Lunar Surface Science Workshop (LSSW)
Planetary Protection / Permanently Shadowed Region (PSR) Classification Report

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NASA Lunar Surface Science Workshops (LSSWs)

NASA is currently embarking on plans to send humans forward to the Moon and create a sustainable human presence on the lunar surface as well as ramp up the cadence of landed robotic lunar missions. Given these anticipated robotic and human flights, multiple areas of discussion and research have emerged to enable and optimize these flight opportunities as well as to conduct mission operations in a responsible manner. To address these issues and solicit community input as these new lunar robotic and human flight programs are created, NASA has started a series of short, focused workshops to solicit community input to help identify and close knowledge gaps associated with robotic and crew surface activities.

Planetary Protection / Permanently Shadowed Region (PSR) Classification Workshop

On 4 September 2020, an LSSW was held focused on "Planetary Protection / PSR Classification". For this LSSW, we assumed that for the purposes of Planetary Protection as well as addressing science and exploration questions, not all PSRs are created equal. Questions to be addressed during the LSSW included:

- What are the major distinctions among PSRs?
- How do we identify and classify different PSRs (e.g., keep-out zones vs. robotic/crew exploration targets vs. impact targets)?
- What other locations (or portions therein) need to be classified? (e.g., heritage sites [A11–17, Luna, Surveyor, Chang'E]; past impact sites [LCROSS, S-IVB, Apollo ascent stages,

LADEE, etc.]; current missions [NASA, commercial, international]; future infrastructure sites [crewed landings, solar farms, sustainable base]).

- How do we set policy to govern PSRs and other sensitive/strategic sites within our own agency, the commercial sector, and internationally?

Planetary Protection (PP) is a vast field which could by no means be thoroughly addressed in a single day workshop. In an effort to create a focused study, the workshop discussion was focused on the PP policies needed to ensure scientific integrity and provide the protection of future scientific potential. We acknowledge that the sociologic, religious, economic, or other aspects of PP are also important; however, these were not topics for this particular workshop.

The workshop was underpinned by the understanding that lunar "reverse contamination" would be generally considered to not be central to our discussion. Life as we know it has little chance of surviving the vacuum and radiation heavy environment on the Moon. While organic compounds are likely to survive and are of future exploration interest, especially in permanently shadowed regions, it is unlikely that such compounds will be of danger of widespread contamination upon return to Earth.

Instead, this LSSW was focused on the fact that any exploration of the Moon, especially by landed operations with humans, is likely to produce waste products and fuel exhausts that could be measurable by current and/or future scientific exploration of the Moon. Here we aim to identify how these contaminants would impact potential future measurements. Regions of interest include highly sensitive measurements of the lunar PSRs (and micro-PSRs) that may be contaminated and contaminants that may collect on sites visited by human exploration. The LSSW also aimed to identify any other sites of unique interest that might be of protection interest (e.g., caves, magnetic anomalies, fresh impacts).

The workshop also highlighted the potential relevance of lunar Planetary Protection activities for informing Planetary Protection policies enacted for Mars. The Moon is generally considered sterile as compared to Mars, where the presence of extant or past life is considered open. Knowing the level to which robotic and human exploration can impact the lunar environment may aid our approach and policy in Mars Planetary Protection.

The full meeting agenda is shown in Table 1. All talks were recorded and are available for online viewing at https://sservi.nasa.gov/lssw/theme-6.html.

Current Planetary Protection Status:

As we push forward to the Moon and work towards building a sustainable lunar human presence, we recommend due diligence in assessing the potential impacts surrounding human exploration and resource utilization which may compromise future scientific exploration.

Planetary Protection (PP) typical refers to (i) managing contact between terrestrial life forms and organic material from celestial bodies as it relates to adversely affecting the scientific study of these bodies, called forward contamination; and (ii) mitigating harmful contact between pathogens or biology from other celestial bodies and terrestrial biology, called backward contamination. (Planetary Protection Board Report, 2019).

The following to Planetary Protection categories are of most relevance to the Moon:

> **Category I.** includes any mission to a target body which is not of direct interest for understanding the process of chemical evolution or the origin of life. No protection of such bodies is warranted, and no planetary protection requirements are imposed by this policy (COSPAR Policy on Planetary Protection).

