NASA’s draft Environmental Impact Statement is likely to face many challenges in the courts as it ignores objections from previous comments, fails to consider some impacts outlined in Mars sample return studies, and fails to consider the weight of impacts – and what they could do to fix it

Section titles are written like mini-abstracts. For a fast overview, read the headings, and drill down into sections of interest for more details

This contains some sections from the main paper plus several extra sections not yet added as of writing this, about the NASA EIS submission and how it doesn’t adequately address the potential effects of their actions.

Current title for the main paper: NASA and ESA are likely to be legally required to sterilize Mars samples to protect the environment through to 2039, or until proven safe – technology doesn't yet exist to comply with ESF study's requirement to contain viable starved ultramicrobacteria, and legal process followed by build and training of technicians takes at least 17 years - proposal to study samples remotely in a safe high orbit above GEO with miniature life detection instruments – and immediately return sterilized subsamples to Earth

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For latest version of the main paper preprint please visit: (url https://osf.io/rk2gd)

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Writing as an enthusiast who wants the mission to succeed – an analysis of issues with the proposal and then suggestions for how it can be transformed into one with no risk of cancelation

First, I am writing this as an enthusiast who wants the mission to go ahead. As I'll show in this contribution, the impact statement is sadly inadequate. It mentions but doesn't cite the extensive literature on the topic and the statements they make contradict the findings of numerous panels of experts in the Mars sample return studies.

However, I suggest with some changes the proposed action can go ahead in a way that is safe for the environment and maximizes return for astrobiology and geology.

If this EIS is kept "as is" there is a high risk of the mission being stopped altogether or for the courts to say all samples have to be sterilized to protect Earth.

Introduction – significant risk the mission is stopped or an injunction issued to NASA to sterilize all samples as a result of an inadequate Environmental Impact Statement

There is a significant risk that the mission is stopped altogether, or that the decision is made that NASA have to sterilize all samples from Mars to keep humans, other species and Earth's environments safe.

Amongst other things NASA

- Have not made any changes in response to any of the main objections presented in the first round of comments on their draft proposal.
- Don't mention the potential for large scale effects from a sample return highlighted in the National Research Council report
- Claim that there is a consensus that the Martian surface is too hostile for life to survive there today – none of the major Mars Sample Return studies have come to this conclusion

- Claim that these reports use the evidence of Martian meteorites transferred from Mars to show that a sample return would be harmless – the opposite, they say that transfer by meteorite is different from transfer via a sample return mission and that they can't rule out the possibility that Martian life in the distant past could have had large scale effects on Earth
- Rely on BSL-4 procedures to contain the samples, despite limits in the most recent study by the European Space foundation in 2012 that far exceed what is possible in a BSL-4 laboratory

For details see the sections below starting with: (internal link):

- **NASA have made no significant changes in their safety assessments in response to objections made in previous requests for comments**

[Or go back to contents list]

As a result they the proposal seems likely to be very vulnerable to litigation. See:

- **NASA's Environmental Impact Statement is vulnerable to litigation on the basis that it doesn't consider impacts of a sample return properly, doesn't take account of the main issues mentioned by the Sample Return Studies and say things that contradict their conclusions – potential remedies include stopping the mission altogether or an injunction, e.g. to sterilize all samples before they contact Earth's biosphere**

That would be a great shame. We can transform it into a mission of far greater interest for astrobiology and at the same time a mission with zero risk to the environment of Earth.

That should be the alternative to the mission. Not "no action" but a safe mission of great astrobiological interest.

Sterilization is the simplest solution. It retains geological interest and some astrobiological interest.

