214-306	Bag, Lunar Surface safety Line	1
SV729602-9	Buddy SLSS Assembly	1
V36-601012-35l	Sleeping Restraint Assembly	2
SEB39106716-302	Tool Carrier, PLSS (CDR)	1
SEB39106717-J02	Tool carrier, PLSS (LMP)	1
SEBJ9106736-301	Strap, LCRU Retainer	1
SEB33100794-301	Helmet and LEVA Interim Stowage Container Assy	1
14-0121-301	Food Assy. LM(A/S)	used of 1
14-0121-302	Food Assy. LM (D/S pallet)	used of 1
14-0121-303	Food Assembly LM (D/S pallet NO. 3)	used of 1
14-0228	Wet Wipes , Facial	used of 9
2265826	GCTA- Ground Controlled TV assy. (includes (c))	1
8370855-502	Communication Relay System (includes (d))	1
209-42999-8	Lunar Roving Vehicle (LRV)	1
10M34951-1	Tool , Deployment- LRV	1
SEB39105177-301	Flag Kit, Lunar Surface	1
SEB33100733-301	Staff, 16mm camera	1
SEB33100865-301	Holder , Map-LRV	1
SEB33100879-301	Bag, Stowage-Gnomon	1
SEB33100881-303	Adapter Assy., -20 DSBD 70mm Hasselblad	2
LDW340-56013-7-1	Adapter, SCR/OPS	2
LSC 330-122-3-12	Cannister, ECS LIOH	2
LSC 340-201-529-8	Urine collection assy., (small)	2
60-0074-001	Bag , Emisis	6
LDW340-55500-1-1	Tripod, TV	1
LDW340-52261-27	strap, ECS LIOH Cannister	1
LDW340-11246-35	strap, LIOH	1
LSC340-1000-19-1	Urine receptacle system	1
LDW340-60611-1-4	Pallet assembly No. 1, Equipment Transfer	1
LDW340-60612-1-3	Pallet Assembly No.2, Equipment Transfer	1
LDW340-60614-3-5	Pallet Assembly No.4, Equipment Transfer	1
LDW340-56272-1-3	Hammock Assembly	1
LDW340-56272-3-1	Hammock Assembly	1
LDW340-58464-3-1	Container, Buddy SLSS assembly stowage	1
LDW340-11976-1-1	Foam Side	1
LDW340-11976-15	Foam Side	1
LDW340-11977-1-1	Strap Assembly	1
LDW340- 60720-1	Pallet, LRV Aft Chassis	1
LDW340-6077S-1	Pallet, Quad 3- Payload	1
LDW340-57303-39	Webbing, Tiedown- contingency	1

Mission ID Apollo 15	Earth Launch Date 07/26/71	Lunar Landing Date 07/30/71	1 of 4
Landing Location 26 6N 3 39E		Lunar Depart Date 08/02/71	

Part Number	Nomenclature	Quantity
LDW340-60784-5	Vise Device, Drill string	1
LDW340-60187-1	Bag, stowage- 70mm magazine	1
LSC330-122-3-13	Cannister, ECS LIOH	1
LDW340-11386-7	Strap Assembly, Sleep Restraint	2
2338660 REV R	Mounting Assembly, RTG Fuel Cask	1
47E301134-G2REVN	Fuel cask	1
470300400-G1REVR	Fuel capsule assembly	1
2344986 REV V	Pallet Assembly No. 1	1
2338460-8 REV G	Experiment, passive seismic	1
2330658	Experiment, solar wind	1
2341440 REV A	Experiment, dust detector	1
2339080 REV J	Pallet Assembly No. 2	1
2345430-101 REVA	Experiment, heat flow	1
23 44723-501 REVA	Stool, PSE leveling	1
47E300779-G6REVF	Generator, radioisotope	1
N/A	Tools ALSEP deployment	1
2338104 REV A	Side/CCGE	1
SEB39105248-306	Tool, Extension	1
SEB39106245-301	Tongs, 32 inch	2
SEB39100317-302	Gnomon	1
2347200-501 REVE	Reflector, Laser Ranging Retro	1
SGB39105801-402	Lunar Geology Exp. Tool Carrier with tools	1
SEB39105725-301	Scoop, Adjustable Sampling	1
SEB39100319-301	Hammer	1
467A8060000-099	Drill Assembly, Apollo L.S.	1
SEB39106050-302	Penetrometer Assembly, Self Recording	1
SEB39106329-301	Accessory Holder assy., Penetrometer (includes (e))	1
SEB39106380-303	Rake, Lunar Sampling	1
SV706100-7-14	(a) PLSS	1
8358750-503	(a) EVCS-1	1
SV722862-2	(a) Battery, PLSS	1
SV710854-11	(a) cartridge, LIOH	1
SV706100-7-14	(b) PLSS	1
8358751-503	(b) EVCS-2	1
SV722862-2	(b) Battery, PLSS	1
SV710854-11	(b) Cartridge, LIOH	1
2265840-501	(c) CTV camera, color TV	1
2265825	(c) TV control unit	1
8370854-502	(d) Lunar communication relay unit (LCRU)	1
8670958-501	(d) Stowage contain., LCRU ancillary items)	1
8151103-3	(d) Batteries , LCRU	3

