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Report of the Joint Workshop on Induced Special Regions

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ABSTRACT

The Joint Workshop on Induced Special Regions convened scientists and planetary protection experts to assess the potential of inducing special regions through lander or rover activity. An Induced Special Region is defined as a place where the presence of the spacecraft could induce water activity and temperature to be sufficiently high and persist for long enough to plausibly harbor life.

The questions the workshop participants addressed were:

(1) What is a safe stand-off distance, or formula to derive a safe distance, to a purported special region?

(2) Questions about RTGs (Radioisotope Thermoelectric Generator), other heat sources, and their ability to induce special regions.

(3) Is it possible to have an infected area on Mars that does not contaminate the rest of Mars?

The workshop participants reached a general consensus addressing the posed questions, in summary:

(1) While a spacecraft on the surface of Mars may not be able to explore a special region during the prime mission, the safe stand-off distance would decrease with time because the sterilizing environment, that is the martian surface would progressively clean the exposed surfaces. However, the analysis supporting such an exploration should ensure that the risk to exposing interior portions of the spacecraft (i.e., essentially unsterilized) to the martian surface is minimized.

(2) An RTG at the surface of Mars would not create a Special Region but the short-term result depends on kinetics of melting, freezing, deliquescence, and desiccation. While a buried RTG could induce a Special Region, it would not pose a long-term contamination threat to Mars, with the possible exception of a migrating RTG in an icy deposit.

(3) Induced Special Regions can allow microbial replication to occur (by definition), but such replication at

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the surface is unlikely to globally contaminate Mars. An induced subsurface Special Region would be isolated and microbial transport away from subsurface site is highly improbable.

1. Background

1.1. Origin

A Special Region on Mars is defined as an environment that has conditions to allow terrestrial life to propagate. This is currently defined as temperatures warm enough, and water activity high enough for reproduction (Beaty et al., 2006; Rummel et al., 2014). Although the focus of these two important Mars Exploration Program Analysis Group (MEPAG) studies was naturally occurring Special Regions, Rummel et al., 2014 also presented preliminary analysis of the possibility of what they called "Spacecraft-Induced Special Regions" (see especially their Finding 5.1). At the Planetary Science Subcommittee (PSS) meeting of the NASA Advisory Council (NAC) in September of 2016, concern was raised about "the potential of 'induced special regions' through landers or rovers creating a local environment that would be heated and contain aqueous fluids that have sufficiently high water activity and that could persist long enough to plausibly harbor life." [PSS Recommendations for September 2016]. The PSS chair noted that concerns about the potential for inducing Special Regions on Mars had been discussed for over two years with no apparent progress. As a result, a workshop of scientists and planetary protection experts was proposed, to be sponsored by both the NAC Planetary Protection Subcommittee (PPS) and the PSS. Considering the breadth of issues involved, it was thought that this workshop could be the first of a series spanning the intersection of planetary protection and science.

With exchange of preparatory emails, Jim Green (then Director, NASA Planetary Sciences Division) and the conveners, Robert Lindberg, Michael Meyer, and Clive Neal, (Cassie Conley was unable to make the meeting), met at the 2017 Lunar and Planetary Science Conference to establish an invitation-only workshop, its goals, and the process for conducting a Joint Workshop on Induced Special Regions. Over the ensuing months, the Terms of Reference were established and a workshop announcement developed. In addition, a list of potential invitees was developed to establish a well-informed, balanced, and cross-disciplinary participant list.

1.2. Workshop preparation

The Workshop announcement, invitation, list of participants, and questions posed to the workshop participants before their participation, are in Appendix I. Pre-workshop questions were given to the participants recognizing that they are experts in diverse disciplines and would be approaching the concept of Induced Special Regions (ISR) from very different perspectives. The responses were consolidated and sent back to the participants, providing the different discipline perspectives to all the participants. Furthermore, the responses informed the conveners of potential knowledge gaps and the workshop was restructured to provide three upfront tutorials and to provide a blend of subgroups members to encourage the exchange of information and ideas.

2. The workshop

The Workshop was hosted by USRA (Universities Space Research Association) at their headquarters in Columbia, Maryland, November 29–December 1, 2017. In the first part of the workshop (see Agenda, Appendix II), the conveners and participants reviewed the goals of the workshop and definitions of terms in order to establish a common basis for discussion, including a review of the answers to the questions distributed before the workshop. Conveners then introduced three sets of new more-specific questions addressing items that could directly affect mission operations and design. This was followed by introductory presentations by participants with pertinent expertise on major subjects concerning those questions.

The participants were then divided into three subgroups, each possessing a balance of expertise and personalities. All three subgroups then addressed each question separately, and presented their answers in plenary sessions. Through this process, workshop conveners hoped to create an environment where everyone in the subgroups would have a voice, and each of the subgroups would have the opportunity to develop unique answers, in order to highlight areas of consensus and divergence. The resulting presentations from each group provided the opportunity for in-depth discussion in areas of disagreement with all expertise represented. On the final day, the participants were remixed into three new groups, and each group synthesized the responses to one of the workshop questions developed over the previous two days, with the goal of deriving a consensus. In the final plenary session, the answers to the questions were reviewed, discussed, and consensus achieved. Achieving a consensus was a goal, but not a requirement, of the workshop.

2.1. Three workshop questions and answers

Question 1: What is a safe stand-off distance, or formula to derive a safe distance, to a purported Special Region (SR)?

