MSR PEIS Comments

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1 Introduction

The Mars Sample Return (MSR) Preliminary Environmental Impact Statement (PEIS) appears to assert that environmental risks associated with the MSR Campaign are acceptable because:

1. consensus opinion within the astrobiology scientific community supports a conclusion that the Martian surface is too inhospitable for life to survive there today, particularly at the location and shallow depth (6.4 centimeters [2.5 inches]) being sampled by the Perseverance rover in Jezero Crater[1]; and

2. with regard to Earth Entry System (EES) release and landing, the MSR Campaign has established stringent probability targets to drive robust containment engineering. by selecting a target value equivalent to a 99.9999 percent probability of successful containment[2].

The objective of the MSR Campaign is to enhance our understanding of possible Mars biology.

Comments pertaining to the MSR Campaign proposed action and alternative are the subject of Section 2, while Section 3 addresses the likelihood of possible adverse consequences resulting from the interaction of Mars material with earth's biosphere. Issues relating to the MSR Campaign's stringent probability targets are the topic of Section 4. Some recommendations for enhancing the MSR PEIS are proposed in Section 5.

2 Proposed Action and Alternatives

The justification for the MSR Campaign subjecting Earth's biosphere to the risk of contamination from material returned from Mars is to support major goals of the international planetary science community. Since the complexity and cost of sending advanced instruments to study Mars in situ would restrict the scope and detail of the science that could be done, the international planetary science community desires that Mars samples be returned to Earth.[3] According to the PEIS the only options relating to these goals are to undertake the MSR Campaign, or take no action at all. This could be interpreted as a "now-or-never" situation where either the MSR Campaign is undertaken as planned or we obtain nothing with respect to advancing astrobiology science. Most likely a "now-or-never" situation is not what the astrobiology scientific community means, but a better statement of options should include the possibility of delaying the

1 See the third paragraph on page S-4 of the MSR PEIS.

2 According to the MSR PEIS paragraph beginning at the bottom of page S-11 and continuing at the top of page S-12.

3 Refer to the first paragraph on page S-2 of the MSR PEIS.

return of Mars samples until the risks associated with their return are better understood.[4] Moreover, if evidence of ancient life forms on Mars is expected to be so slight that the full breadth and depth of analytical science instruments available in Earth laboratories is necessary to detect it, will the contents of approximately 30 sample tubes, collectively containing on the order of 450 grams of Mars material, be sufficient to provide the astrobiology scientific community with the information it seeks? Probably not, so in order to satisfy our desire to understand life, possible life, or relic life on Mars, additional sample returns will likely be needed. Since the MSR Campaign will return samples from different locations in Jezero Crater future missions (if undertaken) will likely sample from locations that have the greatest chances of furnishing material of interest to astrobiologists. While we can enhance our understanding of biology on Mars from the initial 30 or so samples (so we'll better understand the environmental risks associated with such samples), samples that could contain material that is more biologically viable or harmful to Earth's biosphere would introduce a new set of unknowns into the risk profile associated with a second sample return. Thus there is a trade here, involving sending scientific instruments with limited capability to Mars - which has essentially unlimited material to sample and analyze, or returning about a half kilogram of Mars material to Earth (where there is an abundance of analytical science instruments and skilled scientists to operate them) with the understanding that ultimately more samples will likely be needed. There is probably no statute requiring that risk from follow-on missions be assessed in the MSR PEIS, but from a holistic risk management perspective it is recommended that the MSR PEIS look beyond the "now-or-never" alternatives it currently addresses. Even if such possibilities have already been considered and discarded as infeasible, adding a paragraph to the MSR PEIS summarizing this and citing the appropriate references would assuage concerns that the MSR PEIS has too narrow a focus.

3 Likelihood of Adverse Consequences Resulting from the Interaction of Mars Material with Earth's Biosphere

That the consensus opinion within the astrobiology scientific community supports a conclusion that the Martian surface is too inhospitable for life to survive there today, particularly at the location and shallow depth being sampled by the Perseverance rover in Jezero Crater, is not disputed. The concern is what level of credibility should be assigned to this conclusion.

Humans have not knowingly encountered Martian life.[5] Consequently our *insights* into Martian life come from extrapolations and interpretations predicated upon our understanding of Earth

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[4] According to Section S.3.2 in the MSR PEIS, under the No Action Alternative, the MSR Campaign as described in the PEIS would not be undertaken. As a result, investigation of Mars as a planetary system would be limited due to the cost and complexity of sending instruments into space or to Mars for in situ analyses. By not undertaking the MSR Campaign, scientists would not have access to the full breadth and depth of analytical science instruments available in Earth laboratories. With a deferred action alternative scientists could have access to the full breadth and depth of analytical science instruments available in Earth laboratories - *at some future time*.