Representative Apollo Artifacts

Mission ID Apollo 15	Earth Launch Date 07/26/71	Lunar Landing Date 07/30/71	1 of 4
Landing Location 26 6N 3 39E		Lunar Depart Date 08/02/71	

Part Number	Nomenclature	Quantity
8370891-502	(d) Hi gain antenna assembly	1
8670954-502	(d) Lo gain antenna assembly	1
SDB39106117-301	(e) Large base assembly	1
SDB39106115-001	(e) Cone, .2	1
SDB39106112-001	(e) Cone, .5	1
SDB39106113-301	(e) Cone assembly, 1.0	1
SDB39106327-301	(e) Cover assembly	1
SJB33100199-318	Kit., Lee-waist, tether	1

Representative Apollo Artifacts

Mission 10 Apollo 16	Earth Launch Date 04/16/72	Lunar Landing Date 04/20/72	1 of 4
Landing Location 8 595 15 31E		Lunar Depart Date 04/23/72	

Part Number	Nomenclature	Quantity
SEB33100113-305	Filter, Polarizing	1
SEB33100040-307	Camera , Hasselblad-Electric Data	2
SEB33100048-305	Lens , 60mm	2
SEB33100046-301	Protective cover, Reseau	3
SEB33100294-303	Trigger, Hasselblad-Electric Data	2
SEB33100293-302A	Handle, Hasselblad- Electric Data	2
SEB33100291-305	Tether EVA Retractable (CDR)	1
SEB33100402-301	Brush , Lens	3
SEB33100295-309	Camera/Power pack Assy. l6mm L.S. (includes (a))	1
SEB3310029l-305	Tether, EVA Retractable -(LMP)	1
SEB42100080-202	utility Towel Assy. LM	used of 3
14-0111-01	Defecation Collection Device	used of 6
A7L-106043-05-06	Boots, Lunar Pr.	2
SEB33100192-309	Life Line, Lunar Equip. (LELL)	1
SEB11100066-146	PLSS/EVCS Assy.-LMP (includes (b))	1
SEB11100066-145	PLSS/EVCS Assy., CDR (includes (c))	1
SEB13l00134-301	Bag, Jettison stowage	4
SEB42100086-203	Dispenser, Tissue	used of 2
A7LB-109042-02	LCG Adapter	2
BW1060-003	Jacket Assy., ICG	2
BW1061-002	Trouser Assy., ICG	2
BW1062-002	Boot, Right , ICG	2
BW1062-001	Boot, Left, ICG	2
14-0112-01	Towels, 1M utility (Red)	2
14-0112-03	Towels, 1M Utility (Blue)	2
SEB39105185-303	Brush, Lunar Dust	1
SV729602-9	Buddy SLSS Assy.	1
V36-601012-351	Sleeping Restraint Assy.	2
SEB9106716-302	Tool Carrier, PLSS (CDR)	1
SEB39106717-303	Tool Carrier, PLSS (UHP)	1
SEB391067360301	strap , LCRU Retainer	1
SEB33100794-301	Helmet and LEVA Interim stowage container Assy.	1
14-0121-301	Food Assy. LM (A/S)	used of 1
14-0152-07	In-suit Beverage Assy.	4
SEB13100218-301	In-suit Food Bar Assy.	6
14- 0121-302	Food Assy., LM (0/5 Pallet No. 1)	used of 1
14-0121-303	Food Assy., LM (0/5 Pallet No. 2)	used of 1
14-0228	Wet Wipes, Facial	used of 9
2265826-502	GCTA- Ground Controlled TV Assy. (includes (d))	1
9370855-502	Communication Relay System (includes (e))	1
290-42999-9	Lunar Roving Vehicle	1
SEB39105177-301	Flag Kit, Lunar Surface	1
SEB33100733-301	Staff, 16mm Camera	1

