Questions for NASA about its mistakes in the Mars Sample Return Environmental Impact Statement submitted under NEPA - these make it not scientifically credible

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Preprint DOI …

[Many candidate microbes and even higher life like lichens have been proposed as Mars analogue organisms, some tested with promising results in Mars simulation chambers, so its biologically credible a species can have adaptations to live on both planets](#h_candidate_terrestrial_microbes_mars)

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Titles of sections are like mini-abstracts and summarize the details of the section. For a first overview of this paper read the section titles.

This focuses on the questions for NASA and the points of top priority for NASA to look at. It consists of sections from the larger review paper here:

…

Many of the internal links are to sections that expand on the points made here in the larger review paper and so don’t work in this page.

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# [Abstract](#h_Abstract)

JAXA can safely return unsterilized samples without any precautions, because any microbes already withstood ejection from Mars, most recently, 700,000 years ago. They then experienced conditions on the surface of Phobos similar to conditions inside martian meteorites arriving at Earth today from that ancient impact.

JAXA warned their meteorite argument is not valid for surface samples never ejected from Mars. NASA’s draft EIS incorrectly says any life from Jezero crater can get here faster and better protected in a meteorite than in a sample tube. Surface dirt and dust can’t get here at all.

NASA’s EIS also proposes to return its samples to a Biosafety Level 4 facility. However, the European Space Foundation study in 2012 set size limits well beyond capabilities of a BSL-4 and indeed beyond any current air filter capabilities.

There are numerous other mistakes in the draft EIS.

We can avoid all these issues and keep Earth 100% safe by sterilizing samples before they get here. with the equivalent of a few hundred million years of Mars surface ionizing radiation. This has virtually no effect on geology, while Perseverance’s forward contamination makes most astrobiology impossible.

We can greatly increase science value with bonus samples in a sterile container returned to a martian gravity centrifuge in an unmanned satellite above GEO, to start Sagan’s “vigorous program of unmanned exobiology”.

## [Questions for NASA](#h_questions_for_NASA) [Next section](#h_controversial_or_mistaken_statements) – [all sections](#h_titles_of_sections) – [previous section](#H_NEPA_say_to_contact)

#### 2012 ESF Mars Sample Return size limit review:

* Are you aware that the European Space Foundation (ESF) Mars Sample Return study in 2012 reduced the size limit from 0.2 microns to 0.01 microns for the 1 in a million threshold and required 100% containment at 0.05 microns? If so, why doesn’t the EIS mention this change?  
  [[details](#x_size_limit)]
* Are you aware that your recommendation to contain the samples in a Biosafety level 4 facility doesn’t comply with the size limit the ESF recommended in 2012, and that the ESF recommended that the size limit and level of assurance is reviewed regularly? If so, why isn’t the reader alerted to this discrepancy?  
  [[details](#x_size_limit_review)]

#### Meteorite argument for samples returned from the Mars surface

* Are you aware the JAXA cite you use says on page 4 not to use their meteorite argument for samples returned from the Mars surface? If so, why isn’t the reader alerted to this discrepancy?  
  [[details](#x_PHobos)]

#### 2015 MEPAG review:

* Are you aware of the 2015 MEPAG review that overturned all the findings you rely on to say that life couldn’t get to Gale crater? If so, why doesn’t the EIS cite it?  
  [[details](#x_MEPAG)]
* Are you aware that you used a cite about searches for current localized habitable regions on Mars to support a statement that conditions on Mars have not been amenable to supporting life as we know it for millions of years? If so, why isn’t the reader alerted to this discrepancy?   
  [[details](#x_RSL)]

#### Large scale effects

* Are you aware of warnings about large scale effects in the NRC study in 2009? If so, why isn’t this mentioned in the EIS?  
  [[details](#x_large_scale_effects)]
* Are you aware of warnings about the potential that we have no defences against alien life by Joshua Lederberg and others? If so, why doesn’t the EIS discuss them?  
  [[details](#x_no_defences)]

#### Mars microbes as pathogens of humans, these are questions for your sterilization working group about its report:

* Are you aware that Legionella pneumophila is a disease of biofilms that also opportunistically infects humans as Legionnaires’ disease, which is sometimes lethal, and is not adapted to multicellular life? If so why isn’t this disease mentioned in the discussion of whether pathogens have to coexist with humans to harm us?  
  [[details](#x_Legionella)]
* Are you aware that the fungus Aspergillus fumigatus is not adapted to any multicellular host and causes an estimated 200,000 life threatening cases of invasive aspergillosis a year, mainly in immunocompromised people, with a 30% to 95% mortality rate? If so, why isn’t this fungus mentioned in the discussion of Candidas yeast’s adaptations to humans?  
  [[details](#x_Aspergillus)]
* Are you aware of the example from the NRC sample return report of an independently evolved hydrothermal vent organism that shares many virulence genes with a human pathogen? If so why isn’t this included in the discussion of Shiga’s toxin?  
  [[details](#x_Shigia)]
* Are you aware that the toxin produced by Clostridium tetani is not a result of adaptation to humans and neonatal tetanus kills thousands of unvaccinated newborns every year? If so, why isn’t this mentioned in the discussion of Shiga’s toxin?  
  [[details](#x_tetanus)]

#### Potential for martian microbes to survive on Earth, more questions for your sterilization working group about its report:

* Are you aware that the extremophile paper you cited lists Planococcus Halocryophilus, a microbe isolated from permafrost at an ambient temperature of about -16 °C, which has an optimal growth temperature of 25 °C and can grow at temperatures up to 37 °C (temperature of human blood) and salinity 0% to 19%? If so why isn’t this microbe discussed in your suggestion that it’s plausible that life adjusted to Martian conditions such as temperatures and pressures would not be viable on Earth?   
  [[details](#x_extremophiles)]
* Did you have any examples of extreme conditions microbes face on Mars that could prevent them surviving on Earth? If you didn’t have specific examples, why doesn’t your report mention this limitation?   
  [[details](#x_extreme_conditions)]
* Are you aware that many Mars analogue terrestrial organisms such as chroococcidiopsis are thought to have some potential for living on present day Mars? If so, why isn’t the reader informed of this?   
  [[details](#x_analogue)]

#### Scoping and requirement for “safety testing”

* With your requirement of “Safety testing”, are you aware that the expected level of forward contamination of 0.7 nanograms per gram per biosignature means all samples will test positive and go to hold and critical review, which will make the safety testing pointless?   
  [[details](#x_safety)]
* Why wasn’t the option considered to sterilize samples before they reach Earth’s biosphere?   
  [[details](#x_sterilize)]

#### Procedure:

* As you surely know, NEPA requires agencies to ensure scientific integrity in an Environmental Impact Statement, so, do you know how the EIS come to have so many citing errors of central importance to your arguments, and can NASA ensure this won’t happen again in any future EIS?   
  [[details](#x_NEPA)]
* The Council for Environmental Quality says the first step is to contact the agency to resolve issues, so, can you respond to these questions?  
  [[details](#x_Council)]

The simplest answer is that it is all a big mistake, and they weren’t aware of any of those things. If so fine, we all make mistakes! But that means we need to start again with a scientifically credible EIS starting with a new size limit review etc .

At some point NASA are going to have to look at these questions and others like them. The public response to the EIS so far shows many will want answers. If these are indeed valid questions, the sooner NASA look at them the easier and less costly the solutions, and the fewer the complications.

### Reasons for these questions: mistakes in NASA's draft EIS and the report of the sterilizing subcommittee [Next section](#h_we_cant_actually_asseses) – [all sections](#h_titles_of_sections) – [previous section](#h_questions_for_NASA)

Here is a list of the mistakes in the EIS or the report of the sterilization working group which that list of questions is based on, with links to the sections of this paper that discuss them:

#### 2012 ESF Mars Sample Return size limit review:

**Are you aware that the European Space Foundation (ESF) Mars Sample Return study in 2012 reduced the size limit from 0.2 microns to 0.01 microns for the 1 in a million threshold and required 100% containment at 0.05 microns? If so, why doesn’t the EIS mention this change?**

[[summary](#xc_size_limit)]

Draft EIS ([NASA, 2022](#b_NASA_2022eis): S-4):

*“The material would remain contained until examined and confirmed safe or sterilized for distribution to terrestrial science laboratories. NASA and its partners would use many of the basic principles that Biosafety Level 4 (BSL-4) laboratories use today to contain, handle, and study materials that are known or suspected to be hazardous.”*

2012 ESF Mars sample return study: [(Ammann et al, 2012:48)](#qa4nethlmcdw):

*RECOMMENDATION 7:  
The probability that a single unsterilised particle of 0.01 μm diameter or greater is released into the Earth’s environment shall be less than 10 -6 .*

*…*

*The release of a single unsterilized particle larger than 0.05 μm is not acceptable under any circumstances*

This is well beyond the capability of a BSL-4. See:

* [2012: The European Space Foundation study reduced the size of particle to contain from 0.2 microns to 0.01 microns at the one in a million threshold, and added that it is not acceptable to release a particle of 0.05 microns or larger in any circumstances – this is well beyond the capabilities of NASA’s proposed BSL-4](file:///C:\Users\rober\Documents\booklets\MSR_papers\Why_we_must_be_able_to_protect_Earth_from_even_mirror_life_in_Martian_dirt.docx#h_the_ESF_study_in_2012)   
  [and following sections]

**Are you aware that your recommendation to contain the samples in a Biosafety level 4 facility doesn’t comply with the size limit the ESF recommended in 2012, and that the ESF recommended that the size limit and level of assurance is reviewed regularly? If so, why isn’t the reader alerted to this discrepancy?**[[summary](#xc_size_limit_review)]

2012 ESF Mars Sample Return Study [(Ammann et al, 2012:21)](#qa4nethlmcdw):

*RECOMMENDATION 8: Considering that (i) scientific knowledge as well as risk perception can evolve at a rapid pace over the time, and (ii) from design to curation, an MSR mission will last more than a decade, the ESF-ESSC Study Group recommends that values on level of assurance and maximum size of released particle are re-evaluated on a regular basis*

See:

* [ESF study said values for required level of assurance and the size limit need to be revisited periodically based on changes in scientific knowledge and risk perception](C:\\Users\\rober\\Documents\\booklets\\MSR_papers\\Why_we_must_be_able_to_protect_Earth_from_even_mirror_life_in_Martian_dirt.docx" \l "h_ESF_study_risk_size_limit)

#### Meteorite argument for samples returned from the Mars surface

**Are you aware that the Phobos sample return study you cite specifically says on page 4 not to use their meteorite argument for samples returned from the Mars surface? If so, why isn’t the reader alerted to this discrepancy?**

[[summary](#xc_PHobos)]

Draft EIS ([NASA, 2022](#b_NASA_2022eis): 3-3):

*“The natural delivery of Mars materials can provide better protection and faster transit than the current MSR mission concept.”*

2009 NRC Mars Sample Return Study ([SSB, 2009](#b_SSB_2009): [48](https://www.nap.edu/read/12576/chapter/7#48))

*The potential hazards posed for Earth by viable organisms surviving in samples [are] significantly greater with a Mars sample return than if the same organisms were brought to Earth via impact-mediated ejection from Mars*

*…*

*Thus it is not appropriate to argue that the existence of martian meteorites on Earth negate the need to treat as potentially hazardous any samples returned from Mars by robotic spacecraft.*

2019 study of planetary protection requirements for Japan’s Phobos sample return ([SSB, 2019](#b_Board_2019) : [43](https://nap.nationalacademies.org/read/25357/chapter/5)) (split the sentences into bullet points):

* *The material will be gently sampled and returned directly to Earth.*
* *The sample may well come from an environment that mechanically cannot become a Mars meteorite.*
* *The microbes may not be able to survive impact ejection and transport through space.*
* *Samples with current liquid water and recent ice seem especially fragile to natural transport to Earth.*

*Finding: The committee finds that the content of this report and, specifically, the recommendations in it do not apply to future sample return missions from Mars itself.*

See:

* [No, life on Mars can't get to Earth faster and better protected in meteorites than in a sample tube - the 2009 Mars sample return study warns against this argument as does the 2019 Phobos sample return study - indeed martian surface brines, ice, salts, dirt and dust can't get to Earth at all](#h_the_meteorite_argument)   
  [and following sections]

#### 2015 MEPAG review:

**Are you aware of the 2015 MEPAG review that overturned all the findings you rely on to say that life couldn’t get to Gale crater? If so, why doesn’t the EIS cite it?**

[[summary](#xc_MEPAG)]

Draft EIS ([NASA, 2022](#b_NASA_2022eis): 1-6):

*“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, which was chosen as the sampling area because it could have had the right conditions to support life in the ancient past, billions of years ago.”*

MEPAG review ([SSB, 2015](#b_SSB_2015) :[28](https://nap.nationalacademies.org/read/21816/chapter/7)).

*Maps that illustrate the distribution of specific relevant landforms or other surface features can only represent the current (and incomplete) state of knowledge for a specific time—knowledge that will certainly be subject to change or be updated as new information is obtained*

MEPAG review ([SSB, 2015](#b_SSB_2015) : [12](https://nap.nationalacademies.org/read/21816/chapter/4?term=dust#12)).