> **Category II.** missions comprise all types of missions to those target bodies where there is significant interest relative to the process of chemical evolution and the origin of life, but where there is only a remote chance that contamination carried by a spacecraft could compromise future investigations. The requirements are for simple documentation only. Preparation of a short planetary protection plan is required for these flight projects primarily to outline intended or potential impact targets, brief pre- and post-launch analyses detailing impact strategies, and a post- encounter and End-of-Mission Report which will provide the location of impact if such an event occurs (COSPAR Policy on Planetary Protection).

At the time of this LSSW workshop, NASA's Planetary Protection policy stated that only polar PSR regions south of 79°S latitude and areas north of 86°N latitude are subject to protections implied by Category II while the remainder of the Moon is Category I. Contamination control is a practice of controlling the introduction and removal of unwanted materials that could impede the proper function of a system or component. While contamination control measures often serve to reduce the risk of forward contamination for planetary production, the ultimate goal is to improve system function (Planetary Protection Board Report, 2019). We also consider the needs of contamination control on the lunar surface for preserving the scientific integrity of lunar sites of interest.

Permanently Shadowed Region (PSR) Classification and Protection Considerations

Based on the current planetary protection guidelines and community focus, this LSSW identified the Permanently Shadowed Regions (PSRs) as a unique area for planetary protection study. There may be a need to potentially redefine a classification scheme for PSR volatile protection for future scientific return on these regions. Forward contamination of these unique environments, namely from landing exhausts or large-scale resource mining, could contaminate these regions to a level which could adversely affect the fidelity of scientific investigations of these regions. However, the level of contamination deemed detrimental enough to science that would warrant a new PSR protection classification is currently unquantified and warrants further study. Further, these areas and effects are not fully represented by the regional approach previously taken to designating the polar regions as Category II.

There are many limitations in our current data, namely in that most methods of searching for the presence of polar volatiles are only searching for surface reservoirs or at very broad scale (e.g., neutron spectroscopy), while theoretical predictions of bulk ice can be highly localized and are namely for subsurface reservoirs. Currently, there is a significant mismatch between theoretical predictions of ice stability and volatile detections. The future wave of "small sat" missions (Lunar Flashlight, LunaH Map, Trailblazer, etc.) can provide large scale reconnaissance, but landed operations like NASA's VIPER (Volatiles Investigating Polar Exploration Rover), and the NASA CLPS (Commercial Landed Payload Services) program polar landers will be needed to ground truth orbital observations. Several speakers at this meeting presented mapped quantification of expected potential for volatile rich environments as based on current data.

In terms of addressing Planetary Protection policies as a function of geography, the LSSW suggests that instead we assess PP as a function of Science. This approach leads to two major classes of "disruption" to scientific investigations: 1) Small scale contamination (e.g., lander exhaust and space suit leakage) and 2) Large scale resource utilization (e.g., mining). We need to determine how much each of these will impact scientific investigations and future science potential. The issue should not be focused on defining 'keep out zones' but instead should consider what science would be lost if contamination or mining occurred. A potential solution could be to find two identical PSRs where one is assigned for mining and general exploration and the other is preserved for scientific investigation, similar to the International Seabed Authority scheme (although this approach could be difficult when deposit identification is localized). There was a discussion during the LSSW that this scenario could be handled similar to the way that the National Park Service (NPS) system, where land and resources are agreed upon and periodically reassessed for commercial use, rather than labeled as "keep out zones". In this scenario, the scientific value of a site could be adequately preserved. Another possibility is to find two similar resources, such as water ice deposits, that have similar features. In this case one resource is for science investigation while the other is mined for in situ resource utilization.

Beyond the full issue of protecting an area we need to further refine the meaning of contamination. Contamination is determined both by instrument sensitivity (current and future) and the mobility (lateral and vertical) of contaminant molecules. The quantity of contamination that will significantly affect our ability to search for endogenous volatiles is currently unknown and the scientific community has yet to define this threshold. It is also not yet understood whether disturbances, regardless of their quantity, will be "skin deep" and affect only the lunar surface layer or will penetrate deeper into the lunar subsurface. Most vertical mixing occurs from the slow process of impact gardening or slow, thermal driven vapor diffusion. During landing and extra-vehicular activities (EVAs), first-order estimates suggest that layers lower than roughly a millimeter down will not be disturbed by surface activities. The LSSW notes that this prediction could be tested with the recently awarded grants on the unopened Apollo drill tubes or that this diffusion depth could be a measurement on early Artemis missions. If contamination from surface activities is proven to only affect the uppermost lunar surface materials, many science operations which analyze samples collected below the surface may be relatively unaffected, even if they are in an area impacted by landed activities.