Mission 10 Apollo 16	Earth Launch Date 04/16/72	Lunar Landing Date 04/20/72 1 of 4
Landing Location 8 595 15 31E		Lunar Depart Date 04/23/72
Part Number	Nomenclature	Quantity
SEB33100865-303	Holder, Map LRV	1
SEB33100881-303*	Adapter Assy., 20 DSBD 70mm Hasselblad, *- 303B	1
SEB33100897-301	Staff Loop Assy., l6mm Camera	1
SEB33100897-303	Staff Loop Assy., Low Gain	1
SEB3310092-301	Sunshade, GCTA	1
LDW340-56013-3-3	Adapter, SRC/Ops	2
LS0330-122-3-12	Canister, ECS LIOH	1
LSC340-201-529-8	Urine Collection Assy. (Small)	used of 2
60-0074-001	Bag, Emesis	used of 6
LDW340-60636-1	Bag, Equipt. Transfer	1
LDW340-55s00-1-1	Tripod, TV	1
LDW340-s2261-27	strap, ECS LIOH Canister	1
LDW340-11246-3s	strap LIOH	1
LSC340-1000-19-2	Urine, Receptacle system	1
LDW340-60611-1-s	Pallet Assy. No. 1, Equipment Transfer	1
LDW340-60612-1-3	Pallet Assy. No. 2, Equipment Transfer	1
LDW340-60614-3-4	Pallet Assy. No. 4, Equipment Transfer	1
LDW340-56272-1-3	Hammock Assy.	1
LDW340-s6272-3-1	Hammock Assy.	1
LDW340-s8464-3-1	Container, Buddy SLSS Assy., stowage	1
LDW340-60781-1	Pallet, LRV Aft Chassis	1
LDW340-60780-3-1	Pallet, Quad 3- Payload	1
LDW340-s7303-39	Webbing, Tie-down contingency	1
LDW340-60784-5-3	Vise Device, Drill string	1
LDW340-60187-s	Bag, stowage. 500mm system	1
LSC330-122-3-13	Canister, ECS LIOH	1
LDW340-11366-7	strap Assy., Sleep Restraint	2
LDW340-6066s-1	container, Bore/core stem stowage	1
LDW340-6066s-9-1	cover, Bore/Core Stem stowage	1
LDW340-60666-s	Retainer Assy., Lower	1
LDW340-60666-7	Retainer Assy., Upper	1
LDW340-P15677-1	Cover Assy., Retainer	1
LDW340M15913-13	Spacer (Bore and Core Stem Stowage)	1
LDW340M15913 -11	Spacer (Bore and Core Stem Stowage)	1
LDW340-P15924-13	stowage Retainer, GCTA Sunshade	1
LDW340-60668-9-1	Stowage strap Assy., GCTA Sunshade	1
2238660 REV R	Mounting Assy., Rtg. Fuel Cask	1
47E301134-G2REVN	Fuel Cask	1
47D300400-G1REV	Fuel Capsule Assy.	1
2339000 REV AB	Pallet Assy. No. 1 (includes (f))	1
2339100 REV AD	Pallet Assy. No. 2 (includes (g))	1
SEB39105248-308	Tool Extension	2
SEB39106245-301	Tongs, 32 inch	2