*"The SR-SAG2 report does not adequately discuss the transport of material in the martian atmosphere. The issue is especially worthy of consideration because if survival is possible during atmospheric transport, the designation of Special Regions becomes more difficult, or even irrelevant."*

MEPAG review ([SSB, 2015](#b_SSB_2015) :[12](https://nap.nationalacademies.org/read/21816/chapter/4?term=dust#12)).

*Physical and chemical conditions in microenvironments can be substantially different from those of larger scales. Although the SR-SAG2 report considered the microenvironment (Finding 3-10), the implications of the lack of knowledge about microscale conditions was only briefly considered.*

See:

* [Jezero crater seems uninhabited from orbit – but so do terrestrial Mars analogue deserts – the 2015 MEPAG review which the EIS doesn’t cite overturned all the conclusions relevant to Jezero crater that NASA’s EIS relies on](#j_jezero_crater_uninhabited)  
  [And following sections]

**Are you aware that you used a cite about searches for current localized habitable regions on Mars to support a statement in the EIS that conditions on Mars have not been amenable to supporting life as we know it for millions of years? If so, why isn’t the reader alerted to this discrepancy?**

[[summary](#xc_RSL)]

Draft EIS ([NASA, 2022](#b_NASA_2022eis): 1-6):

*“Existing credible evidence suggests that conditions on Mars have not been amenable to supporting life as we know it for millions of years.”*

National Research Council, 2022 ([Smith et al, 2022](#b_Smith_et_al_2022): [393](https://nap.nationalacademies.org/read/26522/chapter/16#393))

*Section title: “Are There Chemical, Morphological and / or Physiologic / Metabolic or Other Biosignatures in* ***Currently Habitable Environments*** *in the Solar System*

*The exploration of … Mars (Curiosity, Perseverance) will help establish whether localised habitable regions* ***currently exist*** *within these seemingly uninhabitable worlds.*

[Emphasis on “currently” mine]

See:

* [NASA’s draft EIS argues that existing credible evidence suggests Mars has not been habitable to Earth life for millions of years –– yet their cite for this sentence is about a search for current localized habitable regions on Mars – another conclusion reached through a citing error](#h_NASA_credible_evidence)

See also:

* [2016: NASA discovered potential for current habitats for terrestrial life in Gale crater AFTER Curiosity’s landing](#h_NASA_current_habitats_Gale)

#### Large scale effects:

**Are you aware of the warnings about large scale effects in the NRC study in 2009? If so, why isn’t this mentioned in the EIS?**

[[summary](#xc_large_scale_effects)]

Draft EIS ([NASA, 2022](#b_NASA_2022eis): 3-3):

*“The relatively low probability of an inadvertent reentry combined with the assessment that samples are unlikely to pose a risk of significant ecological impact or other significant harmful effects support the judgement* ***that the potential environmental impacts would not be significant.”***

2009 NRC Mars Sample Return Study [(SSB, 2009](#kix.xed3c1hm3p4k) : [48](https://nap.nationalacademies.org/read/12576/chapter/7#48) )

The committee found that **the potential for large-scale negative effects on Earth’s inhabitants or environments by a returned martian life form appears to be low, but is not demonstrably zero**

… **it is not possible to assess past or future negative impacts caused by the delivery of putative extraterrestrial life**, based on current evidence.  
…  
… It follows that, since the potential risks of pathogenesis cannot be reduced to zero, a conservative approach to planetary protection will be essential, **with rigorous requirements for sample containment and testing protocols of life forms that are pathogenic to humans**

See:

* [The planetary protection literature warns of not demonstrably zero potential for even large scale harm to human health and the environment – NASA’s draft EIS conclusion of no significant risk of environmental effects seems a minority view amongst microbiologist and they don’t alert the reader to this discrepancy](#h_the_plnaetary_protection_literature)

**Are you aware of the warnings about the potential that we have no defences against alien life by Joshua Lederberg and others? If so, why doesn’t the EIS discuss them?**[[summary](#xc_no_defences)]

Draft EIS Sterilization Working Group report [(Craven et al., 2021:6)](#b_Craven_et_al_2021)

*“Since any putative Martian microorganism would not have experienced long-term evolutionary contact with humans (or other Earth host),* ***the presence of a direct pathogen on Mars is likely to have a near-zero probability.”***

Joshua Lederberg [(Lederberg, 1999b)](#kix.ar87fg72xwf2):

***Joshua Lederberg:*** *Whether a microorganism from Mars exists and could attack us is more conjectural. If so, it might be a zoonosis [infectious disease that jumps to humans] to beat all others*

See:

* [Warnings by some astrobiologists such as Sagan and Lederberg that in worst case we could be in effect immunocompromised to an entire exobiology from Mars](#h_warnings_by_some_astrobiologists)   
  [And previous sections]

#### Mars microbes as pathogens of humans, these are questions for your sterilization working group about its report:

**Are you aware that Legionella pneumophila is a disease of biofilms that also opportunistically infects humans as Legionnaires’ disease, which is sometimes lethal, and is not adapted to multicellular life? If so why isn’t this disease mentioned in the discussion of whether pathogens have to coexist with humans to harm us?**[[summary](#xc_Legionella)]

Draft EIS Sterilization Working Group report [(Craven et al., 2021:6)](#b_Craven_et_al_2021)

*Since any putative Martian microorganism would not have experienced long-term evolutionary contact with humans (or other Earth host),* ***the presence of a direct pathogen on Mars is likely to have a near-zero probability.***

Warmflash used Legionnaires’ disease to challenge whether there is a need for human pathogens to co-evolve with us [(Warmflash, 2007)](#inpazll45dhz):

*In essence, all that a potentially infectious human pathogen needs to emerge and persist is to grow and live naturally under conditions that are similar to those that it might later encounter in a human host. On Mars, these conditions might be met in a particular niche within the extracellular environment of a biofilm, or within the intracellular environment of another single-celled Martian organism.*

*…*

*To be sure, the genetic similarity between humans and protozoa is much greater than could be expected between humans and the Martian host of a Martian microbe.*

*Even in the context of a planetary biosphere that is limited to single-celled life, and even where there is unlikely to have been a co-evolution between agent and host organism, the possibility of infectious agents, even an invasive type, cannot be ruled out.*

See:

* [Argument that martian pathogens wouldn’t be adapted to humans or other Earth hosts misses a disease of biofilms that opportunistically infects human lungs - legionnaires’ disease](#h_argument_pathogens_not_adapted)

**Are you aware that the fungus Aspergillus fumigatus is not adapted to any multicellular host and causes an estimated 200,000 life threatening cases of invasive aspergillosis a year, mainly in immunocompromised people, with a 30% to 95% mortality rate? If so, why isn’t this fungus mentioned in the discussion of Candidas yeast’s adaptations to humans?**[[summary](#xc_Aspergillus)]

Draft EIS Sterilization Working Group report [(Craven et al., 2021:6)](#b_Craven_et_al_2021):

*Existing microorganisms that coexist with humans over long periods of time can also …  
  
opportunistically infect a host with a weakened or compromised immune system such as candidiasis yeast infections*

From this list of the most common opportunistic invasive fungal diseases, Aspergillus is at the top alongside Candidiasis [(Brown et al, 2012:table 1)](#kix.jjb1r3cr4sax).

Graphical user interface, text, application

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It’s not adapted to humans or indeed as a pathogen of any higher life ([McCormick et al, 2010](#b_McCormick_2010)).

*According to our current knowledge A. fumigatus lacks sophisticated virulence factors that are solely dedicated to permit a pathogenic lifestyle.*

See:

* [NEW: Sterilization working group’s report gives an example of an opportunistic fungal pathogen, Candidiasis, adapted to humans – the omission here is Aspergillus which is not adapted to humans and is invasive due to adaptations to survive rapid dehydration and rehydration, rapid changes of temperature etc. many of which may be shared by life adapted to Mars – with an estimated 200,000 life-threatening cases of invasive aspergillosis a year – with mortality 30% to 95%](#h_Aspergillus_not_adapted)

**Are you aware of the example from the NRC sample return report of an independently evolved hydrothermal vent organism that shares many virulence genes with a human pathogen? If so why isn’t this included in the discussion of Shiga’s toxin?**[[summary](#xc_Shigia)]

Draft EIS Sterilization Working Group report [(Craven et al., 2021:6)](#b_Craven_et_al_2021).

*Existing microorganisms that coexist with humans over long periods of time can also cause new diseases when the organism takes on new pathogenicity, such as the Escherichia coli strain 0157:H7 that acquired a gene for Shiga toxin, …*

2009 NRC Mars Sample Return Study ([SSB, 2009](#b_SSB_2009): [46](https://nap.nationalacademies.org/read/12576/chapter/7#46)):

*“****However****, it is worth noting in this context that interesting evolutionary connections between alpha proteobacteria and human pathogens have recently been demonstrated for natural hydrothermal environments on Earth … it follows that, since the potential risks of pathogenesis cannot be reduced to zero, a conservative approach to planetary protection will be essential, with rigorous requirements for sample containment and testing protocols of life forms that are pathogenic to humans’*

See:

* [The sterilization working group’s report mentions a strain of e. coli that they hypothesize became toxic by coexisting with humans – however the NRC sample return report gave an example of an independently evolved hydrothermal vent organism that shares many virulence genes with a human pathogen – martian microbes would continue to evolve on Earth – and this omits the suggestion by Łoś et al that e. coli developed Shiga’s toxin to deter protozoan grazing in biofilms and only uses it opportunistically in humans](#h_sterilizing_subc_accidental_toxins)

**Are you aware that the toxin produced by Clostridium tetani is not a result of adaptation to humans and neonatal tetanus kills thousands of unvaccinated newborns every year? If so, why isn’t this mentioned in the discussion of Shiga’s toxin?**[[summary](#xc_tetanus)]

Draft EIS Sterilization Working Group report [(Craven et al., 2021:6)](#b_Craven_et_al_2021).

*Existing microorganisms that coexist with humans over long periods of time can also cause new diseases when the organism takes on new pathogenicity, such as the Escherichia coli strain 0157:H7 that acquired a gene for Shiga toxin, …*

Warmflash et al give examples such as tetanus, locally infectious [(Warmflash, 2007)](#inpazll45dhz).

*Locally infectious organisms, which do not multiply systemically within a host but which produce a toxin which the host can absorb, perhaps through an infected wound, may also be possible on a planet that harbors single-celled life. Clostridia is an example of an anaerobic genus that often lives as spores in soils and some of its species are important human pathogens, including C. tetani and C. perfringens, which are locally infectious in wounds, where they release toxins that can be life-threatening through systemic effects (C. tetani) or local effects (C. perfringens)*

We can now protect babies with widely available tetanus vaccines, yet tetanus still kills thousands of newborns every year in weaker economies ([WHO, n.d.)](#b_WHO_ndt) .

See:

* [Sterilization working group’s report doesn’t mention clear examples of microbes which express accidental toxins without coevolution with humans or higher life, such as neonatal tetanus which kills thousands of unvaccinated newborns every year – and even the internal chemistry of an unfamiliar exobiology could be accidentally toxic](#b_Shigas_toxin_accidental_tetanus)

**Are you aware that the extremophile paper you cited lists Planococcus Halocryophilus, a microbe isolated from permafrost at an ambient temperature of about -16 °C, which shows activity down to the lowest temperature tested of -25 °C, and verified growth in the lab from -15 °C to 37 °C (temperature of human blood) and salinity 0% to 19%? If so why isn’t this microbe discussed in your report?**  
[[summary](#xc_extremophiles)]

Draft EIS Sterilization Working Group report [(Craven et al., 2021:6-7)](#b_Craven_et_al_2021):

*There are many described extremophiles that may survive in environments that are extreme to human or animal life* ***(e.g. extremes of temperature or pressure)*** *but do not survive under conditions in our normal habitat* (Merino et al. 2019).

*… Thus, it is plausible that any Martian microbe, after it arrives on Earth, would not be viable on Earth due to a lack of its required Martian nutritional and environmental conditions.*

One of the extremophiles listed in their cite ([Merino et al, 2019](#b_Merino_2015): table 3) is Planococcus Halocryophilus with a temperature range -15 °C to 37 °C and optimal growth 25 °C which was actually isolated from permafrost soil, where it like inhabits cold brines in the soil ([Mykytczuk et al., 2013](#b_Mykytczuk_2913)) ([Mykytczuk, 2012](#b_Mykytczuk_2012)).

