

**LUNAR LANDING AND OPERATIONS POLICY ANALYSIS.** Gabriel Swiney<sup>1</sup> and Amanda Hernandez<sup>2</sup>, <sup>1</sup>NASA Office of Technology, Policy, and Strategy (gabriel.w.swiney@nasa.gov), <sup>2</sup>BryceTech (amanda.hernandez@nasa.gov).

**Introduction:** At least 22 lunar missions are planned in the next four years. Half of these missions will occur in the Moon’s south polar region. Due to this upcoming proliferation of actors and activities at or near the lunar south pole, and due to the potential close proximity of operations, NASA and other operators will face challenges never faced before.

NASA’s Deputy Administrator and Associate Administrator of the Science Mission Directorate tasked the Office of Technology, Policy, and Strategy with answering two questions related to the Artemis campaign: (1) what technical and policy considerations should NASA take into account in the selection of lunar landing and operations sites, and (2) what technical and policy considerations should NASA take into account when implementing tools such as safety zones in order to protect these operations and U.S. interests?

We present policy tools (options and recommendations) to NASA leadership and program planners so that they can consider policy measures to respond to challenges inherent in landing and operating at the lunar South Pole—this answers question one. We also describe a set of options (transparency, coordination, and implementation) to increase the effectiveness of these tools—this answers question two.

**Setting the Scene:** Initial Artemis surface missions present unique constraints that limit what operations are possible and where those operations can take place. Availability of sunlight for power and thermal control impact all missions reliant on solar energy. Terrain for safe landings, navigation, and access to volatiles affects all surface missions. Direct line-of-sight with Earth is needed for communications, specifically related to crewed missions. Given these constraints, we identify seven main challenges or hazards to surface missions at the lunar South Pole: landings, surface operations, surface travel, radio-frequency interference, human heritage, areas with special characteristics, and unexpected activities. Each of these challenges is amenable to one or more policy tools that can reduce the risk to NASA operations.

**Policy Tools:** We provide the following policy tools to mitigate each challenge. We also note that not all policy tools need be implemented immediately, simultaneously, or for every mission. NASA leadership will determine which, if any, warrant consideration.

*Challenges posed by landings.* Landings will create plume-surface interactions (PSIs) that can damage as-

sets—significant gaps in understanding their effects exist. We recommend that NASA increase priority of obtaining PSI measurements; identify distances from landing sites that will reduce danger from particles to tolerable levels; develop “gold standards” for PSI predictions with partner space agencies; and work with partners to develop landing and ascent infrastructure to mitigate dangers from particles.

*Threats to and from surface operations.* Activities on the surface can cause damage to or interfere with surface assets and operations. We recommend that NASA begin implementation of the concept of safety zones (envisioned in the Artemis Accords), incorporating them into mission planning and designing on a mission-by-mission basis; take additional steps to reduce the need for safety zones (e.g., landing infrastructure); and respect similar tools used by non-signatories to the Accords.

*Challenges to moving across the lunar surface.* Technical constraints limit the ability to move between areas of interest—there is a need to ensure navigable pathways remain available for use. We recommend that NASA ensure its understanding of navigable pathways between sites of interest is robust; if there continues to be a need to protect these pathways, identify them as “transit corridors” and ensure their protection; and if fixed facilities must be placed on these corridors, make their locations known and ensure they do not block mobile assets.

*The danger of radio-frequency interference.* Surface operations could be subject to radio-frequency interference. We recommend that NASA continue to engage with the interagency and rely on the International Telecommunication Union. Specialized policy tools for lunar surface operations are not needed.

*Threats to areas with special characteristics.* Certain locations may warrant protection if operations may render them less useful. We recommend that NASA ensure freedom of access to areas conducive to operations, such as the Connecting Ridge, and work with Artemis partners to support United Nations space resource efforts for sustainable in-situ resource utilization (ISRU).

*The challenge of unexpected activities on the surface.* Security-related concerns could interfere with surface operations. We recommend that NASA consider incorporating multi-purpose hardware (e.g., cameras, sensors) onto missions that can identify proximity operations from other actors.