Another mitigation strategy to understand the effects of contamination is to catalog all materials brought to the Moon for comparison with the analyzed lunar samples. Samples of spacesuit water and propellant can be characterized prior to launch so that we can compare what is measured on the lunar surface to the composition of those known contaminants. Early missions should include sampling or instrumentation to measure what extent surface operations are actually affecting the surface and subsurface. In some sense, it is important to have at least some samples that are purposely contaminated by human operations and brought back for assessment in the future. For missions collecting these contamination samples, it is important that all propellants be known and sampled, and if not an unreasonable expense, chemically tagged in some form.

Such scientific tracking of contaminants in early lunar missions should be planned for future mission operations, but detailed modeling work can be done now. For example, we can now use cutting edge exospheric transport models detailing how rocket exhaust may spread into polar cold traps. Such models depend on unknown parameters of the retention of volatiles on the surface (the "stickiness") which are fairly uncertain. However, such work can help to constrain the areas and amounts of expected contamination.

Here we attempt to summarize the primary issues to be addressed by the scientific community in order to inform a coherent Planetary Protection Policy for the Polar Shadowed Regions.

1) Quantify the maximum surface contamination level permissible while protecting high priority scientific investigations. Identify a sensitivity (e.g., # of molecules/m^2) that would be considered a threshold of detectability. This value could be designed around current sensitivity limits (e.g., M^3 3-micron feature observation threshold), or be estimated for future technologies.
2) Understand the uniqueness of individual polar shadowed environments. Obviously, there is only one Shackleton Crater, for example, but at a given scale we need to understand if any patch of high latitude area is "exchangeable" scientifically. At current, landing sites seem highly dictated by the rare areas of extended illumination (namely the sites under study for VIPER, PRIME-1, and other polar missions).
3) Improve understanding and models of exospheric transport. A more detailed understanding of how molecules move in the lunar exosphere as well as how molecules are deposited and evolve on the Moon is key to distinguishing what materials were introduced to the Moon versus materials that were already present. Ground truthing via spacecraft data will be key to refining and validating these models.
4) Identify how/if geologic features can mitigate contamination. For example, how does proximity to a PSR or micro-PSR affect contamination?

The LSSW notes that the amount and variety of contaminants emitted from landers, rocket exhaust, boil off, surface crew activities, etc. may be large and thus the work to understand and mitigate contamination effects is likely non-trivial. However, attempting to understand the threshold of contamination from human-induced sources is fundamentally the issue to be addressed in order to preserve scientific integrity. The scientific community must decide if mitigation includes avoidance of contamination at scientifically-compelling locations, and/or if simply tracking and being aware of the contamination is sufficient.

In order to address these issues, the LSSW considered several different scenarios. For example, if there is substantial rocket exhaust contamination in the polar regions, how does this affect the scientific understanding and exploration of the PSRs? With the microcoldtraps surrounding a lander, consider the case of a static lander tasked with looking for water in the local coldtraps. If the lander just outgassed significant quantities of water during landing, how do we quantify the native water versus water that was delivered from the spacecraft to the cold traps? One solution may be to use a rover (or other vehicle with mobility) in order to traverse beyond the disturbed landing area. However, we must consider that microcoldtraps may prevent large distance escape in cold traps. For example, NASA's LADEE (Lunar Atmosphere and Dust Environment Explorer) mission demonstrated that the lunar surface is 'stickier' than expected, meaning molecules tend to stick to the surface. After meteor impacts on the lunar surface, the water doesn't remain in the exosphere for very long. Modeling suggests that for a lander near the equator, then ~10% of the delivered water ends up uniformly distributed within cold traps. When landing at higher latitudes then more direct deposition in cold traps occurs which results in a higher concentration of volatile material landing in cold traps based on the precise landing site and trajectory (orientation of thrusters).