Representative Apollo Artifacts

Mission 10 Apollo 16	Earth Launch Date 04/16/72 Lunar Landing Date 04/20/72	1 of 4
Landing Location 8 595 15 31E	Lunar Depart Date 04/23/72	
Part Number	Nomenclature	Quantity
SEB39100317	Gnomon	1
47J224510G2	Cosmic Ray Detector Package	1
A13581-D201-B	Magnetometer, Lunar portable	1
SGB39105801-404	Lunar Geology Exper. Tool Carrier (includes (h))	1
687401	U V Camera, L.S.	1
467A8060000-129	Drill Assy., Apollo L.S.	1
SEB39106050-303	Penetrometer Assy., Self Recording	1
SEB 39106329-301	Accessory Holder Assy. (Penetrometer)	1
SEB39106380-303	Rake, Lunar Sampling	1
467A8060016-059	Bore Stem, Lower	2
467A80600l6-069	Bore stem, Upper	4
467A8060190-009	Bits, Solid Face Bore	2
467A8090000-011	Bit, Open Face Core	1
467A8060014-009	Reducer, Core Bit	1
5EB39108120-301	Bag, Core Stem Teflon	1
SEB39108120-302	Bag, Core Stem Teflon	1
SEB33100100-218	Camera, 16mm Battery operated	1
SEB33100010-303	Lens, 10mm, 16mm Battery Operated camera	1
SEB33100303-302	Handle , 16mm Battery Operated Camera	1
SEB33100304-303	Power Pack, 16mm Battery Operated Camera	1
SEB33100396-301	RCU Bracket, 16mm Battery Operated Camera	1
2265840-502	(d) CTV camera, color TV	1
2265825-5C2	(d) TCU (Television control unit)	1
8670958-501	(d) stowage container, LCRU ancillary items	1
8151103-3	(e) Batteries, LCRU	2
8370891-502	(e) Antenna assembly, hi gain	1
8670994-502	(e) Antenna assembly lo gain	1
2338460-9 REV J	(f) Experiment, passive seismic	1
2330750-7 REV A	(f) Experiment, Active seismic	1
2345430-101 REVB	(f) Experiment, heat flow	1
2344723-501 REVA	(g) Stool , PSE leveling	1
47E300779-G9REVF	(g) Generator, radioisotope, thermoelectric	1
N/A	(g) Tools, ALSEP deployment	1
2339230 REV F	(g) Anchor, ASE-cable	2
2330657	(f) Magnetometer, Lunar surface	1
SDB39106117-301	Large Base Assembly	1
SDB39106115-001	Cone, .20	1
SEB39106113-301	Cone Assembly, 1.0	1
SDB39106327-30l	Cover Assembly	1
SEB33100100-218	(a) Camera , 16mm, battery operated	1
SEB33100010-303	(a) Lens, 10mm, 16mm battery operated camera	1
SEB33100303-302	(a) Handle , 16mm battery operated camera	1
SEB33100304-303	(a) Power pack, 16mm battery operated camera	1

Mission 10 Apollo 16	Earth Launch Date 04/16/72	Lunar Landing Date 04/20/72	1 of 4
Landing Location 8 595 15 31E		Lunar Depart Date 04/23/72	