Table

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See:

* [NASA’s biological safety report agrees on the potential for an invasive Martian species to harm or displace terrestrial photosynthetic bacteria – but says life adapted to Martian conditions such as the temperatures and pressures plausibly wouldn’t be able to survive on Earth – their own cite mentions Planococcus Halocryophilus, a microbe which lives in Arctic permafrost soils and likely grows in sub zero brine veins down to at least -15 °C with an optimal growth temperature of 25°C and growth up to 37 °C (human blood temperature)](#h_argument_by_sterilizing_subcommittee)

**Did you have any examples of extreme conditions microbes face on Mars that could prevent them surviving on Earth? If you didn’t have specific examples, why doesn’t your report mention this limitation?**[[summary](#xc_extreme_conditions)]

Draft EIS Sterilization Working Group report [(Craven et al., 2021:6-7)](#b_Craven_et_al_2021)

*“There are many described extremophiles that may survive in environments that are extreme to human or animal life (e.g. extremes of temperature or pressure) but do not survive under conditions in our normal habitat … Thus, it is plausible that any Martian microbe, after it arrives on Earth, would not be viable on Earth due to a lack of its required Martian nutritional and environmental conditions.”*

See:

* [Microbes from near the surface in Jezero crater would withstand temperatures varying from below -70 °C to above 15 °C in a single day – and major changes in humidity and pressure – this is likely to favour polyextremophiles – while microbes able to resist stresses like UV, low humidity, vacuum, and ionizing radiation do not require a non-terrestrial biology and there is no reason for them to be dependent on these conditions to survive](#h_although_martian_life_is_likekly)  
  [And following sections]

**Are you aware that there are many Mars analogue terrestrial organisms such as chroococcidiopsis are thought to have some potential for living on present day Mars? If so, why isn’t the reader informed of this?**  
[[summary](#xc_analogue)]

See:

* [Several candidate terrestrial microbes and even higher organisms such as lichens may be able to survive on Mars, with promising results in Mars simulation chambers, suggesting a possibility that their Mars analogues may be able to live on Earth](#h_candidate_terrestrial_microbes_mars)

#### Scoping and requirement for “safety testing”

**With your requirement of “Safety testing”, are you aware that the expected level of forward contamination of 0.7 nanograms per gram per biosignature means all samples will test positive and go to hold and critical review, which will make the safety testing pointless?**   
[[summary](#xc_safety)]

Draft EIS ([NASA, 2022](#b_NASA_2022eis): 3-3)

*These same principles regarding the importance of using terrestrial laboratories to enable the best scientific return also apply to the care and attention to detail that would be required to conduct a proper and comprehensive sample safety assessment in a proposed SRF.*

See:

* [NEW: Sadly Perseverance’s permitted levels of 0.7 nanograms per gram for their most abundant biosignatures would overwhelm any faint signature of biosignatures from past life or even as many as thousands of cells per gram of present day life, even if viable](#h_sadly_perseverances_permitted)
* [So sterilization preserves virtually all geological interest with minimal impact on astrobiological impact – but NASA’s EIS doesn’t permit it due to a requirement for “safety testing”](#h_so_sterilization_presevers_virtually)
* [NEW: Even if samples are returned unsterilized this “safety testing” seems to serve no useful purpose – all the samples would be guaranteed false positives – with no available biosignature to distinguish terrestrial from potential martian life – and we can’t distinguish Martian life by gene sequences as nearly all terrestrial microbes are unsequenced – and we can’t test for martian life by trying to cultivate it as we can’t reliably cultivate even terrestrial life in a lab](#h_even_if_samples_are)  
  [And previous and following sections]

**Why wasn’t the option considered to sterilize samples before they return?**   
[[summary](#xc_sterilize)]

See:

* [We can forestall all these issues and make the mission 100% safe by sterilizing samples before they reach Earth – NEW](#h_we_can_forestall)

#### Procedure:

**As you surely know, NEPA requires agencies to ensure scientific integrity in an Environmental Impact Statement, so, do you know how the EIS come to have so many citing errors of central importance to your arguments, and can NASA ensure this won’t happen again in any future EIS?**  
[[summary](#xc_NEPA)]

*Agencies shall ensure* *the professional integrity, including scientific integrity, of the discussions and analyses in environmental impact statements*[§ 1502.23](https://www.ecfr.gov/current/title-40/chapter-V/subchapter-A/part-1502/section-1502.23)

* [NASA’s draft EIS fails NEPA requirement for a valid Environmental Impact Statement to ensure scientific integrity – with missing cites and cites that overturn the sentences they are cited to](#h_NASAS_draft_EIS_fails)

**The Council for Environmental Quality says the first step is to contact the agency to resolve issues, so, can you respond to these questions?**   
[[summary](#cx_Council)]

Council of Environmental Quality ([COEQ, 2007](#b_COEQ_2007):28):

*Your first line of recourse should be with the individual that the agency has identified as being in charge of this particular process.*

* [The Council of Environmental Quality says the first step is to contact the agency to resolve issues, however NASA has not yet responded to attempts to contact them on this topic](#H_NEPA_say_to_contact)

## [NASA’s draft EIS fails NEPA requirement for a valid Environmental Impact Statement to ensure scientific integrity – with missing cites and cites that overturn the sentences they are cited to](#h_NASAS_draft_EIS_fails) [Next section](#h_NEPA_erasonable_alsternatives) – [all sections](#h_titles_of_sections) – [previous section](#h_many_legal_ramifications) [[question](#xc_NEPA)]

NASA’s draft fails several of NEPA’s central requirements for a valid EIS.

*Agencies shall ensure* *the professional integrity, including scientific integrity, of the discussions and analyses in environmental impact statements*[§ 1502.23](https://www.ecfr.gov/current/title-40/chapter-V/subchapter-A/part-1502/section-1502.23)

The EIS has major issues, mainly

* **Currency:** uses out of date research, with major omissions of later studies that overturn results it relies on.
* **Accuracy:** sentences in the EIS are contradicted by the cites attached to those sentences, and the reader isn’t alerted to this discrepancy
* **Accuracy:** doesn’t mention views opposed to their conclusions in their own sources or other sources with views that contradict the agency’s conclusions in the EIS.

A credible scientific report needs to be reviewed carefully to eliminate or minimize such errors ([Blakeslee, 2004](#b_Blakeslee_2004)) ([Tripp, n.d.)](#b_Tripp_nd) ([Nausman, n.d.](#b_Nausman_nd)). For a list of the main issues found in the draft EIS see:

* [Questions for NASA](#h_questions_for_NASA)
* [Reasons for these questions: controversial or mistaken statements in NASA's draft EIS and the report of the sterilizing subcommittee](#h_controversial_or_mistaken_statements)

On the last point of omissions of opposing views ([Feldman et al., n.d.](#b_Feldman_nd))

*An agency must address in an EIS “responsible opposing view[s].” Courts have  
interpreted this regulation as requiring agencies to address opposing scientific viewpoints. In recent years, courts have given an agency’s response to opposing scientific viewpoints deferential treatment, so long as the agency addressed the opposing statements and differing opinions in a meaningful way during the decision-making process.*

So, for instance on the topic of environmental effects, it seems the courts would be able to pass it as a valid Environmental Impact Statement under NEPA based on NASA’s own statement that in their view there is no significant risk of environmental effects, so long as NASA alert the reader to the opposing views in sources such as the

* the NRC Mars sample return study in 2009
* the ESF Mars sample return study in 2012

and so long as NASA address these differences of view in a meaningful way in the EIS. Presumably NASA would need to discuss the reasons the ESF and the NRC gave for their views, and explain why they came to a different view.

However, the views in the ESF and NRC studies on environmental effects are simply not mentioned. So, it would seem to fail this requirement for a valid EIS. For a discussion of the views they omitted see:

* [The planetary protection literature warns the potential for even large scale harm to human health and the environment isn’t demonstrably zero – NASA’s draft EIS conclusion that there is no significant risk of environmental effects seems a minority view amongst microbiologist and they don’t alert the reader to the existence of any other view on the topic](#h_the_plnaetary_protection_literature)

For a list of the main issues found in the draft EIS see:

* [Questions for NASA](#h_questions_for_NASA)
* [Reasons for these questions: controversial or mistaken statements in NASA's draft EIS and the report of the sterilizing subcommittee](#h_controversial_or_mistaken_statements)

### [NASA’s draft EIS fails the NEPA’s requirement to consider reasonable alternatives in detail so that reviewers may evaluate their comparative merits – as it doesn’t examine the reasonable alternatives to sterilize samples in space first or to delay the mission until it can be done safely](#h_NEPA_erasonable_alsternatives) [Next section](#h_NASA_interdisciplinary) – [all sections](#h_titles_of_sections) – [previous section](#h_NASAS_draft_EIS_fails)

Another of the NEPA’s central requirements for a valid EIS.

*(a) Evaluate reasonable alternatives to the proposed action, and, for alternatives that the agency eliminated from detailed study, briefly discuss the reasons for their elimination.*

*(b) Discuss each alternative considered in detail, including the proposed action, so that reviewers may evaluate their comparative merits.*[§ 1502.14](https://www.ecfr.gov/current/title-40/chapter-V/subchapter-A/part-1502/section-1502.14)

NASA's EIS doesn't have rigorous analysis of ANY alternative except "no action". Reasonable alternatives include sterilizing samples in space before they approach humans or our biosphere or delaying the mission until it can be done safely.

### [NASA’s draft EIS fails the NEPA’s requirement to use an interdisciplinary approach including the social sciences, by failing to involve the public early on, not just in the USA but through fora open to representatives from all countries globally, as recommended in sample return studies – so the public weren’t given the opportunity to comment on a scientifically valid draft EIS](#h_NASA_interdisciplinary) [Next section](#h_other_commentators_raised) – [all sections](#h_titles_of_sections) – [previous section](#h_NEPA_erasonable_alsternatives)

Another of the NEPA’s central requirements for a valid EIS.

*Agencies shall prepare environmental impact statements using an interdisciplinary approach that will ensure the integrated use of the natural and social sciences and the environmental design arts*[§ 1507.2](https://www.ecfr.gov/current/title-40/chapter-V/subchapter-A/part-1502/section-1502.6)

Mars sample return studies emphasize the need to involve the public early on, not just in the USA, but through fora open to representatives from all countries globally because negative impacts could affect countries beyond the ones involved directly in the mission [(Ammann et al, 2012:59)](#qa4nethlmcdw)

*RECOMMENDATION 3*

*Potential risks from an MSR are characterised by their complexity, uncertainty and ambiguity, as defined by the International Risk Governance Committee’s risk governance framework. As a consequence, civil society, the key stakeholders, the scientific community and relevant agencies’ staff should be involved in the process of risk governance as soon as possible.*

*In this context, transparent communication covering the accountability, the benefits, the risks and the uncertainties related to an MSR is crucial throughout the whole process. Tools to effectively interact with individual groups should be developed (e.g. a risk map).*

*RECOMMENDATION 4*

*Potential negative consequences resulting from an unintended release could be borne by a larger set of countries than those involved in the programme. It is recommended that mechanisms and fora dedicated to ethical and social issues of the risks and benefits raised by an MSR are set up at the international level and are open to representatives of all countries*

The public weren’t involved early on in that way. Not only that, those in the public who did discover NASA’s request for public comment weren't given the opportunity to comment on a scientifically valid EIS.

I hope NASA and other space agencies can ensure a mishap like this never happens again.

### [Other commentators raised significant issues – including one of the principle authors of NASA’s probabilistic risk assessment guide who said a better statement of options should include the possibility of delaying the return until the risks are better understood](#h_other_commentators_raised) [Next section](#H_NEPA_say_to_contact) – [all sections](#h_titles_of_sections) – [previous section](#h_NASA_interdisciplinary)

Several other commentators raised significant issues including some of the ones already mentioned as well as new ones ([Dehel, 2022](#b_Dehel_2022)) [(DiGregorio, 2022)](#b_DiGregorio_2022) ([Everline, 2022](#b_everline_2022)) .

Everline, a JPL employee and a principal author of NASA’s probabilistic risk assessment guide [(Stamatelatos, 2011)](#b_Stamatelatos_2011), made a detailed public comment which said ([Everline, 2022](#b_everline_2022))

***Chester Everline:*** *A better statement of options should include the possibility of delaying the return of Mars samples until the risks associated with their return are better understood*

### [The Council of Environmental Quality says the first step is to contact the agency to resolve issues, however NASA has not yet responded to attempts to contact them on this topic](#H_NEPA_say_to_contact) [Next section](#h_questions_for_NASA) – [all sections](#h_titles_of_sections) – [previous section](#h_other_commentators_raised)

[[question](#cx_Council)]

The Council of Environmental Quality say the first step is to contact the agency to resolve issues ([COEQ, 2007](#b_COEQ_2007):28):

*Your first line of recourse should be with the individual that the agency has identified as being in charge of this particular process.*

The natural point of contact is NASA’s planetary protection office. They haven’t responded to my email about the issues I raised after the draft EIS was published.

The comments section of the draft EIS didn’t include responses to substantial issues I raised in May [(Walker, 2022a)](#b_Walker_2022)

NEPA don’t mention the many significant issues I or anyone else raised with the draft EIS in their final letter to the public comments page on the last day of the public comments period, December 7th [(EPA, 2022)](#B_epa_2022).

It’s also not appropriate to try to work with other employees of NASA to resolve this issue when NASA’s planetary protection office aren’t responding.

There seems no way forward by way of dialog with NASA at this point in time. I encourage NASA to respond. I encourage any reviewers for this paper to ask NASA themselves.

## [We can’t actually assess the level of risk until we know more about Mars – it could be zero or it could be far higher than expected](#h_we_cant_actually_asseses) [Next section](#h_worst_case_scenarios) – [all sections](#h_titles_of_sections) – [previous section](#h_controversial_or_mistaken_statements)

This mission raises many novel ethical and legislative questions. First, as the NRC observed, we can’t actually assess the current level of risk [(Space Studies Board, 2009: 48).](#kix.xed3c1hm3p4k)

… **it is not possible to assess past or future negative impacts caused by the delivery of putative extraterrestrial life**, based on current evidence.

If later we find only prebiotic synthesis on Mars, or slowly and imperfectly reproducing life with a biochemistry compatible with terrestrial predators, our risk from an unsterilized sample return is zero. Our main risk is in the forward direction that we might lose the chance to discover and investigate early life or prebiotic synthesis on Mars.