(a) *What is viability/distance for microorganism transport?*
(b) *Is there a residence time for a lander on Mars by when a rover/lander will be "safe"?*

Consolidated Response: A spacecraft on the surface of Mars will contain viable microorganisms (bioburden) from Earth and a fraction of the viable bioburden on the spacecraft can be progressively released to the martian environment over time (van Heereveld et al. 2017; Harstad and Bellan 2006). It is also reasonable to assume that a fraction of the released bioburden will survive various lethality factors (UV radiation, free radicals, etc.) (Mancinelli and Klovstad 2000; Schuerger et al., 2003; Schuerger et al., 2005; Schuerger et al., 2006; Tauscher et al., 2006; Rummel et al., 2014; Wadsworth and Cockell, 2017). The current NASA Planetary Protection policy allows for the delivery of 30 spores to a Special Region on a sterilized Class IVb spacecraft, the safe standoff distance is therefore one where <30 spores could be transported to the SR (a derived maximum permitted contamination level obtained by the reduction by four orders of magnitude of the permitted bioburden of a Class IVa mission of 3×10^5 spores total on the surface of the spacecraft),.

However, the probability of terrestrial organism survival and viability is a function of time because: (i) the martian surface environment presents survival challenges to life as we know it (UV radiation, chemical reaction, static charging, etc.) and shedding of microbes decreases the bio-load with time, while (ii) coverage of the spacecraft by Mars dust represents a means to shield spacecraft microbes from these effects (Mancinelli and Klovstad 2000; Schuerger et al., 2003; Schuerger et al., 2005; Schuerger et al., 2006; Tauscher et al., 2006). Nonetheless, it can be envisioned that the percentage of viable microorganisms on the spacecraft will decrease the longer the spacecraft is on the surface of Mars and the safe distance to a designated SR becomes shorter. Therefore, at some point during the mission, the nominal safe standoff distance will approach zero. However, for a rover to explore a SR, the environment of that specific SR needs to be evaluated in terms of mission operations, risk to the mission, and also the potential for exposing sealed (potentially terrestrial organism-rich) areas of the spacecraft. The safety (integrity) of the spacecraft is paramount so as not to accidentally expose the spacecraft interior to the Mars environment, as these areas/volumes would not have been sterilized by environmental exposure to UV radiation and shedding once on the surface of Mars, and could still be a source of contamination.

A series of processes were identified that could contribute to the reduction of the bioburden on the spacecraft, including assumptions of attachment and environmental conditions, that would potentially reduce the bioburden from the initial level to a "safe" level at a Special Region. For example:

- Lethality of the Mars environment over time (UV radiation, chemical reaction, static charging, thermal cycling, low water activity).
- Processes by which organisms are liberated from spacecraft (wind, dust devils, sandblasting, contact transport).
- Processes by which organisms are transported to a Special Region (prevailing winds, directional winds).
- Processes by which organisms/particles are deposited on a Special Region (surface topology, stickiness).

It was assumed, as a thought experiment, that of the bioburden delivered to Mars, 10% of viable organisms would be liberated from the spacecraft, but for the remaining organisms the probability of survival and viability is a function of time on Mars. We conservatively set this survival probability to be a factor of 10 reduction (10% survival) per Mars year. It was further assumed that of the liberated organisms, no more than 10% would survive in the toxic martian surface environment long enough to be able to replicate.

The possibility exists that a viable organism can be attached to (or become) a particle small enough that it can be suspended in the atmosphere for extended periods (Kahre et al., 2008). Under this situation, without any information to the contrary, we must assume that it can eventually be deposited globally anywhere, but the dilution factor (the ratio of total surface area to Special Region surface area) would be $>> 10^4$. However, we must also consider the possibility of multiple transport events until a particle reaches a "sticky" Special Region (i.e., one from which the particle is not further transported). In other words, an organism-burdened particle may be lofted, settle to the surface, and be re-lofted multiple times until it comes in contact with a surface to which it becomes indefinitely bound.

So, organism transport to a SR is a function of:

M_E	Number of viable microbes leaving Earth on s/c surfaces
f_M	Fraction viable arriving on Mars on s/c
K	Fraction not surviving onboard after exposure to Mars environment
f_R	Fraction of microbes released during operations
f_T	Fraction of microbes transiting alive once released from spacecraft
T	Fraction of f_T delivered to SR

With an additional factor considering what happens in the SR

H Fraction of microbes surviving and replicating in SR, an indicator of "habitability" or how conducive the Special Region for terrestrial microbes to survive and thrive

These factors can be combined into a predictive scaling equation:

$$\frac{C}{H} > \int^{D} (r, \theta)\cdot\frac{L(1-St)}{K(t)}dt$$

C = "contamination" [#/m^2] [Class IVc requirement]
D = "dispersion" function $T(r, \theta, t)\cdot S$
$T(r, \theta, t)$ = "transport function" of radius (r), azimuth (θ), *and time* (t)(m^{-2})
S = "shedding" rate (s^{-1}) [f_R x f_T]
L = "initial bio-burden" at Mars [M_E x f_M]
t = "time" [s]
K = "kill factor" or organism destruction factor

During the discussion, it was noted that the shedding rate could be describable as a function of the spacecraft design (Schuerger et al., 2005) and the initial bio-burden arriving on the martian surface. These, of course, would be subject to environmental factors once on Mars, such as wind speed, dust lofting, etc. Data that would be needed include information about what exactly is left on the spacecraft after cleaning/dry heat sterilization (e.g., total abundance, variety of types, spore-forming percentage, etc.) (e.g., Beaudet 2013; Benardini et al., 2014; Smith et al., 2017). The transport function would also be a function of spacecraft design and environmental factors.

Finding: While a spacecraft on the surface of Mars may not be permitted to explore a Special Region during the prime mission, the sterilizing environment that is the martian surface and near surface would progressively clean the exposed spacecraft surfaces so that such SR investigations could be proposed for later in the extended mission. However, such an investigation should ensure that the risk to exposing interior portions of the spacecraft (i.e., essentially unsterilized) to the martian surface and shallow subsurface would be minimized (e.g., steep slopes may have higher risks, as would non-trafficable areas such as salt-crust, etc.).