*The need for human heritage protection.* The U.S. may wish to preserve non-operational sites for their historic or cultural value. We recommend that NASA continue to implement the 2011 Recommendations to Space-Faring Entities [1] for Apollo and Surveyor sites; apply them to any new heritage sites; use restraint in identifying any new heritage sites; determine if other nations request human heritage protection; and look to terrestrial heritage protection to develop formal processes.

**Increasing the Effectiveness of Policy Tools:**

When implementing policy tools to address challenges to landing and operating at the lunar South Pole, we suggest the following as a means to increase their effectiveness, thus protecting operations and U.S. interests.

*Transparency.* The purpose of transparency, which builds off of the Artemis Accords, is to address potential concerns and increase the effectiveness of policy tools. Most of the policy tools presented here have never been used in outer space. We will need to engage in a concerted effort to describe what we are doing and justify those actions to all actors. Transparency can also serve practical goals. For policy tools to be effective, other actors must know that they exist so that they can respect them.

To this end, we recommend that NASA build on the transparency section of the Artemis Accords by 1) meeting with signatories, or a subset thereof, to discuss policy tools for upcoming missions and, 2) developing a public relations strategy along with multilateral engagement to explain rationale for policy tools.

*Coordination.* Active coordination with the space community is needed before implementing policy tools, especially when related to cooperative missions. More general coordination is also necessary when multiple actors are operating in proximity on the Moon.

We recommend that NASA 1) work with the Department of State to ensure partners on joint missions share our views on responding to challenges and, 2) develop mechanisms for consultation and coordination to deconflict surface operations.

*Implementation.* Implementing policy tools refers to putting one or more tools into practice by incorporating into mission plans. The approach may differ by how much operational control NASA has over a mission. We therefore recommend that for missions over which NASA has operational control, build policy tools into mission planning, and for missions operated as a service, work with contracting companies to implement relevant policy tools.

**Summary and Next Steps:** The Artemis campaign has already begun with the June launch of the CAPSTONE lunar orbiter and November launch of

Artemis I. Uncrewed surface missions will begin in a matter of months, ushering in years of high-cadence, increasingly complex missions to the lunar surface by NASA and commercial and international actors. In addition to the challenges inherent in lunar exploration, this new era raises a number of challenges that require a mix of policy and technical solutions.

Not all policy tools need to be evaluated or adopted immediately; some may only become relevant as increasing numbers of missions go to the lunar South Pole. Increasing volumes of traffic to the lunar surface may require stricter implementation of certain tools; conversely, advances in technology and infrastructure could allow relaxation of those same measures.

Key next steps to address challenges to landing and surface operations include: 1) working desired policy tools into current and upcoming mission plans, 2) building options for transparency, coordination, and implementation into desired policy tools, and 3) revisiting these policy tools as needed, and especially as we learn more from early lunar surface missions.

**Acknowledgments:** This analysis would not have been possible without the extensive cooperation of experts across NASA. The work of NASA's Cross-Artemis Site Selection Analysis team has been particularly valuable, and we have relied on experts across mission directorates, centers, and within NASA Headquarters for every section of this study. We are also grateful to external reviewers, representing a range of disciplines and backgrounds, for their valuable input. This effort underscores the reality that creating a safe, sustainable, and predictable presence on the Moon and beyond is a task for the entire agency.

**References:** [1] NASA Human Exploration and Operations Mission Directorate. (2011) NASA'S Recommendations to Space-Faring Entities: How to Protect and Preserve Historic and Scientific Value of U.S. Government Artifacts.

**Additional Information:** To view the full report, please visit: [https://www.nasa.gov/offices/otps/NASA\\_Releases\\_Report\\_on\\_Policy\\_Matters\\_in\\_Upcoming\\_Moon\\_Missions](https://www.nasa.gov/offices/otps/NASA_Releases_Report_on_Policy_Matters_in_Upcoming_Moon_Missions).