First safe alternative to the proposal and simplest solution: sterilize all the samples on the journey from Mars to Earth or captured and sterilized in Earth orbit using ionizing radiation – this is not likely to impact on geological studies, and after sterilization it would still be possible to recognize biosignatures of present day life

Sterilization is the simplest solution. If present day life is unlikely in the samples and if the past life samples are seriously degraded already by exposure to surface cosmic radiation, we find the extra radiation to sterilize the samples is not likely to impact on geological studies, while any extant life, while not viable, would still be recognizable as such by astrobiologists. As far as extant life is concerned, the mission would then be a technology demonstration, preparing for a future mission that is more likely to return any viable Martian microbes.

From the Mars Sample Return Planning Group 2 MSPG2 (Meyer et al, 2022) most of the Mars Sample Return science could and should be done on samples that are deemed safe.

> QUOTE Summary-3. Most aspects of MSR sample science could, and should, be effectively performed on samples deemed safe (either by test or by sterilization) in uncontained laboratories outside of the SRF. However, other aspects of MSR sample science would be both time-sensitive and sterilization-sensitive, including the search for life, assessment of habitability, and volatile exchange processes, and would need to be carried out in the SRF.

I cover this in my paper under

- Sterilized sample return as aspirational technology demonstration for a future astrobiology mission

This is a possible solution if the samples are believed to be unlikely to be of great astrobiological interest. Sterilizing the samples will have little effect on the geological interest as I cover in the paper under:

- Experimental data on effects of sterilizing doses of gamma radiation – preserves the geological interest of rock samples - need to test effects of X-rays

However I suggest that another alternative is a mission with some changes, mainly design changes to the ESF sample retrieval rover, that would make it of much greater astrobiological interest. Design of this rover is still at an early stage and could be modified.

Current mission has low chance of returning present day life even if there is life in Jezero crater – but NASA's proposal can be transformed into a mission of far greater interest to astrobiology by enhancing the ESA fetch rover with simple capabilities to take samples of dirt, dust and a compressed sample of gas from the atmosphere to detect even small traces of biologically relevant gases – Perseverance already has an atmospheric gases compressor but it is used for Moxie rather than sample return

NASA's mission is designed for geology not astrobiology. All the astrobiology papers I have found on the topic say that an astrobiology mission needs to do in situ life detection to make an intelligent choice of the samples to return. Even if there is abundant life on Mars, in condition similar to the harshest terrestrial deserts, most samples may well be lifeless. It is hard to return life when you can't see it. Astrobiologists have designed numerous miniature life detection instruments that could be sent to Mars.

See the sections in my paper:

Perseverance can't search for life in situ, which is why we won't even know if the samples contain life until they get back to Earth.

The geological nature of this mission is most clear in the permitted levels of contamination in the sample tubes which will make it near impossible for astrobiologists to tell if it has traces for past or present day life unless very obvious. The permitted levels of biosignatures are so high that we wouldn't notice if the sample contained tens of thousands of terrestrial ultramicrobacteria or tens of millions of hypothetical minimal RNA world ribocells. See section below (internal link):

- Perseverance's sample tubes weren't sterilized 100% leading to risk of false positives that may prevent distribution of unsterilized samples from containment – estimated 8.1 nanograms maximum organic contamination per sample tube are equivalent to 81,000 ultramicrobacteria or 160 million hypothetical RNA world mirror nanobes

We also see this in the decisions to not take a compressed atmosphere sample or dust sample, and not to take a sample of the dirt – all materials of high interest to astrobiologists and of less interest to geology. NASA did send an atmospheric compressor to Mars on Perseverance but it is used for Moxie, an independent experiment to test options for creating fuel from the atmosphere, not to compress a sample of atmosphere to return to Earth.

It will be impossible to detect small trace amounts of biologically relevant gases in the atmosphere with their small uncompressed atmospheric sample, and with the high levels of permitted contamination of the tubes.

Also the only dust they plan to collect is any that accidentally gets stuck to the sample tubes. This is not enough dust to have a reasonable chance to return spores or viable propagules even if there are large numbers of them transported every year in the dust storms.