Question 2a: Can a rover RTG or another warm component on the surface induce a Special Region?

Consolidated Response: Probably not, but the result depends on kinetics of melting, freezing, deliquescence, and desiccation. It is not clear that conditions are met on the surface to generate an ISR. Data are needed to help resolve the following questions: What is the availability of water freed by mineral dehydration/deliquescence and/or ice melting? How long, if at all, is water available in the liquid state? How fast does water go into the vapor state or re-freeze? Models and/or tests that evaluate end-member cases under different temperature, pressure, and surface regolith/ice ratios and mineral compositions should be formulated and used to investigate the issue further. The main effect of heat exposure is drying, and the end state of a long-duration exposure to a warm component would be a localized desiccation.

Three main cases were discussed: (1) Nominal Surface Operations; (2) Worst-Case Nominal Surface Operations; (3) Off-Nominal Operations.

(1). Nominal Surface Operations:

If the surface is primarily composed of ice, heat from the spacecraft is dissipated rapidly due to high thermal conductivity and high sublimation rates, so in this case, it is more difficult to raise the temperature of ice to the melting point. Models should be used at appropriate spatial scales to determine if, and for how long, liquid water is present at the surface or in the near subsurface.

If the surface is composed primarily of hydrated minerals, deliquescence may occur temporarily, but the resulting liquid will have a low water activity (Gough et al., 2011). It follows that spacecraft-induced deliquescence would not create a Special Region. The time periods are similarly transient for other dewatering processes (e.g., of gypsum or water-bearing phyllosilicates). Models should be used to test the kinetics of dehydration processes in Mars-relevant environments.

(2). Worst-case nominal surface operations:

Assuming nominal operations, a worst-case scenario that may result as one where the hydration state is much higher than what was gathered from orbital assets. As a rover moves over the icy/hydrated regolith, a terrestrial microbe is deposited by the wheel in a void within a highly hydrated regolith with a low permeability salt cap at a depth that ideally balances the rate of heat transfer from the RTG above the regolith and the rate of liberation of water from the surrounding hydrated minerals. As long as the heat source remains, a microbe could potentially survive and replicate (contingent upon the duration of heating from above the regolith and other habitability factors such as nutrient availability) but transport mechanisms beyond the ISR would be inefficient or non-existent. Even if this worst-case scenario occurs, when the rover leaves the area, the ISR will cease to exist and the microbe(s) would be unable to continue to replicate.

(3). Off-nominal operations:

The results are largely the same as for the nominal case, but with dispersed hardware elements, more heat is applied directly to the surface, so the kinetics of the processes becomes more important. A model that includes terms related to the size of the RTG, proximity to surface, and the amount of ground ice that could melt and form habitable fluids would be useful.

Question 2b: *Can a buried RTG induce a Special Region? In ice, hydrated minerals, or regolith?*

Two analyses were discussed during the workshop: A recent analysis for Mars 2020 and a previous analysis for Mars Science Laboratory (the Curiosity rover). The two sets of results have different findings, as a consequence of input model assumptions. Overall, ISRs produced by a buried RTG, while still transient, are expected to last longer than any ISRs produced by an RTG on the Martian surface. In each of these cases, the ISR is isolated, and surrounded by an environment that precludes reproduction beyond the area of RTG influence.

Consolidated response: A buried RTG could produce a Special Region in regolith with ~6 wt.% H_2O (Shotwell et al., 2019). Similarly, a buried RTG will produce a Special Region in regolith with higher water content. If an RTG is buried in ice, a subsurface pool of liquid water can be expected to persist for 2+ martian years (Hecht and Vasavada, 2006). Overall, ISRs produced by a buried RTG, while still only transient, are expected to last longer than any ISRs produced by an RTG on the Martian surface. In each of these cases, the ISR is isolated, and surrounded by an environment outside the ice shell that precludes reproduction. Even if microbes replicated in the ISR, transport processes away from the ISR are anticipated to be slow or nonexistent and Earth life would not be able to propagate outside the ISR.

A potential worst-case scenario is a mobile subsurface RTG in a polar ice cap, glacial deposit, or massive ice deposit. In this case the RTG could melt the ice and gradually migrate down until reaching a non-melting (mineral) surface (and a potential natural Special Region). Only if the ISR intersects a naturally occurring martian SR, or an environment that has viable (dormant?) indigenous martian organisms present, would there be the potential for propagation.

Does a buried RTG pose a long-term contamination "threat" to Mars?

An RTG buried in hydrated regolith with ~6 wt.% H_2O, would not result in a long-term contamination threat to Mars. Recent analysis (Shotwell et al., 2019) indicates that the contamination will remain localized in the subsurface. For cases of greater or lower water content, the size of the ISR will depend on the abundance of hydrated minerals, but will remain localized.

In icy regolith (e.g., permafrost), there may be a "Goldilocks zone" under which the low thermal conductivity of the surrounding regolith combined with relatively high water concentration could lead to a locally optimum case for sustaining a melt pool for a significant period of time. However, this ISR would still be encapsulated, the region outside of the ISR would still preclude reproduction, and transport processes would be inefficient or nonexistent.