[5] Humans have discovered indications of Martian life, beginning with the Viking landers (see the article, "Viking program", which was available from Wikipedia November 29, 2022). However, these and subsequent indications were neither viable Martian life nor interpreted unequivocally.

life. While most Earth life could not survive in an environment analogous to those locations being sampled by the Perseverance rover in Jezero Crater, it is unclear to what extent possible Mars life aligns with the behavior and survivability of Earth life. This is one reason to question the applicability of extrapolations and interpretations regarding Mars life that originate from knowledge limited to Earth life.

Even within Earth's own biosphere the relatively recent discovery of extremophiles demonstrates that life can and does exist in environments once considered too inhospitable to support even Earth-based life. As noted in the first paragraph of page 5 in [National Research Council. (2009)][6], discoveries over the past decade about environmental conditions on Mars today and in the past and about terrestrial extremophiles have supported an enhanced potential for the presence of liquid water habitats and, perhaps, microbial life on Mars.

The repeated appearance of statements pertaining to the Martian surface being too inhospitable for life to survive there today, particularly at the location and shallow depth being sampled by the Perseverance rover in Jezero Crater conveys the impression (perhaps unintentional) that from an environmental risk perspective there is very, very, likely nothing that will be returned from Mars capable of adversely impacting Earth's biosphere. However, the basis for such statements is a conclusion drawn from a consensus. If the MSR Campaign really expects to find nothing of biological significance within Jezero Crater why are they even going there? If there is a real chance that something of biological significance will be returned to Earth the MSR PEIS should explicitly state why biologically significant samples will not or cannot harm Earth's environment. For the sake of transparent and unambiguous risk communication, such clarity is needed in the MSR PEIS.

4 Stringent Probability Targets

It is unclear, from a risk management/environmental impact perspective, what a stringent probability target is. It is explicitly stated (in the last paragraph on page S-11 and its continuation at the top pf page S-12,), that the MSR Campaign:

- has established stringent probability targets to drive robust containment engineering;
- selected a target value equivalent to a 99.9999 percent probability of successful containment;
- applies these targets to each of three material vectors or pathways along which Mars material may reach Earth.

With respect to the three material vectors or pathways, if each pathway has a 99.9999 percent probability of successful containment, then the probability the MSR Campaign achieves successful containment is 0.999999 cubed or 99.9997% if the probabilities for each pathway are

[6] A complete bibliographic citation for this reference is provided at the top of page 7-5 in the MSR PEIS.

independent. If this is the intent it should be explicitly stated and if the intent is that the entire campaign must have at least a 99.9999 percent containment probability that should be explicitly stated.

The second paragraph on page 2-7 of the MSR PEIS informs us that the MSR Campaign is performing analyses based on both designs and operational planning to meet this target. A comment pertaining to these new analyses is what, relative to the older analyses, makes the newer ones better? Since the analyses include efforts to better understand: 1.) the population of Mars material transported by the wind on the planet (dust particle sizes, etc.); 2.) improved knowledge about how and how fast this material accumulates on specific exposed surfaces over time; and 3.) the rate and timing of particle emission from surfaces exposed to space, including the effects of the space environment on particle sterilization and trajectories; it is necessary to understand where the empirical data being used to achieve these analysis enhancements originates. It seems unlikely that NASA assets deployed to Mars are currently conducting experiments or performing detailed observations that would inform such modeling. However if newer empirical evidence is available the source should be cited and summarized in the EIS. If the model revisions are simply predicated on the opinions of experts regarding the anticipated phenomenology exhibited in previous data, the admonition from Arnald Puy et al in their article, *Models with higher effective dimensions tend to produce more uncertain estimates*,[7] merits consideration in the MSR PEIS. Specifically, Puy et al note that while many scholars assume that more detailed models produce sharper estimates and better predictions because they are closer to reality, research suggests they may have the opposite effect.

Sterilization of Mars material is mentioned in the fourth paragraph on page 3-16. Certainly, sterilization is an important tool for protecting Earth's biosphere. However, what empirically-based techniques are available to sterilize life forms we have never knowingly encountered? Biochemically, sterilization involves breaking molecular bonds to a sufficient degree that the bio organism is rendered unviable. Sterilization on Earth could involve exposing organisms to:

- high temperature;
- radiation; or
- caustic chemicals.

If Mars material was exposed to temperatures or radiation doses high enough to permanently break carbon bonds, sterilization of carbon-based lifeforms would be achieved. However, such extreme conditions are likely to damage parts and components comprising the MSR system that will return the samples to Earth. This would seriously reduce the chances for campaign success with respect to its science objectives. It would be informative for the PEIS to summarize how the MSR Campaign plans to balance mission success with environmental protection.

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7 The article by Puy et al was published in SCIENCE ADVANCES, October 19, 2022, Vol 8, Issue 42.