However, if later we discover a mirror life analogue of chroococcidiopsis on Mars, our risk from an unsterilized sample return of even large scale harm is far higher than we currently assess it to be.

### [Worst case scenarios introduce novel ethical and legal questions – is a 1 in a million level of risk acceptable?](#h_worst_case_scenarios) [Next section](#h_synthetic_biologists_suggest) – [all sections](#h_titles_of_sections) – [previous section](#h_we_cant_actually_asseses)

The very worst case scenarios for martian life such as mirror life also introduce novel ethical and legal questions about the level of risk we are prepared to take.

Kelly has traced the 1 in a million figure back to a 1 in 100 million figure in a 1961 article, introduced by Mantel et al for the purpose of discussion ([Mantel et al, 1961](#b_Mantel_1961)). When asked why he chose this figure he replied ***"We just pulled it out of a hat"*** ([Kelly, 1991](#b_Kelly_1991)). The FDA adopted this in 1973 but it became 1 in a million when the final rule was issued. Graham [(Graham, 1993)](#b_Graham_1993) says in practice, EPA's air office tries to reduce the risk to as many people as possible to 1 in a million and the maximally exposed individual to 1 in 10,000. In other situations, EPA recommends a range of risk levels from 1 in 100,000 to 1 in 10 million, and sometimes approves at a level of 1 in 10,000.

This is an ad hoc ethical decision by regulators about levels of acceptable risk, which got accepted more widely by legislators and the general public.

It also doesn’t take account of human error. There are many examples, such as a SARS outbreak in 2003 in Taiwan which happened because a technician skipped the standard procedure after a spill, because it would make him late for a conference [(Demaneuf, 2020)](#b_Demaneuf_2020).

Other escapes could happen from equipment failure. During the Apollo sample returns, two technicians had to go into isolation after a leak was found in a sample handling glove for Apollo 11 [(Meltzer, 2012:485)](#kix.cewdeelxmotf), and 11 technicians in a similar incident for Apollo 12 [(Meltzer, 2012:241)](#kix.cewdeelxmotf).

All this needs especially close scrutiny once there’s potential for novel and even unprecedented larges scale harm – including other issues such as accidents, a fire at the facility or criminal actions.

### [Synthetic biologists suggest a safety mechanism for synthetic life should be many orders of magnitude safer than a BSL-4](#h_synthetic_biologists_suggest) [Next section](#h_society_places_very_high) – [all sections](#h_titles_of_sections) – [previous section](#h_worst_case_scenarios)

Synthetic biology already permits the creation of inheritable synthetic life such as life with hachimoji DNA [(Hoshika et al, 2019)](#kix.7yh9gckbgm8u). They make sure that this is safe by designing nucleotides that depend on chemicals only available in the laboratory.

Synthetic biologists have suggested that a safety mechanism to contain synthetic life should be many orders of magnitude safer than any contemporary biosafety device. Schmidt puts it like this [(Schmidt, 2010)](#kix.olm1b61u9vxl)

*The ultimate goal would be a safety device with a probability to fail below 10−40, which equals approximately the number of cells that ever lived on earth (and never produced a non-DNA non-RNA life form). Of course, 10−40 sounds utterly dystopic (and we could never test it in a life time), maybe 10−20 is more than enough. The probability also needs to reflect the potential impact, in our case the establishment of an XNA ecosystem in the environment, and how threatening we believe this is.*

*The most important aspect, however, is that the new safety mechanism should be several orders of magnitude safer than any contemporary biosafety mechanism.*

We can’t rely on the same risk-benefit calculus for release of SARS and for release of mirror life, without legislative / executive / public involvement to decide if this is what we should do.

### NEW: [Society places very high value on the environment and given the potential for large scale effects, we might require Earth is kept 100% safe for this mission – i.e. use the prohibitory precautionary principle](#h_society_places_very_high) [Next section](#h_carl_sagan_and_others) – [all sections](#h_titles_of_sections) – [previous section](#h_synthetic_biologists_suggest)

This mission also leads to novel questions about variations on the precautionary principle – principles to do with how we need to handle situations where the level of risk can't currently be assessed because the science is incomplete.

The ESF study considered variations on the precautionary principle [(Ammann et al, 2012:25)](#qa4nethlmcdw) based an analysis of the principle by Stewart [(Stewart, 2002)](#kix.i6axx1j5e276), including:

* **Best Available Technology Precautionary Principle**: Activities that present an uncertain potential for significant harm should be subject to best technology available requirements to minimise the risk of harm unless the proponent of the activity shows that they present no appreciable risk of harm.
* **Prohibitory Precautionary Principle**: Activities that present an uncertain potential for significant harm should be prohibited unless the proponent of the activity shows that they present no appreciable risk of harm

The ESF ruled out the Prohibitory Precautionary Principle on the basis that it would simply lead to cancellation of the mission [(Ammann et al, 2012:25)](#qa4nethlmcdw):

*It is not possible to demonstrate that the return of a Mars sample presents no appreciable risk of harm. Therefore, if applied, the Prohibitory Precautionary Principle approach would simply lead to the cancellation of the MSR mission.*

They did this as experts mandated to find the safest way to conduct the mission.

However Stewart, elsewhere in that same paper, suggests there may be situations where prohibition may be needed, since society places very high value on the environment and its protection [(Stewart, 2002:15)](#kix.i6axx1j5e276).

## [Carl Sagan and others warning we can’t take even a small risk with a billion lives – this could be formalized into law as a requirement to use the prohibitory precautionary principle whenever there is any appreciable risk for harm unprecedented in human history](#h_carl_sagan_and_others) [Next section](#h_the_decision_about) – [all sections](#h_titles_of_sections) – [previous section](#h_society_places_very_high)

Chester Everline in his comment said ([Everline, 2022](#b_everline_2022)):

*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)*

Is a sample return mission one where we should consider the prohibitory version of the principle?

Carl Sagan said we can’t take even a small risk – that’s the prohibitory version [(Sagan, 1973)](#kix.urfjjsuep509):

***Carl Sagan:*** *Because of the danger of back-contamination of Earth, I firmly believe that manned landings on Mars should be postponed until the beginning of the next century, after a vigorous program of unmanned Martian exobiology and terrestrial epidemiology.*

*…. I, myself, would love to be involved in the first manned expedition to Mars. But an exhaustive program of unmanned biological exploration of Mars is necessary first****. The likelihood that such pathogens exist is probably small, but we cannot take even a small risk with a billion lives.****.*

Gill Levin, who died shortly before the EIS, said the same, as recorded on video by Dehel and mentioned in his public comment ([Dehel, 2022](#b_Dehel_2022)).

***Gill Levin:*** *I believe people will realize, especially after the Covid-19 catastrophe, that even if there’s only a small chance that something could be contagious and pathogenic, coming from a foreign planet, I don’t think it’s worth taking that chance….you don’t take unnecessary chances where the risk-to-benefit ratio is almost infinite.”*

DiGreggorio in his public comment quotes from an interview he did with Dr Carl Woese who also expressed a similar sentiment [(DiGregorio, 2022)](#b_DiGregorio_2022)

***Carl Woese:*** *Unless you can rule out the chance that it might do harm, you should not embark on such a course*

One possible outcome of public debate on this topic is to formalize Woese, Levin and Sagan’s ethical views on this topic into legislation. The general public, and legislators, could decide that if an action has potential for unprecedented levels of harm to human health or the environment, the prohibitory version of the principle should always be used.

Perhaps it might be formulated something like this (for illustrative purposes only not a proposal):

*If it is impossible to show that there is no appreciable risk of unprecedented levels of harm to public health or the environment, the Prohibitory version of the Precautionary Principle must always be used*

Unprecedented here means unprecedented in human history (e.g. mass extinction level events).

There’s an interesting way of working with this mathematically derived by Nick Bostrom which may help others to understand the perspective of those who think a one in a million chance of a severe impact like this is unacceptable. His approach is to multiply the probability by the population to get the expected number impacted ([Bostrom, 2002](#b_Bostrom_2002))

Let’s apply his approach to this back contamination scenario. With a population of 7.7 billion and a 1 in a million chance of a severe impact, suppose that it affects half the population, that multiplies out to an expected 3,350 people that would be impacted by the sample return.

But if it is something that has long term future effects on our ecosystem, leaving Earth significantly less habitable to humans for all future time - the numbers become far greater. For instance, if you look forward a 100,000 years, or 3,000 generations, those 3,250 people become 9.75 million.

Nick Bostrom suggests that this can give a way to think about these existential risks, that take us out of our instinctual responses. His paper also looks at a way of calculating the impact for potential for human extinction, but in the back contamination scenarios arguably that’s not a risk as we could survive using space technology and paraterraforming Earth.

### [The decision about acceptable levels of risk for large scale harm is an ethical decision and can’t be decided on the basis of science or engineering](#h_the_decision_about) [Next section](#h_public_comments_on) – [all sections](#h_titles_of_sections) – [previous section](#h_carl_sagan_and_others)

This decision is something that needs global public debate.

NASA are likely to set a higher priority to completing the mission assigned to them than the general public, but we are all potentially affected in the worst case. It needs to be opened out to larger debate.

This is something we can’t decide on the basis of science or engineering. It is an ethical and legislative choice. As Randolph put it [(Randolph, 2009:292)](#xs0gwy1vf9ff).

*The risk of back contamination is not zero. There is always some risk. In this case, the problem of risk – even extremely low risk – is exacerbated because the consequences of back contamination could be quite severe.* ***Without being overly dramatic, the consequences might well include the extinction of species and the destruction of whole ecosystems****. Humans could also be threatened with death or a significant decrease in life prospects*

***In this situation, what is an ethically acceptable level of risk, even if it is quite low? This is not a technical question for scientists and engineers. Rather it is a moral question concerning accepting risk.***

### [Public comments on the EIS show that many members of the public have similar views to Carl Sagan that this is a qualitatively different situation from a human pathogen in a BSL-4 and that NASA shouldn’t take even a low level of risk with Earth’s biosphere](#h_public_comments_on) [Next section](#h_EPAs_letter) – [all sections](#h_titles_of_sections) – [previous section](#h_the_decision_about)

The public comments aren’t a poll, but they do show that many members of the public have similar views to Carl Sagan, Gill Levin, Carl Woese and others, that this is a qualitatively different situation from a known pathogen in a BSL-4 lab and that we shouldn’t take even a low level of risk.

Many specifically mention potential for unprecedented harm in one way or another. I think it is also reasonable to assume that all or nearly all the ones that say, test first, sterilize first or stop mission would support Carl Sagan’s quote [(Sagan, 1973)](#kix.urfjjsuep509):

***“The likelihood that such pathogens exist is probably small, but we cannot take even a small risk with a billion lives.”***

Here are the comments summarized, and I’ve shown in bold the ones that likely support Carl Sagan’s statement that we can’t take even a small risk with a billion lives.

As a rough estimate, 50 supporting some variation on Carl Sagan’s view out of a total of 63 separate people commenting (selected one only for duplicate entries). Some were anonymous and it’s not possible to know for sure if some of those were also duplicate. At any rate, several dozen distinct members of the public expressed views that suggest they would be in support of Sagan’s quote, on a not very widely publicised EIS.

* [**stop mission, unprecedented harm**](https://www.regulations.gov/comment/NASA-2022-0002-0177) **–** [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0178) **–** **[protect Earth](https://www.regulations.gov/comment/NASA-2022-0002-0179)** **–** [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0180)**–** [**stop mission**](https://www.regulations.gov/comment/NASA-2022-0002-0181)
* [**stop mission**](https://www.regulations.gov/comment/NASA-2022-0002-0182) **–** [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0184) **–** [**test first, unprecedented harm**](https://www.regulations.gov/comment/NASA-2022-0002-0183) **–** [**keep Earth 100% safe**](https://www.regulations.gov/comment/NASA-2022-0002-0186) **–** [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0188)

* **[stop mission](https://www.regulations.gov/comment/NASA-2022-0002-0190)** – [need clarity about security measures](https://www.regulations.gov/comment/NASA-2022-0002-0187) – [off topic](https://www.regulations.gov/comment/NASA-2022-0002-0191) – [alternative design](https://www.regulations.gov/comment/NASA-2022-0002-0192)  - [**keep Earth 100% safe**](https://www.regulations.gov/comment/NASA-2022-0002-0189)
* [**unprecedented harm**](https://www.regulations.gov/comment/NASA-2022-0002-0194) **–** **[stop mission, unprecedented harm](https://www.regulations.gov/comment/NASA-2022-0002-0193)** – [alternative design](https://www.regulations.gov/comment/NASA-2022-0002-0196) – [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0202) **–** [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0207)
* [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0203) **–** [**unprecedented harm**](https://www.regulations.gov/comment/NASA-2022-0002-0206) **–** [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0204) **–** [**Test first**](https://www.regulations.gov/comment/NASA-2022-0002-0197) **–** [**Don’t return unless 100% safe – or sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0210)
* [**Don’t return**](https://www.regulations.gov/comment/NASA-2022-0002-0199) **–** [**don’t return until 100% safe**](https://www.regulations.gov/comment/NASA-2022-0002-0205) **–** [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0208) **–** [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0209) **–** [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0198)
* [**ISS first**](https://www.regulations.gov/comment/NASA-2022-0002-0200) **–** [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0201) **–** [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0213) **–** [**unknown risk, test first**](https://www.regulations.gov/comment/NASA-2022-0002-0214) **–** [**sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0218)
* [extra precautions for EES reentry](https://www.regulations.gov/comment/NASA-2022-0002-0215) - [**sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0216) **–** [**sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0217) **–** [**sterilize in space station first**](https://www.regulations.gov/comment/NASA-2022-0002-0222) **–** [**sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0220)