Part Number	Nomenclature	Quantity
SEB33100396-301	(a) RCU bracket, 16mm battery operated camera	1
SV706100-7-19	(b) PLSS	1
8358751-5C3	(b) EVCS-l	1
SV722862-5C3	(b) Battery, PLSS	1
SV710854-11	(b) cartridge, LIOH	1
SEB13100219-301	(b) Cover, gas connector	1
SEB13100230-301	(b) Cover, MWC dust (multiple water connector)	1
SEB13100232-302	(b) Cover, electrical connector, dust	1
SV706100-7-19	(c) PLSS	1
8358751-5C3	(c) EVCS-2	1
SV722862-3	(c) Battery, PLSS	1
SV710854-11	(c) cartridge, LIOH	1
SEB13100219-301	(c) Cover, gas connector	1
SEB13100230-301	(c) Cover, MWC dust (multiple water connector)	1
SEB13100232-302	(c) Cover, electrical connector, dust	1
SDB39106112-001	Cone, .5	1
SEB33100040-309	Camera, L.S. Electric	1
SEB33100284-302	Lens , 500mm	1
SEB33100031-204	Ringsight	1
SEB33100900-301	Shelf, interim stowage	1
A6L400000-16	Garment , liquid cooling	1
SV721783-14	Remote control unit-PLSS	2
SV742170-3	Bracket, camera mount (-7)	2
SEB11100112-301	cartridge, container Assy., PLSS/LIOH	4
SV723240-1	container Assy., protective, PLSS/LIOH	4
SV710854-11	cartridge, PLSS/LIOH	4
SV722862-3	Battery, PLSS (-7)	4
SJB33100199-319	Kit, Lec-waist tether	1
SEB33100198-303	Bag Assy., Lec-waist	1
SEB33100191-312	Lifeline (lightweight)	1
SDB33100214-305	Bag, deployment, lifeline	1
SEB33100192-307	Tether, waist, EVA, left	1
SEB33100192-308	Tether, waist, EVA, right	1
SEB33100015-302	Straps	2
SEB33100192-309	Lifeline, lunar equipment (LELL)	1
SEB39107047-302	(h) Scoop, large adjustable	1
SEB39100319-301	(h) Hammer	1
SDB39106391-302	(h) Tool Assy., drive tube	1

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Mission 10 Apollo 17	Earth Launch Date 12/07/72	Lunar Landing Date 12/11/72	1 of 4
Landing Location 20 10N 30 46E		Lunar Depart Date 12/13/72	

Part Number	Nomenclature	Quantity
SEB33100113-305	Filter, Polarizing	1
SEB33100040-307	Camera, Hasselblad-Electric, Data	2
SEB33100048-305	Lens, 60mm	2
SEB33100277-304	Adapter Bracket, Rt. Angle, (16 mm DAO)	1
SEB33100046-301	Protective cover, Reseau	3
SEB33100294-303	Trigger, Hasselblad, Electric Data	2
SEB33100293-302A	Handle, Hasselblad- Electric Data	2
SEB33100291-305	Tether EVA Retractable	2
SEB33100402-301	Brush, Lens	2
SEB33100040-309	Camera, L. S. Electric	1
SEB33100284-302	Lens , 500mm	1
SEB33100031-204	Ringsight	1
SEB33100900-301	Shelf, Interim stowage	1
SDB12100086-001	Wrist Mirror	2
SEB12100030-201	Watchband	2
SV721783-14	Remote Control unit- PLSS	2
SV742170-3	Bracket, camera mount (-7)	2
SEB11100112-301	Cartridge Cont. Assy., PLSS/LIOH	4
SV723240-1	Container Assy., Protective- PLSS LIOH	4
SV710854-11	Cartridge, PLSS LIOH	4
SEB42100080-202	Utility Towel Assy., LM	used of 3
14 - 0111-01	Defecation Collection Device	12
A7LB-203034-15/	Gloves, EV Pair	2
A7LB106062-03/04	Boots , Lunar pair	2
SEB33100199-320	Kit, LEC waist tether (a)	1
SEB33100192-310	Lift Line, Lunar equipment (LELL)	1
SEB11100066-148	PLSS/EVCS Assy.-LMP	1
SV706100-7-19	PLSS	1
8358751-5C4	EVCS-2	1
SV722862-3	Battery, PLSS	1
SV710854-11	cartridge, LIOH	1
SEB13100219-301	Cove r , Gas connector	1
SEB13100230-301	Cover, MWC Dust (Multiple water Connector)	1
SEB13100232-302	Cover, Electrical connector, Dust	1
SEBIII00066-145	PLSS/EVCS Assy.- Cdr	1
SV706100-7- 19	PLSS	1
8358750-503	EVCS-l	1
SV722862-3	Battery, PLSS	1
SV710854-11	Cartridge, LIOH	1
SEB13 100 219-301	Cover, Gas connector	1
SEB13100230-301	Cover, MWC dust (Multiple water connector)	1
SEB13100232-302	Cover , Electrical connector, Dust	1