We need a dedicated dust collector, to either collect propagules or to produce a first realistic bound on the amount of material transported in the dust storms in this way and a first bound on the potential for distant habitats on Mars to transport spores to landing sites.

Finally the dirt on Mars is of great interest to astrobiologists, because of the discovery by Curiosity of brines that form in the evening and early morning and the intriguing Viking results not yet fully explained. The Viking results may be complex chemistry rather than astrobiology, but we need to know what is going on there in order to help shape future searches for life on the planet.

I suggest modifications to the ESA fetch rover to rectify these omissions. If not, some other nation, perhaps the Chinese, could return a mission of far more interest to astrobiology at far less expense, just a sample of the dust, atmosphere and a scoop of dirt, and can do it far faster than the USA can.

All of these would need to use sterile containers. For astrobiologists the small risk of a container not opening on Mars is worth it for the very high pay off of avoiding terrestrial contamination of the samples altogether by using enclosed sterilized containers to collect the samples.

These are changes that can be made within the spirit of the mission, not “mission creep”.

See below:

- Proposals to modify the ESF lander and sample selections to increase potential for returning viable present day or identifiable past life with samples of the dirt, dust from the air during dust storms, and compressed large samples of Martian air collected in 100% sterile containers by the fetch lander – and to use Marscopters to search for freshly excavated young craters for Perseverance to sample

With these changes the mission becomes of sufficient biological interest to return the samples unsterilized for study in a high orbit first.

Second safe alternative to this mission: sterilize samples that contact Earth’s biosphere – and to study unsterilized samples in orbit so that there is no loss of information for astrobiology and viable cells from Mars can be cultivated safely in orbit even in the case of something as risky to Earth’s biosphere as mirror life

If the mission is of astrobiological interest, the samples can be returned for preliminary study in a location not connected to Earth's biosphere. This solution is a way to avoid the need to sterilize native life in the sample,

We can then sterilize sub samples which can be returned for immediate study in terrestrial laboratories, while the unsterilized materials are studied in a safe location off-planet until we know what is in them. Future decisions then are made based on what we find in the samples.

I cover this in my paper under

- Recommendation to return a sample for teleoperated ‘in situ’ study above Geosynchronous Equatorial Orbit (GEO)

My paper also recommends a particular orbit – the orbits in the Laplace Plane where the balance of the pressure of sunlight and of gravity is such as to keep debris from satellites in the same orbit as for a ring plane. I cover this in my paper under

- An orbit within the Laplace plane above GEO contains debris in event of an off nominal explosion or other events

NASA have made no significant changes in their safety assessments in response to objections made in previous requests for comments

So far NASA don't seem to have made any modifications of their plans as a result of the comments on the previous round of NEPA comments including my own previous comment and many others.

This latest submission doesn't include any changes to their assessments of the risks.

Compare the "Safety of MSR" in the Nov 4 project fact sheets
With: MSR Safety Fact Sheet 4-18-22 in the April 18th project fact sheets.

The changes are only cosmetic, minute changes in grammar and phrasing. This is the part I'll focus on here, which in a short paragraph has many serious omissions that I mentioned in the uploaded paper attached to my previous comment as part of the NEPA process. Other commentators there also pointed out some of these omissions.

The one on the left is the one from April 18, the one on the right is from Nov 4.