Ultimately, the scientific community must quantify the levels and areas of acceptable contamination. It is insufficient to simply state that we want to avoid all contamination. At a high level, we need to understand the requirements for measurements. For example, the scientific community must assess how local contamination will affect measurements and instrument contamination. We need to identify a minimum detectability that will influence contamination allowances to still preserve high priority lunar science as well as enable sufficient ground truth data for orbital datasets , e.g., we want to avoid outgassing more than the detectability and not be able to collect adequate ground truth data.

Multiple questions remaining outstanding that should be addressed in order to inform an effective Planetary Protection policy that can be implemented to preserve high priority lunar science. Several of these questions are listed here as prompts for future research and study.

Outstanding Questions

1. How important is protecting lunar science as compared to other objectives such as enabling long-term human lunar settlement and feed-forward to Mars? What are the most effective PP policies for enabling competing interests from multiple stakeholders?
2. How do we set policy to govern PSRs and other sensitive/strategic sites within our own Agency, the commercial sector, and internationally?

3. Given that US policies regarding PSRs are more permissive than the existing norms in the international community, what happens if there is disagreement with the US categorization?
4. Not all PSRs are created equal as PSRs range in size, minimum and maximum temperature, accessibility, and relative scientific importance. What are the major distinctions among PSRs?
5. How do we identify and classify different PSRs (e.g., keep-out zones vs. robotic/crew exploration targets vs. impact targets)?
6. What is the threshold of illumination for being considered "permanently shadowed" for PP purposes?
7. Are *all* PSRs necessarily Category II? Is a broad regional characterization too coarse for the types of protection needed, and might a feature-based characterization be more appropriate?
8. Is any special policy required pertaining to radiogenic power that could potentially melt PSR volatiles long term?
9. How important is the age of the ice/volatiles for quantifying its importance? Is young ice or old ice more interesting, or is the age of the volatiles not critical to science? How does the volatile age relate to processes such as gardening and/or original emplacement (older ice) and diurnal migration (younger ice)?
10. How much water or volatiles would need to be introduced to the Moon before we adversely disturb scientific measurements? Is there a detection limit that can be set as a contamination limit, perhaps decided via detection limits based on spacecraft observations?
11. Do we need a designated area to search for organics for science and/or PP purposes?
12. Can we define “preservation” zones by using PSRs and a contamination radius or terrain set by micro-coldtraps? Or is limiting and cataloguing the amounts and areas of contamination sufficient to preserve high priority science? Who has the authority to ban a spacecraft or vehicle from entering a certain region?
13. Do we have the appropriate tools to measure high pressure outgassing both of spacesuits and PSRs that we illuminate or heat up through surface operations?
14. How will all potential contaminants of interest be identified? There will likely be many different contaminants, especially if there are different missions requiring different propulsion methods. To what extent (if at all) do we define mission criteria based on science versus engineering (e.g., if the mission objective includes searching for water then minimize use of propulsion that expels water)?
15. What is the extent of contamination from spacesuit degassing and astronaut surface activities on science measurements? The rate of contaminant dispersal from spacesuits was relatively fast during lunar day near the equator, but the rates of dispersal may be slower in colder polar regions.
16. What specific science is most impacted by surface science operations? What specific investigations would be most adversely affected by landed systems and EVA activities?
17. What are the top scenarios or processes where scientists should be consulted prior to the approval of certain activities on the lunar surface? When would consultation with scientists be more beneficial than a blanket yes/no approach to surface activities?

18. What are the specific risks/threats to PSRs from increased lunar activity? Describing these specific PSR alterations in detail can help to develop policies/norms/regulations for the preservation of PSR-based scientific investigations.
19. What kinds of information will the science community need in order to properly evaluate proposed PSR activities?
20. Are there potential synergies that could be identified between mission operations and science goals - e.g., scientific information sharing for non-commercial purposes?
21. The rims of PSRs are likely to be desirable landing sites due to the extended illumination durations at these sites. How does landing at/near these crater rims relate to the need to also protect the nearby shadowed regions for science?
22. What lessons-learned from the terrestrial mining industry, including within lands of Earth's designated parks and nature preserves, be applied to lunar ISRU?
23. Where and how will the international community register information about areas designated as protected (Category II)?

Lunar Heritage Sites and Exploration Infrastructure Considerations

The LSSW considered which locations (or portions therein) on the Moon require special classification to preserve the sites and/or heritage items on the lunar surface (e.g., heritage sites [A11–17, Luna, Surveyor, Chang'E]; past impact sites [LCROSS, S-IVB, Apollo ascent stages, LADEE, etc.]; current missions [NASA, commercial, international]; future infrastructure sites [crewed landings, solar farms, sustainable base]).

