# Non-Interference of Lunar Activities

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**Abstract**

As dozens of countries and private sector companies have expressed interest in establishing lunar operations by the end of the decade, it will be critical to determine how to minimize interference in lunar activities. Although lunar interference concerns have been broadly identified, and deconfliction has been identified as an area of further work in Section 11 of the Artemis Accords, there is not broad consensus in the lunar scientific or technical community on key questions such as standards and best practices for non-interference or mechanisms for mitigation. This paper seeks feedback from the scientific and technical community to determine the breadth of interference concerns and clarify community usage of the terms "interference" and "contamination".

**1. Introduction**

Dozens of countries and private sector companies are looking to establish lunar operations over the next decade. Unlike historic lunar operations which have operated in locations largely isolated from other missions, in order to achieve scientific and operational objectives, future operators will need to share information, consult, and potentially coordinate to mitigate interference for simultaneous and planned missions in proximity to one another, especially in the lunar south pole region. In order to determine what level of coordination could be needed, and what information should be shared, we explore the extent of contamination and interference concerns, and existing or proposed mitigation mechanisms (both policy and technical).

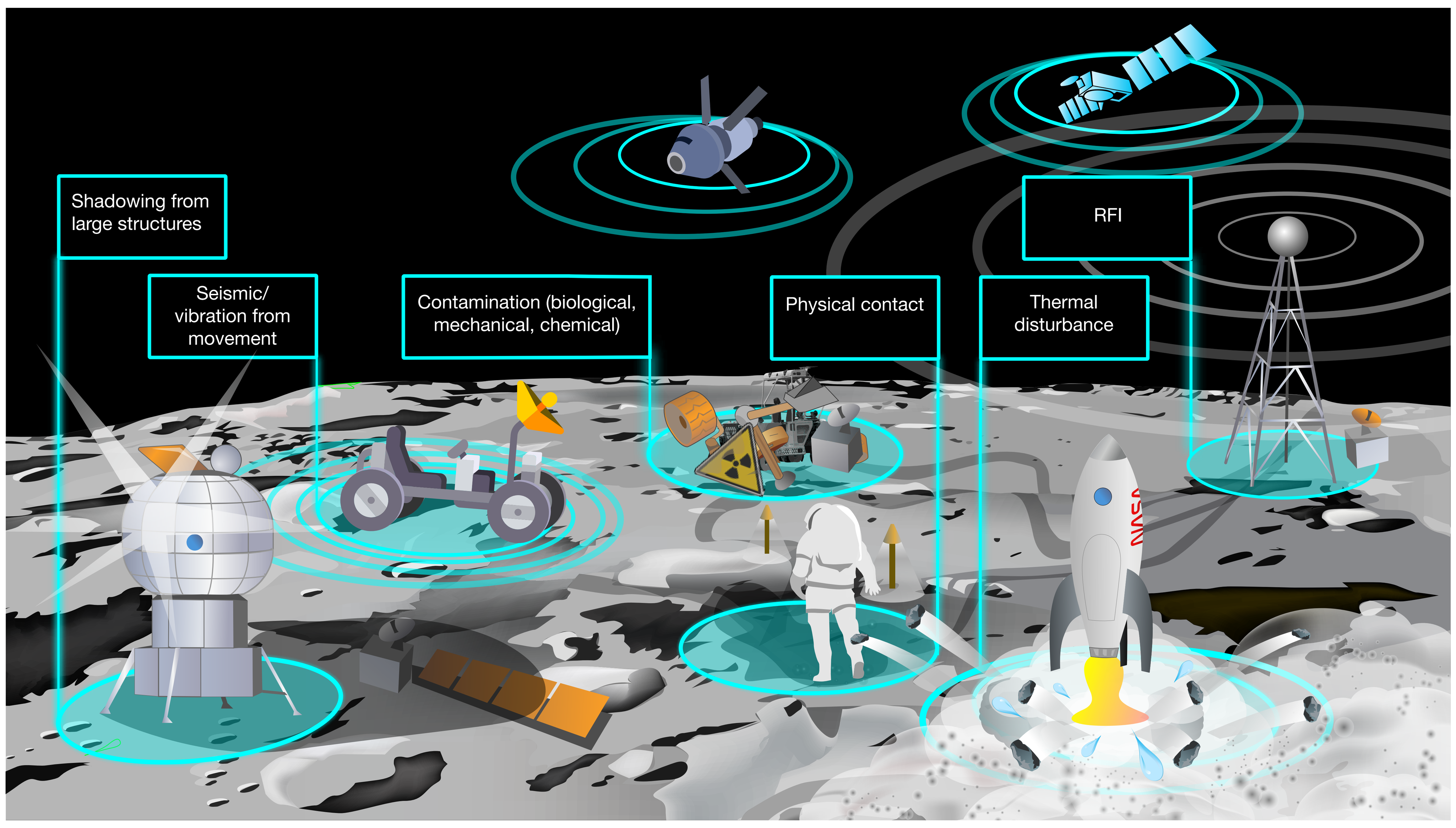


Figure 1– Respondent categories of interference

**2. Methods**

OTPS developed a public questionnaire on lunar interference and contamination concerns, understanding site value, and mitigation mechanisms. OTPS held two breakout sessions at the April 2024 LSIC to get feedback from participants on the questionnaire. Participants were asked to define interference and contamination, discuss ways they measured site value, and potential impacts to site value. OTPS released the questionnaire publicly on the NASA website, social media, and relevant list-servs. Input was received from roughly 50 individuals or organizations between the workshop and questionnaire, representing both scientific and technical interests, including academia and industry. Responses to each question were qualitatively analyzed using an open coding model, which thematically grouped responses as they were digested.