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Relative to the design, assembly, testing, and flight operations of MSR, what does a *stringent probability target* of 99.9999 percent probability mean? If the assurance case concludes that the probability of successful containment is only 99.9998%, or 99.9973%, will the mission be cancelled, will it be postponed until compliance with the *stringent probability targets* is achieved, or can NASA unilaterally decide to accept the higher risk because the 99.9999 percent probability is only a target (i.e., something to air for)? Does NASA intend to impose a threshold for acceptable risk (i.e., a value above which the mission is considered too risky to proceed)? A possible consequence of unsuccessful containment is an ecological catastrophe. Although such an occurrence is unlikely, NASA should at least be clear regarding what level of risk it is willing to assume (for the biosphere of the entire planet).

Much of the emphasis in the PEIS focuses on biological harm associated with Mars pathogens (e.g., the references to sterilization). Suppose, however, the risk to human health and Earth's biosphere is not from Mars pathogens, but mutagens. For example, some particulate matter returned from Mars might be sufficiently mutagenic to transform some benign Earth microbe into something virulent. Certainly such a fantastic scenario is extraordinary unlikely, but given that we know essentially nothing about how Martian material may interact with Earth life we can neither rule it out nor completely protect our planet from such a potentiality. Given our lack of scientific insight into possible life on Mars, relics of life we may return from Mars, or simply organic substances from Mars that could interact with certain life forms on Earth, how can we possibly assert with confidence that MSR poses an acceptable risk to Earth's biosphere, even if the incredibly difficult target of a 99.9999% target for successful containment is satisfied? Given that sample return missions of the type proposed for MSR have never been attempted before, is it even feasible to do enough testing to assure that a 99.9999% target can be achieved?

5 RECOMMENDATIONS

The last paragraph on page 3-3 states that one of the reasons the scientific community thinks the risk of pathogenic effects from the release of small amounts (less than 1 kilogram) of Mars samples is very low is that pieces of Mars have already traveled to Earth as meteorites. No discernible adverse environmental impacts have been associated with these meteorites. A person could expect that other Mars meteorites will impact Earth in the future. Instead of focusing on a 99.9999% target for successful containment (whatever *target* means), augmented with conclusions from consensus opinions that a loss of containment of Mars samples would pose an extremely low risk of an adverse effect to human health or the environment, the MSR Campaign should adopt, as a threshold for risk acceptance, that the risk of an adverse effect to human health or the environment from the MSR Campaign shall be no greater than the risk to human health or the environment expected from the next Mars meteorite that impacts Earth.

Rigorously demonstrating compliance with a one-in-a-million loss of containment probability will be extremely challenging, and deploying such a containment system may not be technically achievable. Moreover, with respect to Mars material that is not contained being returned to Earth, Mars is not a cleanroom (and MSR is still studying dust issues) so it is difficult to understand what rigorous assurance there is that all Mars material returned to Earth by MSR will

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be contained. Sterilizing Mars pathogens or neutralizing Mars mutagens is problematic because we do not have empirical knowledge of their biological composition or life processes.

Science has a far greater understanding of Mars meteorites than it does of Mars biology, and despite the best intentions of their creators all devices developed by humans can fail. With respect to Mars biology and the reliability of the MSR containment system there are a lot of unknowns that can contribute to the risk of adverse environmental effects on Earth. By comparison the unknowns associated with our understanding of Mars meteorites are small.

As noted in the paragraph beginning at the bottom of page 3-3 in the MSR PEIS, the natural delivery of Mars materials to Earth can provide better protection and faster transit than the current MSR mission concept. Consequently, material returned by MSR will have greater exposure to environmental conditions harmful to biological entities in general, be they pathogenic or mutagenic. Moreover, Mars material returned by MSR will be exposed to these conditions for longer periods than is material transported to Earth by natural delivery. Whether the Mars material received by natural transport initially contains no entities or compounds harmful to Earth's biosphere, or such entities or compounds were neutralized during their transport to Earth's biosphere, no resultant harm has occurred. This affords empirical information (as opposed to extrapolations and interpretations) regarding how Mars material has been transported to Earth and interacted with its environment after arrival. If the MSR Campaign can convincingly demonstrate that material returned to Earth by MSR will be subjected to more severe conditions than those transported by natural processes, then MSR poses no greater risk to Earth than we would expect from the next Mars meteorite. However, if this cannot be convincingly demonstrated the MSR Campaign should seriously consider not returning samples using the technology described in the PEIS (i.e., transition to a deferred return campaign option).

As of 2020, 262 individual samples of Martian meteorites have been recovered from six different continents. There is no evidence that any of these meteorites has been environmentally harmful. Using just this information a Bayesian analysis can disclose that the probability the next Martian meteorite will effect Earth differently (i.e., adversely) has an expected value of 0.19%. Though far greater than one-in-a-million this is a risk from a natural hazard. If the MSR Campaign is unable to convincingly demonstrate that the risk it poses to Earth is not less than an analog natural hazard the risk from MSR should be considered unacceptable. If the MSR Campaign can convincingly demonstrate the risk it poses to Earth is less than an analog natural hazard, then returning samples using MSR is analogous to having another Mars meteorite impact earth. The MSR assurance case should focus on this.