In dirty ice (e.g., polar ice cap or glacier), the RTG could descend through the vertical extent of the ice layer, potentially taking terrestrial microbes along with it, but with the ice layer freezing and sealing the path above the RTG. At some point the RTG would reach the regolith or bedrock where it could sustain an encapsulated viable population for some period of time (contingent upon other habitability factors such as nutrient availability). The possibility of that population posing any risk beyond the local area is remote, because the possible associated transport mechanisms would be inefficient or nonexistent, unless the RTG reaches an existing natural Special Region (e.g., the base of a warm-based glacier). Under some circumstances, melting ice could dissolve substantial volumes of salt, lowering the freezing point of the fluid and leading to a larger local melt pool, relative to pure water under the same conditions. While this would change the scale of the localized ISR, it does not change the nature of the assumed transport mechanisms, and as such would not change the assessment that such an ISR would not pose a long-term threat to Mars.

Finding: While a buried RTG could produce an ISR, it would not pose a long-term contamination threat to Mars. One possible exception would be a migrating RTG in an icy deposit that reaches an existing natural Special Region.

Questions 3: Is it possible to have an infected area on Mars that does not contaminate the rest of Mars? What would be a proper buffer zone?

3a Considerations if a Surface Special Region is Induced

Is it possible to have a rover/lander contaminate an area on Mars that could maintain terrestrial microorganisms for an extended period of time and yet not contaminate the rest of Mars?

Consolidated Response: For reasons outlined below, the generation of an ISR at the surface has a low likelihood of globally contaminating Mars if that surface is not connected to other regions on Mars by an aqueous medium. The likelihood of an ISR contaminating a nearby Special Region would be dependent upon local surface conditions, the duration of the ISR, and transport mechanisms. Surface conditions will dictate both the replication and death rates for microbes within the ISR. At the surface, UV and other ionizing radiation, the presence of oxidants and potential electrical effects would negatively impact the survivability of exposed microbes (e.g., Mickol et al., 2017; Schuerger et al., 2006). Sources of water, considered necessary for the replication of microbes, may come from melting surface ice or surface-exposed hydrated minerals that undergo phase change due to the environment induced by the spacecraft. Mobilized liquid water may dissolve salt, depressing the freezing point and lowering the partial pressure of water vapor above the liquid water surface, allowing for extended presence of liquid at the surface. However, the persistence of liquid water is severely limited by the low atmospheric pressure (which may preclude liquid water for long durations) the low atmospheric water vapor pressure (which will lead to rapid evaporation of induced liquid pools) and the low atmospheric temperatures (which may preclude pure liquid water, but permit only strong brines). Once available water is lost from the surface ISR, subsequent survival of the microbes is considered unlikely and the replication of the microbes is considered remote.

Factors such as the availability of nutrients, availability of synergistic organisms, time history of the temperature and water activity, and availability of one or more sources of energy would govern the growth or decline of the population within the ISR over time. Persistence of the risk of contamination is tied to the persistence of the population and/or persistence of the ISR conditions. Evolutionary adaptation of surviving microbes can increase the chance of the most robust individuals surviving for a longer period. Mitigating controls can include both artificial (constructed) or natural barriers, such as biobarriers, shields, in situ sterilization methods, biotards, atmospheric conditions (such as wind), mountains, etc. Given the current state of knowledge, it is thought that the likelihood of contamination of a proximate natural Special Region from a surface ISR created by a robotic mission is low (See answer to Question 1), assuming that the ISR is at a safe distance from a Special Region.

For Example:

To highlight the low likelihood of contaminating a natural Special Region from the local ISR, the following example is provided (all numbers are educated estimates):

- Assume 300,000 viable aerobic spores to start with (based on level IVa requirements). This assumes no net growth of the microbe population in the ISR. What is the probability of these surviving to contaminate another Special Region?
- Release probability from ISR if it is wet: Estimate ~ 1%. Not all individuals can/will be lifted from the surface for transport.
- Surface transport during Mars daytime by dust and the probability

of having microorganisms survive to the other Special Region: 1%. This accounts for destruction of individuals in the Mars daytime environment (e.g., due to UV exposure, oxides) during transport to a Special Region.

- Surface transport during Mars nighttime in dust and probability having microorganisms survive: 100%. At night, UV destruction ceases to be a concern, and we assume a worst-case scenario that all individuals survive nighttime transport.
- Assume uniform wind distribution/dispersal away from the ISR. Assume angular dispersion angle towards Special Region is ~5° (out of 360°) from the view of the ISR.
- Multiplication of these factors yields a value of 0.42 viable microbes (during the day) or 42 viable microbes (at night). This is the number transported to the Special Region (per 300,000 initial spacecraft bioload).

In this example, the dilution effect of distance is ignored (we presume 100% of the organisms arrive at a “sticky” natural Special Region). Also, we do not consider the degree of habitability of the SR when it arrives—which may be low—we consider only that the number of organisms approaches that which would be permitted to be directly delivered to an SR by a Category IVc mission (30 spores). However, numbers attributed to these factors would need to be validated to justify such an approach during a mission.

Period of Concern:

The period of concern should be considered to be the duration of the ISR, or the arrival of humans on Mars, whichever is shorter. Once the ISR ceases to exist at the surface, viable microbes will cease to exist as well.

Finding: Induced Special Regions may allow microbial replication to occur (by definition), and with the spread of contamination from a surface ISR, microbial transport away could carry contamination to a natural Special Region that is closely located.

3b Considerations if a Subsurface Special Region is Induced

The subsurface is less lethal to microorganisms than the surface environment, and it is possible that microorganisms would replicate in the subsurface if the ISR is habitable. The factors that control the rate of replication of terrestrial microorganisms within the ISR will be important. Beyond satisfying the temperature and water activity limits, replication rates will be impacted by the availability of nutrients, availability of synergistic organisms, time history of the temperature and water activity, and availability of one or more sources of energy. Replication rates may be relatively low. UV radiation is attenuated in the subsurface, but other martian environment lethality rates still apply (e.g., cosmic rays, chemical factors). These factors will govern the growth or decline of the population within the ISR over time.