* [**do not return**](https://www.regulations.gov/comment/NASA-2022-0002-0221) **–** [**do not return**](https://www.regulations.gov/comment/NASA-2022-0002-0223) **–** [**do not return**](https://www.regulations.gov/comment/NASA-2022-0002-0219) – [send to Russia first](https://www.regulations.gov/comment/NASA-2022-0002-0226) **–** [issues with disinfection of earth entry site](https://www.regulations.gov/comment/NASA-2022-0002-0230)
* [**test first**](https://www.regulations.gov/comment/NASA-2022-0002-0229) **–** [support EIS](https://www.regulations.gov/comment/NASA-2022-0002-0231) **–** [**study in situ or space lab or sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0232) – [fully support, suggests more samples](https://www.regulations.gov/comment/NASA-2022-0002-0234) – [– [off topic (future missions need to be designed for reeuse)](https://www.regulations.gov/comment/NASA-2022-0002-0233)](https://www.regulations.gov/comment/NASA-2022-0002-0233)

* [multiple cautious measures](https://www.regulations.gov/comment/NASA-2022-0002-0236) – [support EIS](https://www.regulations.gov/comment/NASA-2022-0002-0240) – [support EIS](https://www.regulations.gov/comment/NASA-2022-0002-0241) **–** [**test or sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0251) **–** [**sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0246)
* [**test in situ or don’t return**](https://www.regulations.gov/comment/NASA-2022-0002-0248) **–** [**do**](https://www.regulations.gov/comment/NASA-2022-0002-0247) **not return –** [**unprecedented harm, test first**](https://www.regulations.gov/comment/NASA-2022-0002-0243) **–** [**unprecedented harm, return to space station**](https://www.regulations.gov/comment/NASA-2022-0002-0252)
* - and the four comments already mentioned by name [**(Walker, 2022a)**](#b_Walker_2022) **([Dehel, 2022](#b_Dehel_2022))** [**(DiGregorio, 2022)**](#b_DiGregorio_2022) **([Everline, 2022](#b_everline_2022))**

Also notice that 12 said sterilize first, even though it’s not listed as an alternative action in the EIS.

* [**Don’t return unless 100% safe – or sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0210) **–** [**sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0218) **–**  [**sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0216) **–** [**sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0217) **–** [**sterilize in space station first**](https://www.regulations.gov/comment/NASA-2022-0002-0222)
* [**sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0220) **–** [**test or sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0251) **–** [**sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0246) **–** [**study in situ or space lab or sterilize first**](https://www.regulations.gov/comment/NASA-2022-0002-0232)
* Plus [(Walker, 2022a)](#b_Walker_2022) ([Dehel, 2022](#b_Dehel_2022)) [(DiGregorio, 2022)](#b_DiGregorio_2022)

### [EPA’s letter posted on the last day of public discussion says they didn’t identify significant environmental concerns in their review of the EIS – with no mention of all the public comments raising concerns similar to Carl Sagan’s](#h_EPAs_letter) [Next section](#h_this_doesnt_look) – [all sections](#h_titles_of_sections) – [previous section](#h_public_comments_on)

EPA posted on the last day of public comments. Their letter says it didn’t identify significant environmental concerns in its review of the EIS. It doesn’t say anything about a need for NASA to respond to new issues raised in the comments by the general public mentioned in the previous section [(EPA, 2022)](#B_epa_2022):

*We appreciate NASA addressing EPA’s concerns regarding water resources, unplanned releases and cultural/biological resources identified in the letter.*

*Based on the review of the draft PEIS, EPA did not identify significant environmental concerns to be addressed in the Final EIS.*

If Carl Sagan was still alive today he would surely have commented on the EIS raising the same concerns as many of the general public made.

### [This doesn’t look like the broad acceptance which Rummel et al said is essential for success of this mission – if NASA continues with this action, it is vulnerable to being stopped in the future](#h_this_doesnt_look) [Next section](#h_we_can_forestall) – [all sections](#h_titles_of_sections) – [previous section](#h_EPAs_letter)

Rummel at al wrote [(Rummel et al, 2002:96)](#B_rUMMEL_et_al_2002) :

*“Broad acceptance at both lay public and scientific levels is essential to the overall success of this research effort.”*

This doesn’t look like broad acceptance of NASA’s proposed action. It may be stopped at various points.

First NASA could withdraw the EIS, do the size limit review, do a scientifically rigorous EIS.

This seems far the best outcome for NASA. Not forced to do anything by a court decision. Not responding to public panic. They can decide in their own time how to proceed. For instance they can do a 100% safe mission using sterilize first, or they can work on other ideas, but it’s all done in coordination with the general public, legal experts, ethicists, social scientists etc.

Even a last minute conversion to a 100% safe mission could cause problems if NASA do it in response to panic from a distrustful public. Far better to get the public involved from the outset.

Assuming NASA continue with the EIS, it could be stopped by other agencies but this is unlikely as the draft EIS says that there are no significant environmental effects, so they’d have no reason to look at it closely.

The next point it can be stopped is by a court case. There is no provision for this within NEPA, so it is done through judicial review, usually on the basis that: ([Congressional Research Service, 2021](#b_CRS_2021)).

* the agency failed to consider some of the impacts
* the agency failed to properly consider the weight of the impacts under review

They can only be taken to the courts by someone with “standing”. For this, they need to take part in the public comments or debate in the NEPA process, and need to be directly affected by the proposed action.

There you have to show that you are particularly affected by it, which is normally understood to mean more so than by others. If the petitioner claims NASA overlooked a worst case risk of global effects NASA could try to block it on the basis that in their hypothetical scenario they wouldn’t be affected more than anyone else in the world and so don’t have standing.

In the past, environmental cases have gone either way based on subtle legal arguments about whether environmental effects give the petitioner “standing” for the case ([Birnbach, 1997](#b_Birnbach_1997)).

If it does get as far as the courts, the case is usually ([Congressional Research Service, 2021](#b_CRS_2021))

* referred back to the agency (such as NASA) for further proceedings HOWEVER
* the court can order the agency to stop the project going ahead or issue some other action (in this case perhaps order to sterilize the samples first?).

So if a case is taken out and it’s successful, that could lead to a justice asking NASA to either stop the mission or to sterilize the samples first.

If nobody takes them to court or NASA successfully block the case, the next step is the presidential directive NSC-25, which requires a review of large scale effects that could be reasonably expected to result in allegations of major or protracted effects. It has to be done even if the agency feels confident such allegations are false [(Whitehouse, 1977):](#b_WhiteHouse_1977). This happens after the NEPA process is completed [(Race, 1996)](#kix.7grd10futt6o).

If it gets past all those hurdles with little public awareness, it could be stopped at the last minute with samples already on their way back to Earth.

Mounting global public concern could lead to Congress and the president acting to tell NASA to divert the mission away from Earth. A worst case here might be an infodemic about Mars life similar to the COVID infodemic, junk science, problems for NASA’s credibility, and issues with eventual return of even 100% safe sterilized samples.

# [Conclusion and recommendations for space agencies generally – simplest solution to sterilize the sample before it reaches Earth with ionizing radiation – priority to return dust, dirt, atmosphere and salts – sterilization would have virtually no effect on geology and most likely no effect on astrobiology either](#h_conclusions_space_agencies) [Next section](#h_value_newly_formed_crater) – [all sections](#h_titles_of_sections) – [previous section](#h_we_can_explore)

It’s understandable that space agencies compete to be first to return a sample from Mars. The conclusion of this paper is that we don’t currently have the technology to contain an unsterilized sample that fulfils the size limit requirement of the ESF study in 2012. The cost of such a facility would likely to be high if it can be developed. The simplest solution, which also keeps Earth 100% safe, is to sterilize the sample before it reaches Earth.

The mission shouldn’t be presented as a way to decide central questions in astrobiology. We are unlikely to find present day or past life without in situ searches unless the Viking missions did detect life or life is very common in the dirt or dust on Mars. Any such mission should be presented as a first step in Carl Sagan’s vigorous program in unmanned exobiology. It should be part of a longer term plan to search for present day and past life in situ on Mars itself.

See:

* [We can’t expect samples returned from Mars at this stage to answer central questions in astrobiology even with bonus samples except with extraordinary luck – astrobiologists emphasize that we need to search in situ first – our aim instead is to find a way to turn this into a far more interesting first step for astrobiology](#h_with_more_ambition)

There’s one relatively easy way to return interesting microsamples from Mars that any space agency could do if it can send a mission to orbit around Mars. For instance it’s a possibility for India, Japan, or the UAE. That’s “SCIM”, a proposed mission to use aerogel collectors to skim the Martian atmosphere and return micron sized dust particles [(Leshing, 2002)](#b_Leshing_2002). The proposal is to dip into the Mars atmosphere during its dusty season, and pick up a sample of dusty air, to return to Earth. It would use a "free return" trajectory. As soon as it leaves Earth's vicinity, it's on a trajectory to skim the Mars atmosphere and return to Earth with only minor course corrections after that [(Leshin, 2002)](#b_Leshing_2002) [(Savage, 2002).](#Savage_2002)

Laurie Leshin, interviewed by Space.com, describes it like this [(Tillman, 2014)](#b_Tillman_2014)

"Think of it as a microscopic average rock collection from Mars"

[](https://www.youtube.com/embed/7WorhUTyURg?feature=oembed)

Video: [SCIM Mission to Mars narrated](https://www.youtube.com/embed/7WorhUTyURg?feature=oembed)

A small sample like that could be sterilized during the journey back using nanoscale X-ray emitters or similar – which would have little effect on its science value as it is not likely to contain viable life.

The next step up is Chris McKay’s mission concept. Design the simplest lowest cost way to return a sample from Mars. No rover, just a lander like the Viking lander but with a Mars ascent stage. Just grab it and return [(David, 2015).](#b_David_L_2015)

"***The first thing is getting a mission that scoops up a bunch of loose dirt, puts it in a box and brings it back to Earth***.”

He motivates it by hazards for astronauts in the dirt such as the perchlorates. However the dirt is also of significant astrobiological interest as we saw.

This should be collected in a sterile container. Preferably it needs a sub compartment with a window so that part of the sample is kept in conditions resembling the Martian surface, ideally simulating day / night cycles.

If there are concerns that opening the sterile container would be mission critical, the mission could include a separate smaller container with permitted forward contamination which would return samples of geological interest but likely of little astrobiological interest:

This mission can be greatly enhanced in interest if it can also collect a compressed sample of atmosphere and of dust, and if possible it can also target a sample of salt from the Martian surface. It can also return some pebbles for a technical demo of a contamination free rock sample, and to return our first contamination free rocks from Mars.

See above:

* [NEW: We can transform this into a much more interesting first step for astrobiology with little change in the overall budget by adding bonus samples collected in a STERILE container sent on the ESF fetch rover – the aim is to return dust, dirt, ideally salts, compressed gas from the atmosphere – and some pebbles for a technology demo of a contamination free rock sample](#h_we_could_transform)

These samples again can be sterilized and returned directly to Earth and if sterilized carefully for instance using X-rays would still be of astrobiological interest. A small sample could be sterilized using nanoscale X-ray emitters during the journey back. A larger sample might need to be return to a sterilizing satellite. See:

* [NEW: Samples can be safely sterilized in a satellite similar to geostationary satellites, but positioned in a safe orbit tens of thousands of kilometers above GEO](#h_samaples_can_be_sterilized)

Or they could be returned to a Mars simulation chamber remotely operated in a satellite above GEO as described above in:

* [NEW: These clean samples will be studied above geostationary orbit in Mars simulation conditions with a Martian gravity centrifuge – they are not intended for safety testing - and humans never go near the satellite](#h_these_clean_samples)

Perhaps this sample receiving satellite above GEO could be operated internationally, similarly to the ISS but as a much smaller robotic facility rather than one staffed by humans. As it grows in complexity, it could use the same approach of docked modules, like the ISS in miniature, operated by different countries with the use of telerobotics to move samples and other equipment from one module to another.

A space agency can greatly increase the science value of demo rock samples returned from Mars by targeting pebbles from recently excavated craters on Mars. A new mission has the advantage that it could target one of the hundreds of craters which formed on Mars since we started photographing it from orbit.

If we can return a sample that’s been buried until just a few decades ago there’s a possibility that it’s had almost no exposure to cosmic radiation or solar storms since it was deposited.