The increased cadence of robotic and human missions to the surface of the Moon necessitates guidance regarding the potential for landings and mission operations at or near sites of previous landed missions on the Moon. Preservation of sites on the Moon for historic and / or scientific purposes must be considered. This topic was addressed in a 2011 NASA report titled "NASA's Recommendations to Space-Faring Entities: How to Protect and Preserve the Historic and Scientific Value of U.S. Government Lunar Artifacts" but warrants updated inputs based on the evolving landscape of planned lunar exploration.

Discussions at the LSSW during this breakout session focused on heritage sites and sites of future exploration infrastructure. Heritage sites are considered areas on the Moon previously visited by human and/or robotic missions. Future exploration infrastructure sites are considered as more entities (government, commercial, or other) are developing capabilities to land on the Moon, and infrastructure such as habitats, communications systems, power plants, ISRU mining areas, etc. may be deployed on the lunar surface, so here we consider guidance pertaining to landing near these future assets as well.

There are multiple considerations when discussing lunar heritage sites and exploration infrastructure in the context of future landed missions. One must first determine the value of a site to whom and for what interest. Identifying the stakeholders is critical, as well as defining the uses and functions of the sites under consideration. We note that any intervention at a site is irreversible and thus it is imperative to mitigate the risk for the integrity of the site.

There are multiple methods of exploring a site on the Moon that may have different implications regarding preservation potential. For example, one can still learn about lunar processes without actually landing. Space weathering can be assessed by studying the timescale for rover tracks and/or astronaut tracks to change and/or return to pre-landing conditions. In this case, any landed activity would disturb these current conditions. Note, one can still damage a site without actually landing (e.g., rocket engines disturbing the surface) which must also be considered. However, it is likely that the maximum new science will be achieved by (responsibly) returning to the site to conduct scientific investigations on the lunar surface.

There are a variety of sites of interest for science that are worthy of preservation. Among the types of sites identified as highest priorities within this breakout group include Apollo landing sites and previous robotic landing sites. Previous landing sites can all be considered archeological sites, and therefore no matter the site, there must be solid justification for revisiting that site in situ. No sites are deemed of inconsequential value. The risk of revisiting one of these sites must be justified based on the goals and efforts to mitigate the risk.

In terms of science potential at heritage sites, this group has identified several different research topics that could be conducted on the Moon. Anthropological and archeological values of historic sites are important to consider in terms of preservation.

Astrobiology interests include returning to previous robotic and human landing sites to reinvestigate the site for known microbes that were known to have been brought to the Moon and assess how these microbes have been affected by the lunar environment. There is also significant feed-forward to Mars exploration in terms of assessing microbial viability in extreme environments as well as developing technology and strategies for measuring microbial contamination at a landing site. Materials science is of interest at heritage sites to investigate the effect of exposure in the lunar environment on different materials over time. For example, Apollo 17 left coupons of different materials on the lunar surface for just this purpose.

We note that since the heritage sites have, by definition, already been visited by humans and/or human-built machinery, these sites are no longer pristine in their native form. Each of these sites has already been disturbed, and thus have already experienced an environmental impact. A worthwhile study would be to return to these sites and understand the extent of this impact. For example, Apollo missions left trash, including biological waste, underneath the lunar module. Is this a sufficient methodology of waste management for future human missions to the lunar South Pole or Mars? The environmental impacts of such operations can be assessed at heritage sites on the Moon. Conversely, how have these artifacts been impacted (no pun intended) by the lunar environment in the decades subsequent to these missions, and what can we learn about component and materials performance and degradation in the harsh lunar environment?

The question of the most valuable assets on the lunar surface that require protection is highly context specific, culturally influenced, and nuanced. Currently, we lack a suitable framework for protection. The question of which assets to protect needs to be continually addressed to accommodate future missions. We must work to identify the level of risk we're willing to accept in visiting heritage and/or exploration infrastructure sites, and develop clear strategies for mitigating these risks to acceptable levels.