A subsurface ISR may persist longer than a surface ISR, but microbial transport away from subsurface ISR is highly improbable. The natural subsurface transport mechanism within the top 5 m is interstitial flow, at a rate on the order of microns to millimeters over hundreds of years (ISR conditions can induce faster transport only within the ISR itself). The boundary of the subsurface ISRs (e.g., “hydrated shell”) is governed by the thermodynamics stability of liquid brine/water. Once temperature drops below the eutectic point of the brine/water, all mobility ceases. Therefore, the ISR zone is controlled by the temperature profile and eutectic temperature of the brine/water. Importantly, the subsurface ISR is a cage for life. If life migrates outside ISR, it becomes dormant. Furthermore, the ISR is transient. As the heat source dissipates, the brine/water will freeze. The persistence of the ISR conditions will control the persistence of the contamination threat of the microbial population.

Microbial migration from subsurface ISR to natural Special Regions can occur if there are groundwater systems nearby, but the occurrence of shallow groundwater is considered highly unlikely. If groundwater is physically connected to a subsurface ISR, then no buffer zone will work. However, current orbital radar data indicate that liquid groundwater does not exist in the uppermost few hundred meters of the shallow subsurface (e.g., Rummel et al., 2014). Nonetheless, more measurements are needed to detect groundwater systems and to determine the depth of a possible water table. These data are critical to know definitively if there are deep groundwater systems currently active on Mars, together with how the potential for a descending ISR (through ice displacement or collapse of icy dirt in the subsurface) affects the likelihood of encounter with a groundwater system.

Finding: Induced Special Regions (ISR) may allow microbial replication to occur (by definition), but in the case of a subsurface ISR, microbial transport away from subsurface ISR is highly improbable.

Summary: A workshop discussing the planetary protection challenges of Induced Special Regions on Mars was convened in November 2017 with a wide diversity of disciplines and expertise in the scientific, engineering and policy spheres. The format of the workshop and pre-workshop activities, including information exchange among participants, and revision of workshop key questions based upon preliminary input from the participants, enabled the group to cogently discuss the planetary protection issues confronting Mars exploration, and to develop consensus responses to the key questions.

The following summarize the key findings of the workshop participants:

(1) Over time the sterilizing martian environment will progressively clean exposed spacecraft surfaces such that investigations near, and perhaps on, Special Regions could be considered for extended phases of a surface mission.
(2) A buried heat source (e.g., RTG) could produce an ISR, but would not pose a long-term contamination threat unless the ISR intersects a naturally occurring Special Region.
(3) Formation of an ISR on the martian surface, if in close proximity to a natural Special Region, could lead to long-term contamination of that special region.
(4) Formation of an ISR in the martian subsurface is unlikely to lead to long-term contamination without viable pathways for microbial transport away from the subsurface ISR.

Even if an ISR is created, the isolation, lack of microbial transport, dilution effect of distance to natural Special Regions, and low water activity on Mars make it unlikely that an ISR could globally contaminate Mars.

It is hoped that the content of this report will inform ongoing Mars mission operations and future spacecraft and mission planning.

Addenda

Research recommended

Although the end state of each of the situations described in this report can be reasonably projected, kinetics determine the intermediate state in the transition from one state to another.

- During an induced heating - how long, if at all, is water available in the liquid state? Under what conditions does the heating of ice only result in sublimation rather than melting?

Models are needed to understand details of atmospheric processes (e.g., lofting/saltation and deposition rates; fragmentation of particles during transport, etc.). In the absence of substantial liquid flowing on the surface, surface transport rates would be controlled primarily by atmospheric processes (e.g., dust devils, wind) for long-distance transport, or bulk flow (water-mediated or dry) for short-distance, downslope transport. Data on surface features are currently available at low resolution globally over Mars; high-resolution data (e.g., HiRISE images) would be needed to understand small-scale surface features at each proposed landing site.

Data are also needed on the abilities of Earth organism propagules to facilitate airborne dispersal and survival during dispersal (e.g., pigment shielding of UV by *Deinococcus aerius*). Laboratory data on the time it takes to inactivate spores exposed to UV light suggest that this could be about an hour (Schuerger et al., 2006), depending on the microbe type. However, in the Mars environment, microbes could be shielded from UV – either by their peers or by other particles.

Subsurface transport would require local water/brine aquifers. Limited low-resolution data on possible deep subsurface features are available from SHARAD [Shallow Subsurface Radar] and MARSIS [Mars Advanced Radar for Subsurface and Ionosphere Sounding] radar imaging – more data are needed to understand small-scale features within the accessible (first 5 m) subsurface depth. Synthetic aperture radar (SAR) imaging from orbit could fill these gaps, rover-mounted SAR would provide data on near-subsurface features at locations where landing has already occurred. More subsurface data is needed to determine if deep groundwater systems are currently active on Mars. For planetary protection and landing site selection, the upper 10 m is critical. For human exploration (e.g., ISRU) activities, knowledge of ground water systems at greater depth is relevant.

Considerations related to Landing Site Selection

Landing sites that have indications of potentially being Special Regions require spacecraft landing in them to be cleaned to Category IVc levels. Consequently, if a Category IVa spacecraft might induce a Special Region, the contamination concern must be to reduce contamination to the level of a Category IVc mission. Therefore, a careful landing site analysis needs to ensure that there are no features that could generate Special Regions within the landing ellipse of a IVa spacecraft (as was done, for example, by the US InSight mission).

A key consideration in selecting landing sites for Category IVa missions is to assess the distance to the nearest natural SR, and to characterize potential transport processes for hitchhiking microbes. See answer to Question 1 in the main report.