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Mission 10 Apollo 17	Earth Launch Date 12/07/72 · Lunar Landing Date 12/11/72	1 of 4
Landing Location 20 10N 30 46E	Lunar Depart Date 12/13/72	
Part Number	Nomenclature	Quantity
SEB13100134- 301	Bag, Jettison stowage	4
SEB42100086-203	Dispenser, Tissue	2
A7LB-109042-02	LCG Adapter	2
BWI 060-003	Jacket Assy., ICG	2
BW1061-002	Trouser Assy., ICG	2
BWI 062-002	Boot, right l CG	2
BW1062-001	Boot, left ICG	2
14-0112-01	Towels, LM, Utility (Red)	2
14-0112-03	Towels , UK Utility (Blue)	2
SEB39105185-303	Brush, Lunar Dust	1
14-0151-02	Device, I n-suit, Drinking	4
SV729602-9	Buddy, SLSS Assy.	1
V36-601012-351	Sleeping Restraint Assy.	2
SEB391067°16- 303	Tool carrier, PLSS (Cdr)	1
SEB39106717-303	Tool Carrier, PLSS (LMP)	1
SEB39106736-301	strap, LCRU Retainer	1
SEB33100794-301	Hel met and LEVA interim stowage container assembly	1
SV748660-1	Antenna Repair Kit, Ops	1
A7L-101033-02	Lanyard, IV ITLSA Donning	1
SEC12100087-301	Bag, LM Personal Hygiene Kit	1
N/A	Nail Clippers	1
N/A	Soap	1
14-0121-301	Food Assy., LM(A/S)	used of 1
14-0121-302	Food Assy., LM (D/S Pallet No. 1)	used of 1
14-0228	Wet Wipes, Facial	used of 9
1F218	Ointment, Mycolog Bact.	1
2265826-502	GCTA-Ground controlled television assembly	1
2265840-502	CTV-Camera, color TV	1
2265825-502	TCU-Television control unit	1
2265261-502	Stowage mount Assy., TV camera	1
8370855-502	communication relay system	1
8370854-502	LCRU, (Lunar communications relay unit)	1
8670958-501	Stowage container; LCRU ancillary items	1
8151103-3	Batteries , LCRU	2
8370891-502	Antenna Assy., Hi-gain	1
8670994-502	Antenna Assy., Lo-gain	1
2275697-501	Helper spring Assy., TCU cradle	1
209-42999-10	Lunar Roving Vehicle	1
SEB39105177-301	Flag kit, Lunar surface	1
SEB33100881-305	Adapter Assy., 20 DSBD 70mm Hasselblad	2
SEB33l00897-303	Staff Loop Assy. Lo-gain	1
SEB33100902-307	Sun Shade, GCTA	1
SEB33100911-303	Staff Assy., LRV accessory	1