Key considerations for possible future visits to historic lunar landing sites
Contribution from Justin St. P. Walsh, Ph.D., RPA (Chapman University)

Neither NASA nor any other entity has relinquished ownership of any items placed on the Moon. As a result, under the OST (Outer Space Treaty), the owning entities retain their full rights relating to the disposition of their items. At the same time, the landscape of the Moon is considered international territory, and therefore none of it is currently eligible for legal protection for reasons of natural or cultural significance, including as historic heritage. Only the development of an international treaty can establish heritage protections similar to those that exist on Earth (for example, the 1959 Antarctic Treaty, the 1972 World Heritage Convention, and the 2002 Convention on Underwater Heritage) which would allow for enforcement against bad actors. We recommend that NASA work with the Department of State, as well as with other national space agencies, to propose and enact such a treaty, following recognized best practices in heritage management. In addition to protecting historic sites, this work will also preserve scientific data for all scholars.

In the meantime, NASA has published a white paper establishing recommended guidelines for the protection of its lunar artifacts. This document was developed in 2011 with the input of various stakeholders including at least one archaeologist. Future plans by NASA to visit historic lunar sites should include similar engagement with archaeologists and heritage professionals in order to preserve the scientific and cultural value of those sites.

The historic lunar sites as they presently exist can be considered pristine and enormously significant. There are also relatively few of them. If NASA decides that its scientific goals necessitate a visit to a site – to study how materials have been impacted by long-term exposure to the lunar environment, for example – it should do so with the understanding that any direct intervention will come with irreversible consequences for the integrity of the site such as damage and/or contamination. Some of these consequences may be unpredictable, given that humans are still learning how to operate on the Moon. It is therefore imperative that the choice to visit a site, whether it is determined to be of high or low historic value, be explicitly justified by an explanation of why the risks posed to the site by a visit are outweighed by the potential knowledge that can be gained.

Some principles of archaeological research will be useful for understanding the recommendations made below regarding a process for carrying out scientific study of a historic lunar site. The irreversible consequences of interacting directly with a site, already noted, mean that there is no second chance for conducting some research – the site will be altered, and some potentially significant data will inevitably be destroyed. It is also clear that future generations of scholars in every discipline will have different questions and better methods for conducting research than we do now. Care should be taken to develop a plan that will minimize impact on the site to the extent possible, while recording the data that is determined to be necessary. One way to avoid impact on a site is to avoid a visit by capturing data remotely through imaging or other techniques. Objects and landscapes should be left undisturbed wherever feasible. Remote observation should be preferred to direct visits.

With the preceding points in mind, it is possible to outline in basic terms a process for developing a research program that involves a historic lunar site. At all times, the 2011 guidelines should be followed while planning approaches to sites and objects.

1. Articulate clear mission questions and goals.
2. Identify the required data.
3. Identify the type of site needed to produce required data. Is an impact site (Ranger, Saturn IV-B third stage, etc.) sufficient, or would a lander (Surveyor, Apollo) be needed? Would an uncrewed site suffice? Why or why not? If a visit to an Apollo site is deemed absolutely necessary, the reasons why it is necessary must be articulated.
4. Survey available sites that might provide the required data. Documentation, imagery (including new images at sufficient resolution), and maps should be studied. If contemporary analog equipment exists on Earth, it should be used to develop the survey.
5. Choose site(s) for possible research.
6. Identify site-specific risks.
7. Articulate necessary activities and all potential consequences of those activities.
8. Identify ways to mitigate risks to site integrity – is a human visit required? Can the mission goals be achieved by observation rather than removal? If sampling is required, how little material can be taken to satisfy goals? What methods can be developed to minimize intrusion, either on purpose or by accident?
9. Weigh risks versus gains – do the identified risks outweigh the potential gains? What is the minimum amount of intrusion required to achieve desired goals?
10. Make a final choice of site, taking into account historic significance, likelihood of success, limitation of intrusion, and mitigation of risk in all phases of activity.
11. Determine what archaeological/heritage work can also be achieved in the process of carrying out planning, observation and/or sampling of the site.
12. Develop technology and techniques.
13. Train crew (in the case of a human visit) or rover operators in the use of technology and techniques.

As a final component of responsible science, it will be critical to communicate results of the analysis publicly, especially given the potential irreversible impacts, and to prevent anyone destroying further heritage by duplicating work which has already been done.