Connectivity is needed for subsurface transport to be possible from an ISR to a subsurface natural Special Region. This requires both a source of water, and can be aided by salt to form brines (e.g., perchlorate, sulfate), that can remain liquid at temperatures and pressures above the eutectic, which persist long enough for transport to happen. In addition, it is necessary to know if there are aquifers/groundwater systems currently active on Mars, and their locations and extents.

In this workshop, it was proposed that a parameterization be developed of how effectively a possible Special Region could support replication of Earth microbes: a 'Habitability Quality factor'. This 'H Factor' provides a metric of how well the relevant needs of a notional Earth microbe would be met (e.g., water, heat, energy sources).

Landing site selection should also address the possibility of transport to natural Special Regions, with level of concern related to the H factor.

The H factor should also capture the potential for lethality due to aspects of the Mars environment, and how concentrated (i.e., how lethal) the individual factors could be. For the natural Martian inhibitors – lethality is highly dependent on individual microbe capabilities. These factors include:

UV
Ionizing radiation
Desiccation
Oxidants
Temperature extremes
Thermal cycling
Electrical effects

Overall lethality would be a combination of the various enviromental factors.

For example, if microbes are lifted into the atmosphere with dust during night they could survive because of absence of UV, but there is also a potential for dust electrostatic discharges or oxidants to kill them (both during the day and night). In contrast, spore-forming microbes would have a longer survival time, especially if encased in ice, which attenuates UV and protects them from electrostatic discharges and oxidants.

Considerations in the special case of a Special Region Induced by Human Exploration

In the case of human exploration, we consider it inevitable that ISRs will be created; the crew habitat itself will have temperature and humidity levels maintained above the threshold levels for a Special Region on Mars. Even if habitats are designed as entirely enclosed systems for human activity with currently envisaged state-of-the-art life support system technologies, biological contact with the martian environment is considered inevitable (NRC, 2002). This era of human exploration will begin with the first mission to emplace human life support and power equipment – a step expected to occur before the first humans arrive.

Off-nominal landing or off-nominal operational events involving humans or human support systems, including failure of any biological containment technologies, can introduce terrestrial organisms into the martian environment, further increasing the risk of contaminating Mars.

We note that the population of one human microbiome, alone, is at least 100 times the Category IVa spore limit; the total bioload of a human habitat and its support systems, including multiple humans, will be many orders of magnitude higher than the robotic Category IVa spore limit.

In addition, humans and human support systems will include much more robust and readily available sources of nutrients, synergistic organisms, and energy sources, and more hospitable temperatures and water activity. These sources substantially increase the probability that terrestrial microorganisms will readily replicate and establish themselves at least within the habitat itself, as has been seen in all other crewed long-term space habitats (ISS, Mir, etc.).

To Establish a Buffer Zone for Human Exploration

In support of human exploration, we will need to revisit the acceptable “shedding” rate from the ISR, analogous to the shedding rate from a robotic spacecraft. Shedding modalities will include: leakage or venting from the habitat and from suits, transport on suits and equipment (vehicles, tools) used during human exterior activities, processing/storage of microorganism-containing organic waste and transfer of microorganism-bearing fluids between systems within the human support architecture.

In addition to fluid transport mechanisms, we expect that martian particulates that find a way into habitats and suits will become contaminated with terrestrial organisms and then find a way back into the martian environment.

Further, the likelihood of the use of larger, fixed-base RTGs (e.g., fission) or other power sources will introduce enduring thermal sources in relatively close proximity to the sources of contamination detailed above.

Evaluation of the potential for transport from a human exploration ISR to the balance of the martian environment (including naturally occurring SRs) will still involve the transport mechanisms and rates, and lethality mechanisms and rates addressed in the answer to Question 1. The relative proximity of the ISR (and the extent of any human EVAs) to any natural Special Region must also be addressed as it was in the answer to Question 1. Prevailing wind direction and intensity becomes an increasingly important consideration in the selection of human habitat sites relative to any known/suspected natural Special Region.

The use of natural caves, which may be very attractive for protection against radiation, must be comprehensively evaluated robotically. The potential for a natural Special Region to exist within a cave on Mars is not understood.

We note that human contact with the deep subsurface should be considered separately from the above considerations, as the deep subsurface may provide conditions under which terrestrial organisms are more likely to thrive, as well as conditions that might currently support Mars life. Such environments should remain pristine even well after any human contamination of the Mars surface, and should only be accessed under strictly controlled conditions.

To Establish a Period of Concern

We note that there will be both qualitative and quantitative differences between a limited duration human exploratory mission and an intentional effort to establish a permanent human presence on Mars.

After the onset of human exploration, the period of concern for contamination beyond an ISR ceases to be entirely scientifically driven; other factors concerning exploration and use come into play. False-positive detections of Earth life, identifying it as martian lfe, could have significant consequences for future missions in terms of additional requirements to avoid compromising the newly found “extraterrestrial”.

In addition to the continued scientific interest in searching for signs of extant or extinct life on Mars, especially if it might represent a threat to a human crew, we should consider the potential impacts of contamination on continued human activity, e.g., human health, the effects of contamination on resource utilization, sustained human presence (effects on habitability), and the risks to Earth involved in humans returning to Earth from Mars. Thus the period of concern is linked to the pace and cadence of both robotic and human exploration.

Future workshops

The issues facing the planetary protection discipline often require an assessment of a contamination possibility where not all the facts are known. In these cases, convening a workshop drawing from the science and planetary protection communities can provide focus to identify the bounding constraints of the issue at hand. In the workshop environment, the communities can assess the likelihood of different possibilities and reach a consensus, such that a reasoned evaluation can be made by NASA through the Office of Planetary Protection and its advisory structure.

Declaration of Competing Interest

I don't have and I don't know of any conflicts of interest with the authors and with this submission.