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Mission 10 Apollo 17	Earth Launch Date 12/07/72 Lunar Landing Date 12/11/72	1 of 4
Landing Location 20 10N 30 46E	Lunar Depart Date 12/13/72	
Part Number	Nomenclature	Quantity
SEB33100918-301	Hap holder adapter, loop Assy.	1
SEB33100865-303	Hap holder, LRV	1
SEB33100919-301	Loop Assy., adapter	1
LDW340-56013-3-3	Adapter, SRC/Ops	2
LSC330-12 2-3-12	Canisters, ECS LIOH	1
LSC340-201-529-8	Urine collection Assy. (small)	used of 2
60-0074-001 AND	Bag, Emisis	used of 6
LDW340-60636-1	Bag, Equipment transfer	1
LDW340-52261-27	straps, ECS LIOH canister	1
LDW340-11246-35	Strap LIOH	1
LSC340-1000-19-2	Urine receptacle system	1
LDW340-60611-1-6	Pallet Assy. No.1, Equipment transfer	1
LDW340-60612 -1-4	Pallet Assy. No.2, Equipment transfer	1
LDW340-60614-3-4	Pallet Assy. No.4, Equipment transfer	1
LDW340-56272-1-3	Hammock Assy.	1
LDW340-56272-3-1	Hammock Assy.	1
LDW340-58464-3-1	container, Buddy SLSS Assy., stowage	1
LDW340-60782-21-	Pallet, LRV aft chassis	1
LDW340-60779-1	Pallet , Quad 3- Payload	1
LDW340-57303-39	Webbing, Tie-down contingency	1
LDW340-60784-5-4	Vise device, Drill string	1
LDW340-60187-5	Bag, Stowage, 500mm system	1
LSC330-122-3-13	Canister, ECS LIOH	1
LDW340-11366-7	Strap assy., Sleep restraint	1
LDW340-60665-1	Container , Bore/Core stem stowage	1
LDW340-60665-9-2	Cover, Bore/Core stem stowage	1
LDW360-60666-5-1	Retainer Assy., Lower	1
LDW340-60666-7-1	Retainer Assy., Upper	1
LDW340P-15677-1	Cover Assy., Retainer	1
LDW340M15913-13-	Spacer (Core and Bore stem stowage)	1
LDW340M15913-11-	Spacer (Core and Bore stem stowage)	1
LDW340P15924-11	stowage Retainer, GCTA sunshade	1
LDW340-60668-1-1	stowage strap Assy., GCTA sunshade	1
LDW280-60820-1	Bag, Neutron probe, Thermal	1
2338660 REV S	Mounting Assy., Rig. Fuel cask	1
47E301134-G2REVN	Fuel cask	1
47D300400-G2REVU	Fuel capsule assembly	1
2348700-501REVAE	Pallet Assy., No. 1	1
2348700 REV A	Lunar seismic profiling experiment (S-203)	1
2347400-103 REVN	Lunar mass spectrometer (S-205)	1
2345856, REV. C	Gravimeter, Lunar surface (S-207)	1
2348800-501 REVW	Pallet assy., No.2	1
2345430-102 REVC	Heat flow experiment (S-037)	1

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Mission 10 Apollo 17	Earth Launch Date 12/07/72 Lunar Landing Date 12/11/72	1 of 4
Landing Location 20 10N 30 46E	Lunar Depart Date 12/13/72	
Part Number	Nomenclature	Quantity
47E300779-09REVH	Generator, Radioisotope thermoelectric	1
N/A	Tools , ALSEP deployment	1
2347700-102REVF	Lunar ejecta & micrometeoroid experim. (S-202)	1
SEB39105248-30B	Tool extension 2	2
SEB39106245-301	Tongs 2	2
SEB39100317-304	Gnomon	1
SEB39107047-301	Scoop, large adjustable	1
SEB39100319-301	Hammer	1
SDB39106391-302	Tool Assy., Drive tool	1
464710-2	Transmitter, Sep. expo	1
464711-2	Receiver, Sep. expo	1
2025000-1	Gravimeter, Traverse (S-199)	1
467A8060000-139	Drill Assy., Apollo L. S.	1
SEB39106380-303	Rake, Lunar sampling	1
467A8060016-0B9	Bore stem, Lower 2	2
467A8060016-109	Bore stem, Upper 4	4
2348320-601REV G	Transport module Assy.,(LSP charges)	1
2348320-602REV G	Transport module Assy., (LSP charges)	1
PD000190-009	Bits, solid face bore	2
467A8060014-019	Reducer, core bit	1
SEB39106280-301	Sampler, LRV soil	1
SEB39108120-30S	Bag, Core stem Teflon	1
SEB39108120-306	Bag, Core stem Teflon	1
SEB42100632-301	Earplug and overwrap pouch Assy.	1
14-0121-303	Food assembly, (D/S Pallet No.2)	used of 1
SV722862-3	Battery, PLSS(-7)	4
SEB33100198-303	(a) Bag Assy., LEC+wt.	1
SEB13100061-209	Garment, constant wear	2
A6L-400000-19	Garment , liquid cooling	2

[i] Material degradation may include changes in surface appearance such as discoloration, fading, dulling, flaking, rumpling, pitting, mud-cracking, or scratching.
[ii] The ribbon cables that tended to lay flat on Earth where their own weight pulled them down did not necessarily do so in the smaller gravity of the Moon. This was especially noticed on Apollo 12.
[iii] The SWS radiator faced the LM in the Apollo 15 configuration.