Planetary Protection and Heritage Site Protection Policy Considerations

Science insights influencing policy decisions

Here we highlight recent scientific advances pertaining to PSRs and polar cold traps that were discussed during the LSSW which may affect recommendations for scientific preservation of sites and/or Planetary Protection policy.

- Relatively new scientific results suggest the existence of micro-cold traps widely distributed around the Moon. The existence of such micro-cold traps raises new questions for contamination management. Water and other volatiles are known to be trapped in large PSRs, but now many unmapped cold traps that exist on small spatial scales may substantially increase the amount of area where ice may accumulate.
- Recent missions have provided new information regarding the polar PSRs, but there is still a significant need for detailed characterization of polar PSRs based on expected volatile concentration, distribution, and ease of operational access to inform landing site selection and mission focus.
- Research continues on PSR characterization and terrain classification maps, although the connection to planetary protection needs is still lacking. The community must assess whether we need to protect all of these sites, and/or how do we know when we have protected enough area to enable the high-priority scientific investigations in these areas?
- An improved understanding is emerging regarding how temperature affects the expected volatiles present in different polar regions and samples. Researchers must also assess associated safety hazards such as flammability, reactivity and health for astronauts, crew and scientists working in situ and with samples.

Private Actors and Operational Challenges

The Moon is unique in that there are plans for private entities to send spacecraft to the Moon in the near future. Therefore, any PSR classification and/or planetary protection policies must consider potential operational challenges associated with private actors in lunar spaceflight. How will planetary protection guidelines be incorporated into the review process for launch authorization and/or payload determination? Today, most commercial activity is still government directed or funded, but as commercial activities become more self-directed (for example NASA's CLPS program, iSpace 2022, SpaceIL 2024), what accountability mechanisms will be put in place for PP under commercial missions? Conversely, how could partnerships between scientists and commercial operators be encouraged-- for example, around data sharing, that might enhance scientists' understanding of forward contamination without operator fear of retribution?

The notion of "sufficient protection" for scientific preservation and/or heritage sites is not well defined and requires further clarification for spacefaring entities. Missions must consider operational procedures to prevent forward contamination of their own measurements, especially for scientific investigations, which is a distinct consideration from forward and backward contamination of the environment or scientific records. When landing near the poles, exactly how rocket exhaust gases may migrate to the PSRs and contaminate the lunar exosphere is not thoroughly understood and may be hard to baseline. Specific plans should be enacted early to understand and mitigate this issue. We also acknowledge that there will be a difference between intentional vs. unintentional damage as more missions reach the lunar surface. We understand that there will be various tradeoffs between science and exploration, though these objectives are also not always at odds and often can be complimentary. We appreciate that there may be lessons-learned from how the Mars community has addressed issues of Planetary Protection and preservation of scientific sites of interest. The Martian special regions have been considered a bureaucratic difficulty from the mission developers, and thus the LSSW group highlights a desire to make the lunar approach more agile and smooth in terms of user experience.

Moving Forward

Our understanding of the Moon has greatly evolved since humans last explored the lunar surface. Additionally, we will be exploring an entirely new region of the Moon with the Artemis program. Thus, planetary protection policy must evolve from Apollo to now. The LSSW finds that PP guidelines must be constantly updated and adapt to new technology and scientific understanding (no more than 3-5 year horizon for the current recommendations). A decision-making process and forums for these updates must be developed.

Science investigations should be prioritized both in terms of impact to lunar and Solar System science but also in terms of relative timing. For example, science priorities should be outlined that need to be accomplished early during the Artemis program and prior to irreversible contamination which will adversely affect certain scientific investigations more than others. The role of baseline measurements to understand how human-induced activities are affecting measurements and the environment must also be addressed in order to understand the levels and impact of inevitable site contamination. The LSSW suggests that area-based delimitation of protected regions may not be the most effective approach - e.g., rather than designating a protection category above or below a certain latitude, doing so as a function of the features or qualities of a region or deposit may be more effective. To this end, articulating different categories of entities to protect, e.g., scarce resources (whether a scarce scientific resource such as a radio quiet zone, or a scarce resource for operational or extractive purposes), priority access areas, regions preserving specific scientific records and/or pristine conditions, and/or heritage sites. More work is required to define which of these topics should be included within the scope of “planetary protection”, and the degrees of protection and/or preservation for each site. In addition, different protections may be best implemented under different frameworks. For example, protecting the radio quiet zones on the Moon or protecting priority rights for economically and strategically significant areas such as water ice deposits may or may not be best served by inclusion under a PP framework (by extending the current PP definition) or are such considerations better served under a separate resource management framework? With half-ton landers potentially landing large payloads in the 2020s, time is particularly short to develop these guidelines.