Michael meyer

Appendix I

Joint Workshop on Induced Special Regions

Announcement and Invitation

The following announcement was posted at the Lunar and Planetary Institute (LPI) Meeting Portal website:

Purpose and Scope

The outcome of this invitation-only workshop is to inform ongoing and future missions as to where there might be Special Regions, if a spacecraft can inadvertently create a Special Region, and what buffer zone should be considered in approaching a Special Region. Thorough discussions will be focused on three areas of Special Regions: capabilities of Earth organisms, natural conditions on Mars, and how spacecraft could alter conditions on Mars.

The organizers suggest the following reading materials in preparation of this workshop:

- A New Analysis of Mars 'Special Regions': Findings of the Second MEPAG Special Regions Science Analysis Group (SR-SAG2), Astrobiology, Volume 14, Number 11, 2014
- The Potential for the Off-Nominal Landing of an RTG-Powered Spacecraft [Radioisotope Thermoelectric Generator] on Mars to Induce an Artificial Special Region, Submitted to Astrobiology [This report has subsequently been accepted for publication, Shotwell et al., in press]
- Reports from workshops on planetary protection for human missions that address transport questions

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In addition, the following invitation was sent to scheduled participants:

Joint Workshop on Induced Special Regions

The Planetary Protection Subcommittee and the former Planetary Science Subcommittee opened a discussion on how the two communities could better communicate and ensure mission success without contravening PP [Planetary Protection] requirements. A finding from this meeting was as follows:

“The PSS recommends that a workshop of experts be co-organized, with the Planetary Protection Subcommittee, to *better define naturally occurring special regions and also* assess the potential of “induced special regions” through landers or rovers creating a local environment that would be heated and contain aqueous fluids that have sufficiently high water activity and that could persist long enough to plausibly harbor life, and whether this should prevent further exploration of that site or the return of samples from the vicinity.”

At LPSC in March 2017, through discussion centered on Induced Special Regions (ISRs) on Mars, a workshop was conceived to bring together leading experts, particularly from the planetary science and planetary protection communities, to address the possibility of inducing a special region in martian environments and/or the potential of transport of terrestrial microbes to a special region. This is the most urgent with the Curiosity rover on the martian surface and Mars 2020 soon to launch, and very soon to select a landing site [Jezero Crater has been selected]. In addition, SpaceX is planning to go to Mars in 2020, landing in an area known to have subsurface ice. [Space X plans have since changed]

(Special Region: an environment that has conditions that could permit terrestrial life to propagate)

Circumstances potentially inducing Special Regions:

- Bury RTG during EDL [Entry Descent & Landing] crash, either in subsurface ice or deliquescent minerals;
- Roving with a warm RTG could cause ISR during analytical stops;
- What is the buffer zone surrounding an ISR within which contamination of a SR would be likely?

Workshop focused on Mars ISRs

- Initial presentations focused on what we know: Latest science results, engineering advances, and planetary protection requirements. Need to highlight special regions – where the current state of knowledge of where terrestrial life could propagate.
- Because of the diverse disciplines that should be represented at this workshop, there should also be some overviews on mineralogy, water activity, deliquescence, and life in extreme environments.
- Need to explore the “degree of investigation”: For example, with an RSL [Recurring Slope Linae], can a rover explore the termination of such a feature at the bottom of a hill rather than at the source at the surface? How close can the rover get and what is too close? Is there a difference with a rover versus human exploration scenario? Can this be quantified?
- The outcomes of this workshop could be applied to Ocean Worlds, but this initial workshop in Mars-centric.

Agenda

First day: Mars water cycle (what we know and what is modeled, for example anything below 5 m) and delineating areas of potential SR or ISR.

Subsequent day(s): microclimate, micro- and macro-porosity (e.g., space between sand grains to lava tubes/caves),

Items for consideration

- As a rover stays on the martian surface for a longer period of time, does the potential forward contamination risk decline with time as the rover is continually irradiated? Can this be quantified so after a certain period it could visit an RSL?
- We can anticipate that as we transition from robotic to human exploration, the significance of ISRs will increase.
- Workshop should identify future planetary protection-related research areas.

Logistics

- Aiming for about 30 people
- Breakout groups may be needed to address specific questions.

- Need to invite international participation.
- Potential location: USRA Headquarters [Universities Space Ressearch Association]
- When: 2.5 days, November 29-Dec 1

Proposed Workshop Organizers: Michael Meyer, Cassie Conley, Clive Neal, Bob Lindberg;
Proposed Workshop Sponsor: Jim Green

The target of approximately 30 participants was deemed to be sufficient to provide the needed expertise, potential different perspectives on the possibility of inducing special regions by impacting, landing, or operating a spacecraft on the surface of Mars, to ensure a manageable number of people such that there would be open discussion and to permit a consensus conclusion to be reached. Although there were a few last-minute drop-outs, a diverse set of 26 people were able to participate.

