Lunar Dust Exposure CLIFF Peer Review

1. *Strength of evidence presented in CLIFF in modeling the characteristics and mission impact of this medical condition within the spaceflight environment?*

   Score: 1

   Grading Scale:

   4 - Confident

   3 - Somewhat confident

   2 – Neutral

   1 – Somewhat unconfident

   0 – Not confident

2. How confident are you that these data accurately represent the spaceflight environment?	*Tables 1, 2* *Composite Incidence and Level of Confidence*	*Table 3, 4 BC/WC* *Loss of Crew and probability*	*Table 4 - Clinical Phase 1, 2 durations* *Table 5 – CP 2 Loss of Crew*	*Table 4 – RTDC %* *Table 6 – RTDC Loss of Crew*	*Table 4 – Loss of Crew Life %* *Table 7 – Loss of Crew Life, Loss of Crew*	*Table 8 – TI*
Score	*1*	*0*	*2*	*2*	*2*	*3*

Comments and limitations:

1. **General comments.** This CLiFF characterizes lunar dust exposure that may result from surface EVA's on the moon. Spaceflight experience with lunar dust is limited to manned surface exploration during the Apollo program. Lunar dust is an abrasive substance primarily made up of chemically reactive silica oxide that tends to cling tenaciously to space suits. It can act like an allergen in the upper respiratory tract or can cause pneumonitis if particles reach the lung alveoli. It can also cause dermatitis and eye injury. It is speculated that the moon's reduced gravity enables particles to penetrate deeper into the lungs and deposit in the alveoli. The Apollo astronauts said that it was nearly impossible to keep the dust out of the spacecraft once it was brought inside, and all crewmembers were affected. There were no reports of chronic lung disease resulting from exposure, but there is a theoretical risk of this occurring. Unfortunately, there is no current definitive plan to mitigate the deleterious effects of lunar dust, but possible concepts include "double shell spacesuits" with an outer covering that could be doffed prior to re-entry into the lunar habitat, filtration of dust within the airlock, and "suit ports" from a rover. Therefore, incidence information and BC/WC probability estimates came from subject matter experts. Further refinement of the incidence will need to await maturation of the rover and habitat designs. The best case is considered

to be lunar dust causing transient symptoms in the eyes, skin and respiratory tract that respond to conservative management. The worst case is lunar dust exposure that leads to sustained pulmonary symptoms requiring greater than 1 week of treatment.

2. **Incidence.** Based on spaceflight reports from Apollo astronauts, subject matter expertise, and an analysis of the risk on future missions, an incidence estimation was developed. The result is a fixed distribution on a per EVA basis with the risk dependent on whether a crewmember performs an EVA or is inside the vehicle when the EVA crewmember returns. For EVA crewmembers it is assumed that the incidence is 1.0 as there are currently no means to avoid lunar dust exposure contamination during the EVA and exposure after suit doffing. The incidence for crewmembers inside the lunar habitat or lander is thought to be 50-100% by subject matter experts. A fixed, intermediate value of 75% was chosen for the non-EVA crewmember. These values can be refined when and if mitigation hardware and procedures are developed. The best case/worst case probabilities used data from an analysis of the medical risks of lunar dust exposure. This analysis quoted a 0.1% risk of lunar dust creating a long-term risk to astronauts' health. Upon discussion with subject matter experts, this is interpreted as the risk of the development of long-term pulmonary dysfunction. Since this analysis was based on the assumption of the completion of 251 EVA's during the design reference mission, the risk becomes 4 E-6 per EVA. Given the experience with terrestrial events such as exposure to ash after volcanic eruptions, this is likely to be a significant underestimation, depending on the dose and frequency of exposure. Thus, it is felt that the BC/WC split underestimates the risk of long term lung dysfunction. The clinical phase durations, RTDC and Loss of crew life probabilities are supported by terrestrial evidence and the case definitions, and I am in agreement with their calculation. Loss of crew life is assumed to be 0% for the best cases by condition definition and for the treated worst case. The probability density curve that was derived is a fixed value, depending on the EVA status of the crewmember.

3. **Clinical phase data**. I am in agreement with the clinical phase 1 duration entered in this CLIFF. This data was compiled by a team of expert clinicians, and I was involved in the discussions leading to the calculation of the clinical phase duration. CP2 was supported by terrestrial evidence.

4. **Task impairment**. The analysis was performed and reviewed by a separate team of expert clinicians. I am aware of the methods that were used but did not directly participate in the discussions. Because of a change in BC and WC definitions, the TI% may need to be revised.

5. **Dependence on mission phase or duration of mission**. This medical condition is the result of lunar EVA's and thus is limited to surface operations.

6. **Limitations.**

- There is a lack of evidence to inform the incidence. There is also a paucity of literature to understand the long-term consequences of lunar dust exposure. As a result, most of the incidence data comes from subject matter expert opinion and the recollections of Apollo astronauts.
- There are a number of operational and hardware interventions that could be used to mitigate the risks of exposure. The incidence, BC/WC probabilities and outcome values can be refined when and if mitigation hardware and procedures are developed.
- Lunar dust can act somewhat like an allergen in the upper respiratory tract or can cause pneumonitis if particles reach the lung alveoli. It can also cause a dermatitis and eye injury. Thus, there is overlap with other CLiFFs such as reactive airway, upper respiratory infections, skin rash, and eye irritation.

- The best case/worst case probabilities used data from an analysis of the medical risks of lunar dust exposure. This analysis quoted a 0.1% risk of lunar dust creating a long-term risk to astronauts' health. Given the experience with terrestrial events such as exposure to ash after volcanic eruptions, this is likely to be a significant underestimation, depending on the dose and frequency of exposure. Thus, it is felt that the BC/WC split underestimates the risk of long term lung dysfunction.
- Inhaled particle deposition in the respiratory tract is influenced by gravitational segmentation. However, studies have found a non-linear relationship between deposition and gravity, making prediction of deposition difficult. This sets further limitations on BC/WC scenario probabilities and estimations made from analog populations.

Reviewed by:

David C. Hilmers