The LSSW highlights the importance of universal agreements on protection since these are shared resources and any one actor deviating from the agreement impacts the site for all. There is precedence of a National Academy of Science and Engineering report, strongly recommending to consider Moon and Mars not as monoliths but as planetary bodies with many and diverse zones. The PP guidelines for Mars already include “special regions”, and this approach highlights the importance of polycentricity and diverse frameworks on the Moon.

Considering NASA’s role in capacity building for Planetary Protection

NASA and other space agencies have a significant role to play in educating and building PP capabilities in private actors. The NASA PP Office will likely require increased funding to properly address these emerging lunar surface issues and promptly address the issues highlighted in this report as soon as possible. We note that NASA is not a regulatory body but can influence actions by linking PP compliance to eligibility for future NASA funding. One enforcement option is that NASA could hold private actors accountable to agreed-upon PP policies by attaching conditions to its commercial services contracts and funding, although this approach would of course not be effective for private missions that travel to the Moon without NASA funding. Due to the rapidly changing nature of planned lunar missions and scientific insights, NASA should establish a standing forum for discussion and resolution of emerging issues related to PP and site preservation. Such a forum must include US entities and international partners, including the non-US private sector. Any lack of clarity for non-NASA missions impedes the development of private sector activities, and thus NASA should offer capacity building to private actors. Additional venues also exist for continuing conversations regarding PP issues including, but not limited to, COPUOS, COSPAR, ESA, and civil society dialogs (e.g., Moon Dialogs).

The recommended approach is that PP should enable science and exploration, not prevent new research and discoveries. A dedicated international effort is required to highlight the importance of Planetary Protection and the preservation of scientific areas of interest as well as heritage sites on the Moon, for the benefit of life on Earth today and for future generations.

Lunar Surface Science Virtual Workshop #4
Planetary Protection/Permanently Shadowed Region (PSR) Classification
September 30, 2020

Program and Abstracts
All times are Eastern Daylight Time (EDT) (UTC -4)

Times (EDT)	Presenters	Title
12:00 p.m.	Jennifer Heldmann, Matthew Siegler	Welcome
12:05 p.m.	NASA Office of Planetary Protection	NASA Planetary Protection Overview, Workshop Goals, and Objectives
12:15 p.m.	John Rummel	*A History of Lunar Planetary Protection: Origins, Goals, and Status Changes* **[#7011]**
12:35 p.m.	Scott Hubbard	Planetary Protection: National Academies Activities and Implications for Future Lunar Exploration
12:55 p.m.	Amanda Hendrix	Overview of the NASA Planetary Protection Independent Review Board
1:15 p.m.	Anthony Colaprete	NASA Flight Mission Perspective: Planetary Protection and Contamination Considerations from NASA's LCROSS, LADEE, and VIPER Missions
1:30 p.m.	Paul Hayne	Potential Contamination of Micro Cold Traps by Lunar Exploration Activities
1:45 p.m.	Julie Mitchell	A Classification Scheme for PSR Volatile Hazard Potential
2:00 p.m.		BREAK
2:15 p.m.	Parvathy Prem	*Towards Understanding the Impact of Exploration on the Lunar Environment* **[#7010]**
2:30 p.m.	Kevin Cannon	*Parks and Preserves, Not Keep-Outs and Moratoriums: Avoiding Naïve Views of Enforcement* **[#7004]**
2:45 p.m.	Myriam Lemelin	*Framework for Coordinated Efforts in the Exploration of Volatiles in the South Polar Region of the Moon* **[#7009]**
3:00 p.m.	Cameron Moye	*Lunar Polar Terrain and PSR Classification for Artemis Science and Exploration* **[#7012]**
3:15 p.m.	Marni Rosenthal	*EVA H_2O Release: Planetary Protection Implications for the Human Exploration of the Lunar Polar Regions* **[#7013]**
3:30 p.m.	Norbert Schorghofer	*Classification of Ice Storage Processes on the Moon* **[#7005]**
3:45 p.m.		BREAK

Table 1. LSSW #4 Agenda.