See also:

* [Value of targeting a newly formed crater on Mars as an alternative to drilling meters below the surface – with example of a crater that excavated ice boulders from the Amazonis planitia in the equatorial regions in 2022 – also value of developing a 100% sterile marscopter, rover or complete lander](#h_value_newly_formed_crater)

[Conclusions and recommendations for NASA – need to restart the process with a scientifically credible EIS – simplest solution is to sterilize the samples before they are returned to Earth which retains virtually all the geology and most likely has no impact on astrobiology](#h_conclusions_NASA)  
[Next section](#h_topcs_future_Mars_sample_return_study) – [all sections](#h_titles_of_sections) – [previous section](#h_value_newly_formed_crater)

First, the Environmental Impact Statement needs to be scientifically credible:

* [NASA’s draft EIS fails NEPA requirement for a valid Environmental Impact Statement to ensure scientific integrity – with missing cites and cites that overturn the sentences they are cited to](#h_NASAS_draft_EIS_fails)

At a minimum an independent reviewer needs to check cites are correctly summarized in the sentences they are attached to. Many of the errors found in the EIS would be spotted with this basic level of peer review.

Other errors were missed due to a limited literature review that didn’t pick up such things as the 2015 MEPAG review of the 2014 SR-SAG2, the 2012 size limit revision by the ESF, and many counter examples in the planetary protection literature to the examples in the sterilizing working group report. One way to avoid these issues is to rely on authors already familiar with the planetary protection literature and who have written extensively on the topic.

The former NASA planetary protection officers John Rummel and Cassie Conley wouldn’t be capable of such mistakes. John Rummel in particular is author, co-author or contributor to a significant fraction of the planetary protection literature on a Mars sample return. He is a co-author of the 2012 ESF Mars sample return study [(Ammann et al, 2012:19)](#qa4nethlmcdw) and is one of the individuals who gave advice or comments to the 2009 NRC study ([SSB, 2009](#b_SSB_2009) : [viii](https://nap.nationalacademies.org/read/12576/chapter/1?term=Rummel#viii)). He is principal author of the SR-SAG2 forward contamination study [(Rummel et al , 2014)](#kix.im73nfot8zt5), and one of the individuals who gave advice or comments to the MEPAG review ([SSB, 2015](#b_SSB_2015) :[xii](https://nap.nationalacademies.org/read/21816/chapter/1?term=Rummel#xii)).

Then a new EIS needs to consider reasonable alternatives such as sterilizing the samples before they are returned to Earth

* [NASA’s draft EIS fails the NEPA’s requirement to consider reasonable alternatives in detail so that reviewers may evaluate their comparative merits – as it doesn’t examine the reasonable alternatives to sterilize samples in space first or to delay the mission until it can be done safely](#h_NEPA_erasonable_alsternatives)

Indeed, the simplest solution is to sterilize all samples before they are returned to Earth. In this case all that’s needed is

* A review of methods for sterilization adequate to sterilize even unfamiliar life that may be hardier even than radiodurans while preserving astrobiological interest, including using ionizing radiation or x-rays

The rock samples could simply be sterilized before they reach Earth during the return journey, or they can be returned to a satellite for sterilization in a safe orbit above GEO.

Then even with the Earth kept 100% safe through sterilization, it’s important to engage with the public and get widespread agreement that the chosen method is effective and would keep Earth safe

* To set up fora and other ways to engage with the public and interested experts in countries around the world to make sure that all are in agreement that the method of sterilization will keep Earth 100% safe.

We need to avoid the situation where dozens of members of the public comment on a not well publicised draft EIS saying that the mission needs to be stopped.

See:

* [NASA’s draft EIS fails the NEPA’s requirement to use an interdisciplinary approach including the social sciences, by failing to involve the public early on, not just in the USA but through fora open to representatives from all countries globally, as recommended in sample return studies – so the public weren’t given the opportunity to comment on a scientifically valid draft EIS](#h_NASA_interdisciplinary)

As a bonus NASA could add on the capabilities suggested in the previous section for space agencies to make it a far more interesting mission for astrobiology. Even a pre-sterilized sample of dirt, gas and dust collected in a clean sample container would greatly add to the interest of the mission, and especially so if the unsterilized samples can be studied as suggested in a safe orbit remotely by telerobotics like studying samples on Mars but without the latency.

If NASA wish to continue with the proposed action in the draft EIS, much more is needed.

* The general public must be given the opportunity to comment on a scientifically credible environmental impact statement which must also examine reasonable alternatives such as to keep Earth 100% safe by sterilizing the samples before the return to Earth.

Even if the intention is to continue with the proposed action, the current EIS needs to be cancelled as the general public didn’t get the opportunity to comment on a valid EIS, which should make it invalid under NEPA.

Then before a new EIS:

* We need to follow the ESF study’s recommendation, to review the size limit of particle to be contained, and the level of assurance
* We also need a new Mars sample return planetary protection report to take account of the many advances in our understanding of Mars, of potential habitats on Mars, of Mars analogue terrestrial extremophiles, and of synthetic biology and the potential pathways for a second genesis of life.

The next section looks at some of the topics that a new Mars sample return planetary protection study would need to look at.

Some of the main points. We need to:

* Review the level of assurance and size limit.
* Allow for end of mission sterilization of any equipment or materials that could be contaminated in case the sample contains mirror life or some other form of life that can never be released to the terrestrial environment.
* We can’t rely on quarantine of technicians in case of a breach of containment, see:  
    
  [NEW: It is impossible to use quarantine to protect Earth’s biosphere if humans handle the samples in orbit – the Apollo quarantine procedures never had peer review and missed the issue of a symptomless superspreader – and this can’t keep out mirror life, or molds like the one that killed two plants on the ISS – keeping humans well away from the samples also avoids forward contamination for very sensitive measurements](#h_it_is_impossible_quarantine)  
    
  The facility most likely would need to use telerobotics.
* If the new proposal includes an air incinerator, we need to study the potential that Martian spores would be hardier than Aspergillus niger because of adaptations to the extreme Martian conditions  
    
  [Alternative of an air incinerator for the second HEPA filter – would need to be evaluated for containment of putative Martian life likely more resilient than standard test terrestrial spores – and for 100% containment](#he_alternative_HEPA_air_incinerator)

Also, any new valid EIS needs a proper comparison with reasonable alternatives including the ones outlined in this paper.

In more detail:

### Topics that need to be covered in a future Mars sample return backwards contamination study [Next section](#h_methods) – [all sections](#h_titles_of_sections) – [previous section](#h_conclusions_NASA)

Based on the new material found in this review a new sample return study should consider many topics not previously considered in planetary protection studies. This is not likely to be a complete list of all the topics they need to consider. It is just a list of the main ones that turned up so far in this review.

First, based on the 2012 ESF recommendation to review the size limit and level of assurance, it needs to review:

* The size limit, including reviewing new research on the potential for non terrestrial biology such as ribocells. See:
* [ESF study said values for required level of assurance and the size limit need to be revisited periodically based on changes in scientific knowledge and risk perception](#h_ESF_study_risk_size_limit)
* level of assurance, with a consideration of Carl Sagan’s view that we shouldn’t take even a small risk with a billion lives

On that last point, it needs to:

* examine whether or not to adopt the prohibitory version of the precautionary principle, based on wishes of the public rather than priorities of space agencies
* [Carl Sagan and others warning we can’t take even a small risk with a billion lives – this could be formalized into law as a requirement to use the prohibitory precautionary principle whenever there is any appreciable risk for harm unprecedented in human history](#h_carl_sagan_and_others)

The review of the potential for extraterrestrial pathogens of humans should consider examples such as:

* Aspergillus
  + [NEW: Sterilizing subcommittee’s report gives an example of an opportunistic fungal pathogen, Candidiasis, adapted to humans – the omission here is Aspergillus which is not adapted to humans and is invasive due to adaptations to survive rapid dehydration and rehydration, rapid changes of temperature etc. many of which may be shared by life adapted to Mars – with an estimated 200,000 life threatening Aspergillus infections a year – mortality 30% to 95%](#h_Aspergillus_not_adapted)
* Tetanus

* + [Sterilizing subcommittee’s report doesn’t mention clear examples of microbes which express accidental toxins without coevolution with humans or higher life, such as neonatal tetanus which kills thousands of unvaccinated newborns every year](#b_Shigas_toxin_accidental_tetanus)
* Our immune response to a new genus of fungi as invasive as Aspergillus but with no pattern recognition capabilities to recognize it

* + [NEW: Our immune system responses are highly specific to each of the three genera of opportunistic human fungal pathogens – without the necessary pathogen associated molecular patterns (PAMPS) we might all be immunocompromised to a new genus of fungi from Mars](#h_new_our_immune_system_responses_fungi)
* Allergic reactions e.g. to fungi from Mars
  + [NEW: Possibility of an allergic response to harmless alien life – or indeed a new genus of familiar life - if it is recognized by the immune system but not by the inflammation dampening Treg cells - allergic bronchopulmonary aspergillosis affects around 4.8 million people globally and chronic pulmonary aspergillosis, affects 400,000 globally – these figures could be higher if a normally functioning human immune system doesn’t recognize the need to dampen its response](#h_possibility_allergic_response)

The review of whether life from Mars could affect terrestrial ecosystems and the Earth’s biosphere should look at:

* Fungal parasites of microbes including parasites of photobionts
  + [NEW: Microbes from Mars could have pathogens that can infect terrestrial microbes – example of fungal pathogens of phytoplankton and cyanobacteria – cyanobacteria depend on specific antifungal adaptations to protect against fungi in the chytrid phylum, so may have no adaptations to a novel fungal phylum from Mars](#h_microbes_Mars_pathogens)
* Example of permafrost microbe with optimal growth temperature 25 C and capable of growth at human blood temperature

* + [NASA’s biological safety report agrees on the potential for an invasive Martian species to harm or displace terrestrial photosynthetic bacteria – but says life adapted to Martian conditions such as the temperatures and pressures plausibly wouldn’t be able to survive on Earth – their own cite mentions Planococcus Halocryophilus, a microbe which lives in Arctic permafrost soils and likely grows in sub zero brine veins down to at least -15 °C, with an optimal growth temperature of 25°C and growth up to 37 °C (human blood temperature)](#h_argument_by_sterilizing_subcommittee)
* Species sorting which could lead to species adapted to higher temperatures than currently found in the environment life is returned from

* + [Mars surface temperatures can reach 35°C in the shade in summer – and possibility that some species of Martian surface life are pre-adapted to warmer, even hydrothermal conditions in geologically recent Mars – and may be present in small numbers in surface biofilms which might adapt to warmer conditions by species sorting](#b_Mars_surfacer_temperatures)
* Geobacillus paradox - the possibility that volcanic vents on Mars produce large numbers of hardy spores similarly to the geobacillus spores that then spread widely in the dust and may be found almost everywhere

* + [The geobacillus paradox and potential that present day Mars has abundant spores of life adapted to live in geothermal vents similarly to terrestrial Mars analogue deserts which may have been produced as recently as the last few million years or even be actively produced today](#h_geobacillus_paradox)

A new sample return study should look at possibilities with no terrestrial analogue such as:

* Joshua Lederberg's two papers looking at the possibility that terrestrial immune systems have no defences against alien biology - and Claudius Gros's similar suggestion

* + [Warnings by some astrobiologists such as Sagan and Lederberg that in worst case we could be in effect immunocompromised to an entire exobiology from Mars](#h_warnings_by_some_astrobiologists)
* and the possibility that this extends to even microbial terrestrial life with no defences against alien microbes

* + [Claudius Gros’s scenario extends Sagan and Lederberg’s hypothesis to all higher life, though in the forward direction only – could his scenario be applied in reverse – and could even terrestrial microbial life have no defences against pathogens from a completely alien biology?](#h_Claudius_GRos_scenario_forward)
* Effects of returning mirror life or other life with a radically different internal biology

* + [NEW: Example worst case scenario of a mirror life chroococcidiopsis analogue from Mars which could gradually convert organics in ecosystems into indigestible mirror organics](#h_worst_case_scenario_of_mirror_life)

* + [NEW: Closely related worst case scenario of a shadow biosphere of small mirror life nanobes that produce indigestible mirror life biofilms on Earth with small cells advantages that they take up nutrients faster and avoid protozoan grazing](#h_closely_related_worst_case)
* Life that might be better at photosynthesis than terrestrial life

* + [NEW: Martian life could be better at photosynthesis than terrestrial life since terrestrial photosynthesis works at well below its theoretical peak efficiency and the lower light levels on Mars might favour evolution of more efficient photosynthesis](#h_Martian_life_could_be_better)
* Life that might be better adapted that terrestrial life and spread rapidly
  + [NEW: Worst case scenario - If a martian microbe can grow in the sea, soil, and fresh water like chroococcidiopsis, is adapted to spread in the wind in Martian dust storms, and outcompetes terrestrial biology, e.g. better at photosynthesis or nitrogen fixation, it could be found globally after introduction to Earth in weeks to months, and be one of the most common microbes in our soils and oceans in years to decades or sooner, far more common than nanoplastics or microplastics](#h_worst_case_outcompetes_terrestrial_lif)

When considering whether samples could contain life it should look at:

* Potential for Martian life to make the Curiosity brines habitable through adaptations such as biofilms, perhaps covered with surface mosses that use hair structures that swell when hydrated to block escape of water vapour and maybe even micropores that close at times of lower humidity or in response to daylight

* + [Martian life could be more capable of coping with Martian conditions than terrestrial life – e.g. survive better in dust storms or cope better with cold temperatures and temperature changes – and ways a martian biofilm could retain water in ultracold night time brines through to the midday warmth – fine hairs, pores that close in daytime like cactuses – chemicals that speed up metabolism, slow generation times and novel biochemistry](#b_Martian_life_more_capable)
* New studies on transport of biofilms in the dust