**3. Results**

Respondents largely focused on potential impacts to mission in their discussion of interference, and the alteration of materials or the environment in their discussions of contamination. Many noted that interference could be intentional or unintentional, permanent or temporary. Figure 1 delineates respondents' interference concerns, which are broken out into operational phase (orbital operations; entry, descent, landing and ascent; static surface operations; dynamic surface operations) and interference subcategories in the paper. In Table 1, we break up these interference concerns into scientific vs. operational concerns, and their spatiotemporal extent. While we do not define the delineation between short and long-term, or hyperlocal vs. regional, we hope further work will help refine the extent of these concerns. Table 1 summarizes interference mitigation responses and existing technical or standards work on these mechanisms.

Many respondents focused on broad coordination and communication to mitigate interference of lunar activities. This included the development of recommended concept of operations (CONOPS), to include information such as the activities an actor wishes to perform and their location, planned spectrum use, information to support dust ejecta predictions, and waste generation information. Astronomer respondents emphasized the need to maintain a database of transmitter frequencies used by all lunar assets, and encouragement of coordination between active/passive users during early stages of technology development. Pre-coordination of lunar trajectories, as well as a schedule of activities for long-term surface operations were also highlighted.

Multiple respondents suggested NASA or international technical bodies could provide guidance on sites of scientific interest and how to preserve their value, or even designating certain zones for specific purposes. One respondent suggested adding environmental impact guidance during procurement. Several respondents suggested defining minimum distances from gravitational wave detectors or from passive radio operations. One respondent highlighting an existing EMI standard, MIL-STD-461, which could be adopted to minimize impact of EMI on passive radio operations. Respondents highlighted the desire for guidance on disposal of lunar waste, and how sites might be restored, if possible, after operations.

Several respondents noted that collective investments on infrastructure and data could help mitigate interference. Development of infrastructure such as roads and railways, landing pads, and regolith walls could help mitigate dust. Monitoring data and predictive tools could help assess and rectify impacts of lunar interference. Many respondents highlighted specific technologies or technological development initiatives that could help mitigate dust, provide guidance on reuse, minimize chemical contamination, improve energy efficiency, improve shielding, and more.

Respondents emphasized the need to share data on interference (e.g., plume surface interaction (PSI) data) and lessons learned publicly, and to coordinate on developing best practices to avoid interference.

OTPS reports on a public survey of lunar interference concerns and recommended mitigation mechanisms.

| Interference Concern | Scientific Impact: Concurrent, short, or long | Scientific Impact: Hyperlocal, regional, global? | Operational Impact: Concurrent, short, or long | Operational Impact: Hyperlocal, regional, global? |
|---|---|---|---|---|
| **Physical Contact** | Can be long term for movement of soil/dust | Hyperlocal: Soil disturbance, blocking of transit corridors Regional: dust | Primarily concurrent for surface operations unless physically blocking highly utilized corridor; orbital debris can be long | Dust is regional for surface operations, global for orbital debris. Physical blocking of activity is largely hyperlocal unless blocking a highly utilized corridor |
| **Thermal Disturbance** | Long<br>itself is concurrent, but volatile disturbance could be permanent. | Regional for volatiles; for gravitational wave detectors hyperlocal thermal instabilities are of concern | Concurrent for sunlight reflected onto other elements | Hyperlocal |
| **EMI/RFI** | Concurrent | RFI: Global for cislunar satellites EMI: hyperlocal | Concurrent | RFI: Global for cislunar satellites EMI: hyperlocal |
| **Contamination (biological, mechanical, chemical)** | Long<br>materials and for contamination of polar ice traps from exhaust; some exospheric impact temporary. Localized changes to surface likely permanent on human timescales. | Can be global for exosphere short<br>can be permanently trapped near lunar poles. Changes to surface will affect multiple processes (water transport, particle flow, temperature variation, illumination). Estimated that Starship could dump 70 T of water in the polar region and possibly a similar amount of CO ; water may migrate into polar craters (Farrell et al. 2024) | Could be long<br>chemical contaminant health hazards | Hyperlocal |
| **Shadowing from large structures** | N/A | N/A | Long<br>protocol in highly utilized region | Hyperlocal |
| **Seismic/Vibration from movement** | Concurrent | Can be hyperlocal for some disturbances, global for others | Concurrent | Hyperlocal to regional |
| **Aesthetic Degradation** | Potentially long term if structures are not disposed of | Depends on the extent of visible structures | N/A | N/A |

Table 1– Public spatiotemporal interference concerns