Workshop Participants

Name	**Institution**		**Expertise (comment)**
Corien	Bakermans	PSU, Altoona	microbiology, low-T biology
David	Beaty	Mars Program Office, JPL	Mars geology, mission design
Douglas	Bernard	JPL	flight project systems engineering
Penny	Boston	NAI	astrobiology, caves, PP
Vincent F.	Chevrier	U Arkansas	water activity (remote*)
Cassie	Conley	NASA HQ	PPO, biology
Ingrid	Feustel	EPA HQ	toxicology communication
Raina	Gough	UC, Boulder	deliquescence (remote*)
Tim	Glotch	Stony Brook U	spectroscopy, hydrated-minerals
Lindsay	Hays	ARC	astrobiology, buried RTG model
Karen	Junge	APL-UW	microbiology, low-T biology
Robert	Lindberg	U Virginia	PPS chair, mechanics, robotics
Michael T.	Mellon	APL [now Cornell U]	modelling water on Mars
Michael	Meyer	NASA HQ	MEP, astrobiology. microbiology
Michael	Mischna	JPL	Mars water/climate modelling
Clive	Neal	U Notre Dame	PSS chair, lunar petrology
Betsy	Pugel	NASA HQ	PPO, flight project engineering
Richard	Quinn	NASA ARC	regolith reactivity, deliquescence
Francois	Raulin	Université Paris Est Créteil	astrobiology, astrochemistry, PP
Nilton	Renno	U. Michigan	climate, thermodynamics
John	Rummel	SETI	PP, astrobiology
Mitch	Schulte	NASA HQ	organic chemistry, MEP
Andy	Spry	SETI	PP
Perry	Stabekis	Retired	PP
Alian	Wang	Wash U	mineralogy, hydrated minerals
Nathan	Yee	Rutgers	geomicrobiology

*Presented remotely to the Workshop

Pre-Workshop Questions

Recognizing that the participants were approaching the concept of Induced Special Regions from very different perspectives, the conveners decided that a set of questions, to be answered by participants beforehand, could provide:

- a common understanding of several disciplines needed to discuss Mars exploration potentially involving special regions
- foundational knowledge for workshop discussion
- input to be used to help construct the agenda of talks and discussion groups for the workshop.

Pre-Workshop Questions

(1) **Questions about capabilities of Earth organisms: what do we know, and what additional information would be useful?**
  (a) Under what circumstances could the surface or spacecraft-accessible subsurface of Mars support growth of terrestrial microbes?
  (b) Are there other parameters, beyond temperature and water activity, that could be relevant to the ability of terrestrial microbes to grow on Mars?
  (c) To what extent are conditions on Mars toxic to terrestrial microbes? Over what exposures/timescales?
(2) **Questions about natural conditions on Mars: what do we know, and what additional information would be useful?**
  (a) Do temporal and spatial disequilibria create the potential for transient/periodic 'Special Regions' – considering the extent of diurnal and seasonal cycles?
  (b) Under what conditions could deliquescence contribute to creation of Special Regions?
  (c) Are Recurring Slope Lineae (RSL) Special Regions? Why and why not?
(3) What characteristics of RSL suggest that they could be Special Regions? Are there different sub-categories?
(4) What additional information is needed to establish whether RSL are actually Special Regions? (They are currently considered 'possible Special Regions' and therefore are treated as Special Regions until shown to be otherwise).
(5) **Questions about how spacecraft could alter condition on Mars: what do we know, and what additional information would be useful?**
  (a) What environments are present on/inside spacecraft that could provide more/less-habitable conditions for terrestrial microbes than the natural surface of Mars?
  (b) How might spacecraft alter the natural surface of Mars to create environments that are more/less habitable for terrestrial microbes?
  (c) What effects does a perennial heat source (e.g., RTG) have on the surface of Mars, and how might this affect the potential for local

environments to become 'Special Regions', at least transiently?

(d) How could microbes from spacecraft be transported to possible Special Regions? (Please consider surface/atmosphere processes as well as subsurface processes.)

After receiving submissions in response to these questions, the conveners refined the agenda and determined additional discipline speakers to provide foundational material at the beginning of the workshop. All the participants received an anonymized consolidation of the responses to these pre-workshop questions, providing information and perspective to the participants. All the answers were color coded such that the participants could follow any one responder and yet reduce potential bias toward an answer based on the source. In other words, it was hoped that the answers would provide “food for thought” in preparation for the workshop and not be source for “battle lines being drawn”. The consolidated response helped the conveners develop a second set of questions, directly addressing the purpose of the workshop, and to be answered by the various breakout groups during the workshop.

Appendix II

Agenda Joint Workshop on Induced Special Regions

Day 1	
7:30	**Registration Begins**
	• Coffee & tea
8:00	**Welcome and Introductions,** Robert Lindberg
8:15	**Overview of Special Regions,** John Rummel
8:30	**Purpose and Expected Outcome,** Clive Neal
8:45	**Review of Responses to Questions,** Cassie Conley
9:15	**New Questions to Guide Workshop Discussion,** Michael Meyer
9:30	**BREAK**
9:45	**Background Presentations**
	Resource speakers give 30 min overviews of key topics to inform workshop discussions
	• **Water Activity,** Michael Mellon & Vincent Chevrier
	• **Deliquescence,** Richard Quinn & Nilton Renno
	• **Microbes in Extreme environments,** Karen Jung & Penny Boston
	• **Mars Environment,** Michael Mischna
	• **Mars Minerals,** Timothy Glotch & Alian Wang
12:15	**LUNCH**
13:15	**Questions and Procedure**
	For the remainder of the workshop, participants will split into small groups to discuss each of the three new workshop questions. After small group sessions, participants will meet in plenary to touch base before moving on to the next question. Adjustments will be made as needed.
13:30	**Lightning Talks; Buried RTG model,** David Beaty & Lindsay Hays
14:00	**Question 1 Discussion**, Small Groups
17:00	**Plenary Tag-up**
17:30	**Closing Remarks**
18:00	**Happy Hour**
Day 2	
7:30	**Coffee & Tea**
8:00	**Opening Remarks**
	Review question 1 and procedures
8:30	**Question 2 Discussion**, Small Groups
12:00	**LUNCH**
13:30	**Question 3 Discussion**, Small Groups
17:00	**Plenary Tag-up**
17:30	**Closing Remarks**
19:00	**Group Dinner**
Day 3	
7:30	**Coffee & Tea**
8:00	**Final Plenary**
	Review earlier discussion and identify areas of consensus and contention
11:00	**Additional Items and Next Steps**
12:00	**Closing Remarks**

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