* + [2019: A thin (0.03 microns thick) fragment of desiccated biofilm of chroococcidiopsis would be still viable after blowing 100 km in moderate winds (5 meters per sec) in full Martian sunlight](#h_work_on_survival_dust_2015)
* suggestion that even if microbial life can't get started today, life on Mars could propagate via biofilm fragments

* + [2019: Curiosity found UV radiation fell by 97% at the start of the 2018 dust storm, which could increase Billi et al’s 100 km to 1000s of kilometers in Martian dust storms – and Mosca et al’s suggestion that biofilm fragments established in the past could continue to propagate even if Mars doesn’t have conditions to start a new biofilm today](#h_Curiosity_found)
* Potential for individual microbes to survive in cracks in dust spores

* + [2017: individual microbes can travel in dust storms imbedded in a dust grain for extra protection from UV](#potenial_for_transport)
* Potential for microbes to survive in cracks in bouncing grains of dust up to half a millimeter in size

* + [2019: Microbes can be protected by bouncing sand grains up to half a millimeter in diameter traveling meters in each bounce, and some (less than 1 in 1000) b. subtilis spores remain viable after hundreds to thousands of kilometers of travel in simulation experiments](#h_experiments_in_2019)
* Potential for Martian life to evolve propagules with hardened outer shells to survive bouncing and can be propagated similarly to bouncing grains

* + [New: Martian life could evolve new strategies for dust storm transport such as spores with extra layers to protect against UV, and fruiting bodies for higher life that are detached by strong winds and may be better protected against UV than terrestrial life](#h_potential_for_martian_life_to_evolve)
* Potential for microbial spores on Mars to develop extra layers to protect them from UV, chlorates, chlorites, hydrogen peroxide and desiccation
  + [New: Martian life could evolve new strategies for dust storm transport such as spores with extra layers to protect against UV, and fruiting bodies for higher life that are detached by strong winds and may be better protected against UV than terrestrial life or protection from bounce impacts with biomaterials resembling chitin (used by lichens)](#h_potential_for_martian_life_to_evolve)
* The suggestion that Mars has fresh liquid water seasonally in the polar regions similarly to the subglacial melt in Antarctica which should happen at surface temperatures of -90 C because of the way ice lets light through but insulates the melt water and protects from evaporation in a vacuum which leads to ice melting at half a meter depth in Antarctica - in the different conditions on Mars it should melt at a depth of 5 cms
  + [2009, 2014: Possible future surprise discovery of large quantities of fresh water on Mars: ice lets light through and traps heat, which melts ice half a meter below the surface in Antarctica -– if Martian ice is similar, its polar regions should have meltwater in summer, ~5 cms below the surface, even with surface temperatures below -90 °C – Mars may also have miniature melt ponds around sun warmed dust grains](#h_possible_future_surprise_discovery)

For the idea of testing samples before release it should consider:

* Testing can't protect Earth from life in a sample - that after 10,000 dust grains tested destructively you can't deduce that the 10,001th grain is safe

* + [NEW: Too early for any form of safety testing even for samples returned in sterile containers at the level of assurance needed for potential large scale harm – after destructively testing 10,000 grains of dust the 10,001th grain could have a viable microbe in it](#h_too_early_for_any)

For human quarantine:

* Human quarantine can't work to protect Earth or even humans - issue of life-long symptomless superspreader like Typhoid Mary and that technicians might happen to be immune to a new fungal pathogen which most of the population have no immunity to –
* if a technician got ill with a potentially life threatening disease, ethically you can't leave them to die in quarantine – they would be removed but that's the very time when they need to be kept in to protect Earth  
  Impossibility of keeping out a pathogen of crops or microbes with human quarantine - it can become part of the human microbiome as with the example of the crop pathogen brought to the ISS
* Impossibility of keeping out mirror life with human quarantine

These are all covered in

* [NEW: It is impossible to use quarantine to protect Earth’s biosphere if humans handle the samples in orbit – the Apollo quarantine procedures never had peer review and missed the issue of a symptomless superspreader – and this can’t keep out mirror life, or molds like the one that killed two plants on the ISS – keeping humans well away from the samples also avoids forward contamination for very sensitive measurements](#h_it_is_impossible_quarantine)

A Mars sample return study

* shouldn't be set up with a remit to find a way to return a sample safely
* should be tasked to evaluate whether or not current technology is not able to contain the samples to the required level of assurance, with “no” as a permissible answer

A Mars sample return back contamination study should be empowered to look at reasonable alternatives such as

* sterilizing all samples before they are returned to Earth,

* + [NEW: We can forestall all these issues and make the mission 100% safe by sterilizing samples before they reach Earth](#h_we_can_forestall)
* returning some samples of especial astrobiological interest to a satellite above GEO for study remotely, and sterilizing anything returned from that satellite to Earth. See:

* + [NEW: We can transform this into a much more interesting first step for astrobiology with little change in the overall budget by adding bonus samples collected in a STERILE container sent on the ESF fetch rover – the aim is to return dust, dirt, ideally salts, compressed gas from the atmosphere – and some pebbles for a technology demo of a contamination free rock sample](#h_we_could_transform)
  + [NEW: These clean samples will be studied above geostationary orbit in Mars simulation conditions with a Martian gravity centrifuge – they are not intended for safety testing - and humans never go near the satellite](#h_these_clean_samples)

# [All sections – for an outline of this paper](#h_titles_of_sections)

Titles of sections are like mini-abstracts and summarize the details of the section. For a first overview of this paper read the section titles.

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[NASA’s draft EIS fails the NEPA’s requirement to consider reasonable alternatives in detail so that reviewers may evaluate their comparative merits – as it doesn’t examine the reasonable alternatives to sterilize samples in space first or to delay the mission until it can be done safely Next section – all sections – previous section 18](#_Toc129747299)

[NASA’s draft EIS fails the NEPA’s requirement to use an interdisciplinary approach including the social sciences, by failing to involve the public early on, not just in the USA but through fora open to representatives from all countries globally, as recommended in sample return studies – so the public weren’t given the opportunity to comment on a scientifically valid draft EIS Next section – all sections – previous section 19](#_Toc129747300)

[Other commentators raised significant issues – including one of the principle authors of NASA’s probabilistic risk assessment guide who said a better statement of options should include the possibility of delaying the return until the risks are better understood Next section – all sections – previous section 20](#_Toc129747301)

[The Council of Environmental Quality says the first step is to contact the agency to resolve issues, however NASA has not yet responded to attempts to contact them on this topic Next section – all sections – previous section 20](#_Toc129747302)

[We can’t actually assess the level of risk until we know more about Mars – it could be zero or it could be far higher than expected Next section – all sections – previous section 21](#_Toc129747303)

[Worst case scenarios introduce novel ethical and legal questions – is a 1 in a million level of risk acceptable? Next section – all sections – previous section 21](#_Toc129747304)

[Synthetic biologists suggest a safety mechanism for synthetic life should be many orders of magnitude safer than a BSL-4 Next section – all sections – previous section 22](#_Toc129747305)

[NEW: Society places very high value on the environment and given the potential for large scale effects, we might require Earth is kept 100% safe for this mission – i.e. use the prohibitory precautionary principle Next section – all sections – previous section 23](#_Toc129747306)

[Carl Sagan and others warning we can’t take even a small risk with a billion lives – this could be formalized into law as a requirement to use the prohibitory precautionary principle whenever there is any appreciable risk for harm unprecedented in human history Next section – all sections – previous section 24](#_Toc129747307)

[The decision about acceptable levels of risk for large scale harm is an ethical decision and can’t be decided on the basis of science or engineering Next section – all sections – previous section 25](#_Toc129747308)

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[This doesn’t look like the broad acceptance which Rummel et al said is essential for success of this mission – if NASA continues with this action, it is vulnerable to being stopped in the future Next section – all sections – previous section 28](#_Toc129747311)

[Conclusion and recommendations for space agencies generally – simplest solution to sterilize the sample before it reaches Earth with ionizing radiation – priority to return dust, dirt, atmosphere and salts – sterilization would have virtually no effect on geology and most likely no effect on astrobiology either Next section – all sections – previous section 30](#_Toc129747312)

[Conclusions and recommendations for NASA – need to restart the process with a scientifically credible EIS – simplest solution is to sterilize the samples before they are returned to Earth which retains virtually all the geology and most likely has no impact on astrobiology 32](#_Toc129747313)

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Some of the references have quotes to help the reader, and as part of the processes used to check the sources are cited accurately. This is usually for cites where it’s impossible to give page numbers, or where the source is quite technical.

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*… Our finding suggests that a putative microbial life-form at least as resistant to desiccation and radiation as the investigated desert cyanobacterium could withstand some exposure to UV on the martian surface.*

*… Our findings support the hypothesis that opportunistic colonization of protected niches on Mars, such as in fissures, cracks, and microcaves in rocks or soil, could have enabled life to remain viable while being transported to a new habitat*

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*Even in this dessicated place, she found life: photosynthetic bacteria that had made a home in tiny chambers within halite salt crystals. There’s a small amount of water retained inside the halite and, at night, it cools down and condenses both on the walls of the chambers and on the surface of the organisms that are sitting there.*

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*The U.S. takes a different approach for filter classification of HEPA filters. The mother of all test procedures for these filters in the U.S. is MIL-STD-282, which was introduced in 1956. Other test procedures include e.g. IEST-RP-CC001 and IEST-RP-CC007. Each test procedure specifies certain particle sizes at which efficiency is evaluated. Depending on the filter class evaluated, this is done at 0.3 µm, 0.1 - 0.2 µm or 0.2 - 0.3 µm.*

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For many years a story was told in which it was said that Lascaux was discovered by  
Ravidat’s dog, Robot. There is some basis for this, as during the first trip Ravidat had been drawn to the toppled pine hole by the barking of Robot who had become entangled in its brambly overgrowth. However, it appears that Robot was not around when the boys went down through the hole.

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*The geological environment and history of Amazonis Planitia also has astrobiological implications. The most recent of the lava flows associated with the emplacement of these plains have been dated as extremely young geologically (less than 24 million years old [*[*Hartmann and Berman, 2000*](https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2002JE001842#jgre1547-bib-0035)*]). If fossil or extant life existed at depth in the subsurface groundwater system at this time (a troglodytic fauna), it is highly likely that they would be among the material erupted to the surface during the cryosphere-cracking, dike-emplacement event (J. W. Head and L. Wilson, A model of simultaneous dike intrusion, cryospheric cracking, groundwater release and the eruption of lava: Examples from the Elysium Rise, Mars, manuscript in preparation, 2002), and washed down into Elysium and Amazonis Planitiae. The fate of such effluents under Mars conditions has recently been modeled [[Kreslavsky and Head, 2001](https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2002JE001842" \l "jgre1547-bib-0054),* [*2002*](https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2002JE001842#jgre1547-bib-0055)*] and it has been shown that standing bodies of water at this scale would quickly freeze over and sublimate, leaving a sedimentary sublimation residue. Thus, Elysium and Amazonis Planitiae may be excellent locations to sample recently emplaced troglodytic faunal remains.*

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See section Selective Pressures for Small Size

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*Similarly, the top three most common human pathogens,* A. fumigatus, A. flavus *and* A. terreus*, do not group together in the* Aspergillus *family tree and all possess relatives that rarely, if ever, infect humans. This lack of association between lifestyle and evolutionary affinity is probably because many of the traits render fungi into potent pathogens, agricultural pests, or cell factories are likely features that are generally associated with the saprophytic lifestyle and selected for survival in conditions independent of their current roles in pathogenesis, pestilence, or biotechnology.*

*The advent of* Aspergillus *genomes has also augmented studies on understanding the regulation of SM gene clusters. One of the most interesting recent developments is the discovery that the velvet family of proteins, together with the global regulator* laeA *[*[*73*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R73)*], form a complex that links and coordinates SM production with morphological differentiation [*[*75*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R75)*,* [*76*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R76)*], which is in turn activated when a highly conserved signal transduction module receives the appropriate external environmental signals (*[*Figure 3*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/figure/F3/)*) [*[*77*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R77)*]. This coupling of SM with development presumably evolved because the protection offered by the deposition of SMs into the spores is vital to propagation [*[*76*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R76)*]. In line with this hypothesis,* A. nidulans *mutants deficient in the production of SMs are less toxic to their insect predators than the wild-type [*[*78*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R78)*]. However, SMs are not only important in predator avoidance; evidence that certain* Aspergillus *SM gene clusters are activated only when physically interacting with other microbes [*[*79*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R79)*], that SMs provide a competitive advantage [*[*80*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R80)*], as well as the discovery of self-protection genes nested within others [*[*81*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R81)*], suggest that SMs are also likely to be critical in interactions between* Aspergillus *and other microbes.*

*Additional support for the hypothesis that SMs are critical components of fungal–microbial interactions comes from a recent study aimed at identifying the molecular signature of domestication in* A. oryzae *[*[*7*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R7)*], one of the two fungi used in the making of sake in the last few millennia in the Far East. During sake making,* A. oryzae *is responsible for breaking down rice starch into simpler sugars, a process that occurs, to a large degree, in parallel with the conversion of sugars to alcohol by the brewer’s yeast* Saccharomyces cerevisiae*. In contrast to its wild relative* A. flavus*, the entire SM profile of* A. oryzae *is dramatically downregulated when grown on rice, including the gene clusters responsible for the synthesis of the mycotoxins aflatoxin and cyclopiazonic acid [*[*7*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R7)*]. Because aflatoxin, and presumably other SMs as well, is genotoxic to* S. cerevisiae *[*[*82*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R82)*] and its presence during fermentation would affect yeast survival and, consequently, sake making, the domestication process may have converted* A. oryzae *into a microbe that is ‘friendly’ to its other microbial co-inhabitants.*

*…*

*This dominance of* A. fumigatus *[as a human pathogen] is likely due to ecological traits, such as the high prevalence and buoyancy of its spores in the environment [*[*85*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R85)*], as well as genetic ones, such as the ability to grow well at 37°C and the coating of its spores with a hydrophobin that renders them immunologically inert [*[*86*](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3534798/#R86)*]*

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*QUOTE We also examined the recovery of genomic DNA from CB1000 and CB2000 after exposure to 5,000 Gy of 137Cs (7.8 Gy/min) and compared this with the fate of genomic DNA in the founder strain. The acquired phenotype was evident in this experiment (Fig. ​(Fig.5).5). The DNA from the founder did not recover after this dose of radiation over a 9-hour time course. Even the fragmented DNA appeared to disappear with time, probably reflecting nuclease degradation. No growth of the irradiated cell culture was evident over a period of 9 h. In contrast, the genomic DNAs from CB1000 and CB2000 were repaired, with the normal NotI banding pattern clearly visible in the pulsed-field gel after 2 hours in both cases. Visible genome restoration appeared to peak after 3 to 4 h. The increase in genomic DNA was not due to growth of undamaged survivors. No increase in bacterial cell mass was evident in the cultures until 8 h and 5 h for CB1000 and CB2000, respectively. These results indicate that the genomic DNA was repaired well before the initiation of normal genome replication and cell division.*

*QUOTE One single colony isolate was taken from each of these populations, generating purified strains designated CB2000, CB3000, and CB4000. The founder, like other E. coli K-12 strains, is quite sensitive to IR; exposure to 3,000 Gy gamma radiation (60Co; 19 Gy/min) reduced the viability 4 orders of magnitude compared to that of the unirradiated culture (Fig. ​(Fig.2).2). The D37 value [37% survival] for CB1000 was 1,100 Gy, whereas the D37 value for CB2000 and CB3000 was 2,000 Gy—approximately threefold less than the D37 value measured for actively growing cultures of Deinococcus radiodurans R1 (41). The D37 value for the founder was 730 Gy. Higher doses of IR revealed a major improvement in resistance. CB1000, CB2000, and CB3000 exhibited 1,500- to 4,500-fold increases in survival relative to the founder after exposure to 3,000 Gy (Fig. ​(Fig.2).2). CB4000 was approximately 10-fold less radioresistant than the other isolates.*

*QUOTE 20 iterative cycles of irradiation and outgrowth. The length of each exposure was adjusted to kill >99% of the population, with this dose increasing from 2,000 Gy for the first cycle to 10,000 Gy on the last cycle*

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*Improved instrumentation on rovers that might detect and identify a diversity of potential in situ biosignatures, including ancient organic molecular biosignatures, designed with the ability to differentiate biotic and abiotic signals in micro- or macrostructures. Instrumentation could also be better attuned to the unique complications of biosignature preservation on Mars (e.g., deeper drilling to access potentially better preserved organics)*

*The fluorescence spectrometers on SHERLOC can detect condensed carbon and aromatic organics by deep UV-induced fluorescence, and SHERLOC's Raman spectrometer will allow classification of aromatic and aliphatic organics. Raman spectrometry can also be used to detect minerals relevant to aqueous chemistry. While these measurements would allow us to identify reduced carbon compounds, there may not be sufficient structural information to distinguish between a biological signal and extraterrestrial organic input.*

*A major knowledge gap that will directly impact our ability to choose an appropriate landing site is what terrestrial analog environments might look like—what the biosignature signals might be—if photosynthetic microorganisms had not evolved and instead the environments were only inhabited by chemosynthetic microorganisms*

*4.4. Strategies and priorities*

*In many of the environments discussed, there is a dichotomy between habitability and preservation—many of the conditions that make an environment more habitable are destructive to one or more of the biosignatures of interest. For example, fluid flow in the subsurface of hydrothermal environments helps create the redox gradients that support communities that inhabit the outflow channel. Fluids are also essential for lithification and the associated decrease in permeability essential for long-term preservation. Preservation is enhanced by rapid burial and mineral precipitation that encases and lithifies biological materials in less permeable matrices—in these cases, silica from hydrothermal environments, or silica-enriched aqueous environments, is an important material for preservation. However, these same fluids can degrade biosignatures such as mineralogy, chemistry, and micro- and macrostructures. One strategy for astrobiological exploration has to be to seek out a “sweet spot” where these two balance each other so that long-term preservation is possible. This sweet spot may occur as conditions change through time.*

Head, J.N., Melosh, H.J. and Ivanov, B.A., 2002. [Martian meteorite launch: High-speed ejecta from small craters](https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1945-5100.2002.tb01033.x). *Science*, *298*(5599), pp.1752-1756.

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Specifically, clinical features and radiological findings of CAPA resemble those of severe COVID-19[2](https://www.nature.com/articles/s41564-022-01172-2#ref-CR2) and blood tests lack sensitivitydue to the invasive growth of *Aspergillus* in the airway and the clearance of *Aspergillus* galactomannan (GM) from systemic circulation by neutrophils in non-neutropenic patients

… *However, once CAPA becomes angioinvasive and produces positive serum GM, mortality is more than 80%, even if systemic antifungal therapy is provided*

*… Using these variable criteria, a median incidence of 20.1% (range 1.6–38%) was reported in patients with COVID-19 acute respiratory failure requiring invasive ventilation … bringing the prevalence of CAPA down to about 10% among invasively ventilated patients with COVID-19. However, incidence continues to vary widely between ICUs, due to non-uniform approaches to COVID-19 treatments, different burdens of Aspergillus exposure and differing diagnostic algorithms as well as genetic predisposing risk factors*

*… The combination of dexamethasone and tocilizumab, invasive ventilation and older age, have been reported as risk factors for developing CAPA*

*… Unlike influenza-associated pulmonary aspergillosis, CAPA develops later and is diagnosed a median of 8 days after ICU admission*

*… CAPA has been consistently associated with COVID-19 mortality rates of more than 50%*

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*Stratigraphic relationships indicate a relative age younger than the surrounding volcanic plains and the Zunil impact crater (~0.1–1 Ma), with crater counting suggesting an absolute model age of 53 to 210 ka. This young age implies that if this deposit is of volcanic origin then the Cerberus Fossae region may not be extinct and Mars may still be volcanically active today.*

*…*

*Dike-induced melting of ground ice and hydrothermal circulation could generate favorable conditions for recent or even extant habitable environments in the subsurface. These environments would be analogous to locations on Earth where volcanic activity occurs in glacial environments such as Iceland, where chemotrophic and psychrophilic (i.e., cryophilic) bacteria thrive (Cousins & Crawford, 2011).*

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*Aflatoxins, ochratoxins, trichothecenes, zearelenone, fumonisins, tremorgenic toxins, and ergot alkaloids are the mycotoxins of greatest agro-economic importance. … Mycotoxins have various acute and chronic effects on humans and animals (especially monogastrics) depending on species and susceptibility of an animal within a species.*

*…*

*Mycotoxins are secondary metabolites that have no biochemical significance in fungal growth and development*

*These toxins account for millions of dollars annually in losses world-wide in human health, animal health, and condemned agricultural products.*

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*[Page 175:](https://books.google.co.uk/books?id=PGih0tcJb1MC&pg=PA175&source=gbs_selected_pages&cad=2" \l "v=onepage&q&f=false) "At all distances out to the orbit of Pluto and beyond, it is possible to obtain Earth-normal solar intensity with a concentrating mirror whose mass is small compared to that of the habitat.”*

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*[This corresponds to 7 watts of power output]*

X-rays are almost perfectly blocked when the thickness of the copper collimator is 3 mm

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*After 7 years of air-drying, Chroococcidiopsis not only avoided genome degradation but preserved at least a sub-set of mRNAs and 16S ribosomal RNA.*

*... In the present work, the occurrence of survivors in dried biofilms and dried-UV-irradiated biofilms was proved by growth after transfer into liquid BG-11 medium (not shown) and by INT reduction after 72 h of rewetting.*

*Reshaping the boundaries of Chroococcidiopsis desiccation and UV tolerance has implications in the search for extra-terrestrial life since it contributes to defining the habitability of Mars and planets orbiting other stars. In fact, the UV dose used here corresponds to that of a few hours at Mars’s equator (Cockell et al., 2000). Hence, considering that survivors occurred in the bottom layers of the biofilms (Baqué et al., 2013), it might be hypothesized that if a biofilm life form ever appeared during Mars’s climatic history, it might have been transported in a dried state under UV radiation, from niches that had become unfavorable to niches that were inhabitable (Westall et al., 2013). The reported survival also suggests that intense UV radiation fluxes would not prevent the presence of phototrophic biofilms or their colonizing of the landmass of other planets.*

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[*Page 23*](https://www.nap.edu/read/18476/chapter/5#23)*: It is remarkable that the depth at which surviving lunar organic matter is expected to be localized (section II) is just the depth at which temperatures appear to be optimum for familiar organisms (section IV). At such temperatures and depths, some moisture should be expected, arising from meteoritic and organic bound water. Watson, Murray and Brown (1961) have recently pointed out that ice could have been retained on permanently shaded areas of the Moon. These circumstances provide all the survival requirements of many terrestrial organisms - water and their metabolites, appropriate temperature, and negligible radiation. That autochthons evolving with the changing environment could also survive under these conditions is far from inconceivable.*

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*…*

*"A single terrestrial microorganism reproducing as slowly as once a month on Mars would, in the absence of other ecological limitations, result in less than a decade in a microbial population of the Martian soil comparable to that of the Earth's. This is an example of heuristic interest only, but it does indicate that the errors in problems of planetary contamination may be extremely serious."*

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*Nonetheless, we suggest that the mixed success of the external sediment transport model is still quantitatively better than any competitor (including water), and that we simply lack the model and data resolution to treat RSL at the required meter scales.*

*…*

*Overall, neither frost nor deliquesced brines correlate with RSL activity except for the absence of frost when RSL at Palikir crater are active. Note the RH [Relative Humidity] in the near surface is also poorly constrained as additional in-situ measurements are needed to better calibrate the mesoscale models.*

*We hypothesize that the rough correspondence of RSL activity with warmer parts of the year at most sites may actually be due to seasonal variations of wind speed, direction, and turbulence. Our MRAMS modeling does not show a clear correlation between upslope potential sediment transport and RSL seasonality. However, it is possible that more detailed modeling (higher resolution, varying surface roughness, better PDF evaluation for wind gusts) could find a better correlation.*

*…*

*We also conclude that if the dry RSL mechanism is correct then locations with favorable RSL geomorphology that lack RSL may lack a combination of strong winds and sand grains that can easily saltate on Mars (~100 μm in diameter).*

*…*

*We found that at two of the three RSL sites deliquescence never occurs, and at the third site (Rauna crater) the stability of brines does not correlate with RSL activity. The existence of small amounts of surface brines that could possibly trigger RSL grain flows via efflorescence and associated changes in cohesion appears to be unlikely. Likewise, the absence of frost is only correlated with RSL activity at Palikir crater, thus frost is likely not affecting RSL triggering.*

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*…*

*Applied to Mars, wet streaks are inconsistent with the surface expression and dynamics of RSL. Wet streaks propagate and fade over multiple years, drain onto low angled slopes, and have a characteristic pattern of dark downhill and lateral edges. In contrast, RSL are seasonal features, terminate on angle-of-repose slopes, and typically appear monochromatic. These inconsistencies provide evidence against brine flow hypotheses of RSL formation.*

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*July, 1976, the month that VL1 [Viking Lander 1] landed on the Martian surface, was also the month of the outbreak of Legionnaires’ disease at the American Legion convention in Philadelphia.*

*The cause, Legionella pneumophila, is a facultative, Gram-negative rod that is one of several human pathogens now known to be carried in the intracellular environments of protozoan hosts. L. pneumophila can also persist, even outside of any host, as part of biofilms.*

*In essence, all that a potentially infectious human pathogen needs to emerge and persist is to grow and live naturally under conditions that are similar to those that it might later encounter in a human host. On Mars, these conditions might be met in a particular niche within the extracellular environment of a biofilm, or within the intracellular environment of another single-celled Martian organism. It is important to note the numerous biofilms observed aboard the Mir space station, which were found on surfaces and within water plumbing. These films were often multi-species and included bacteria, fungi, and protozoa.*

*To be sure, the genetic similarity between humans and protozoa is much greater than could be expected between humans and the Martian host of a Martian microbe.*

*However, the L. pneumophila example does bring into question the rationale of the need for host-pathogen coevolution. Even in the context of a planetary bio-sphere that is limited to single-celled life, and even where there is unlikely to have been a co-evolution between agent and host organism, the possibility of infectious agents, even an invasive type, cannot be ruled out.*

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