Assessing the Risks	Assessing the Risks
The question of whether samples from Mars could present a hazard to Earth’s biosphere has been studied by several different panels of scientifc experts from the United States and elsewhere over the past several decades.	The question of whether samples from Mars could present a hazard to Earth’s biosphere has been studied by several different panels of scientifc experts from the United States and elsewhere over the past several decades.
The reports from these panels have found an extremely low likelihood that samples collected from areas on Mars like those being explored by Perseverance could possibly contain a biological hazard to our biosphere.	The reports from these panels have found an extremely low likelihood that samples collected from surface areas on Mars like those being explored by Perseverance could possibly contain a biological hazard to our biosphere.
Multiple different sources of scientifc evidence contribute to this assessment. The evidence includes the absence of any observed harm to Earth’s environment from Martian rocks that frequently fall to Earth in the form of meteorites, and the fact that the Mars samples being gathered by NASA’s Perseverance Mars rover are from the frst few inches of a planetary surface that is very dry and highly irradiated naturally by the Sun, which would sterilize all known active biology. (This is part of why NASA’s science strategy is focused on fnding traces of ancient life from long ago, when the Martian environment was wetter and warmer, and not modern life in these harsh conditions).	Multiple different sources of scientifc evidence contribute to this assessment. This evidence includes the absence of any observed harm to Earth’s environment from Martian rocks that frequently fall to Earth in the form of meteorites. Additionally, the Mars samples being gathered by the Perseverance rover are from the frst few inches of a planetary surface that is very dry and exposed to high levels of harsh natural radiation. These conditions are not compatible with active biology. This is one of the reasons NASA’s science strategy is focused on fnding traces of ancient life from long ago, when the Martian environment was wetter and warmer, and more hospitable than today’s severe conditions.

I used the diff tool here to highlight the differences in the text obtained with copy / paste from the pdfs.

If NASA continue ignore objections they will be stopped just as for projects that push through a new pipeline on tribal lands in the USA or any other project where Federal agencies don’t do a proper risk assessment and ignore objections.

The usual way projects are stopped is because

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

See: National Environmental Policy Act: Judicial Review and Remedies

NASA seem to be failing on both of those.

NASA claim that the Martian surface is too inhospitable for life – but why would they need to take precautions if there is no risk? – it’s not surprising the general public aren’t convinced by these claims and from the comments clearly they are not convinced

From their NEPA announcement, (NASA, 2022nepa), NASA seem to be of the impression that the consensus amongst scientists is that the Martian surface is too inhospitable for life

“The general scientific consensus is that the Martian surface is too inhospitable for life to survive there today. It is a freezing landscape with no liquid water that is continually bombarded with harsh radiation.”

This is an unconvincing approach for the general public. It’s not working for them.

The very fact that they are taking these precautions at all shows that they have to think there is some possibility of life there.

From the first 18 comments on the November 4th request, two were off topic and the 16 on topic responses were:

- Test first: 5
- Stop mission: 5

Then one each of

- Study in space or not at all
- Don't return until we know it is 100% safe
- Are you certain the mission is safe?
- Return to above GEO and return sterilized subsamples immediately [my comment]
- Need clarity about security measures

From the comments, the general public naturally don’t find their statement convincing, and nor should they be. In reality clearly NASA are NOT sure, or they wouldn’t need to take all these elaborate precautions.

Rather than a consensus that Mars is sterile, I couldn’t find one astrobiologist in the literature who says as definitive things about impossibility of present day life on Mars as NASA do.

It is hard to find even one astrobiologist who would agree with NASA in their confidence that the Martian surface is too inhospitable for microbial life, and some astrobiologists say there is a significant possibility of present day life even in Jezero crater

In the case of Mars, it is hard to find even one astrobiologist who goes as far as NASA’s statement. Some think it has a high chance to be inhospitable but not certainty and many think Mars may have small niches suitable for life, similar to niches found in the soil or rocks of our driest coldest deserts which often have small communities of microbes, even if they are only habitable at microbial scales. Many also think it could have extant Martian life. A few think there is a possibility that Viking discovered life in the 1970s. This quote is from a paper about planetary protection in the forwards direction by Rummel and Conley, both former planetary protection officers for NASA (Rummel et al , 2014)

"Claims that reducing planetary protection requirements wouldn't be harmful, because Earth life can't grow on Mars, may be reassuring as opinion, but the facts are that we keep discovering life growing in extreme conditions on Earth that resemble conditions on Mars. We also keep discovering conditions on Mars that are more similar—though perhaps only at microbial scales—to inhabited environments on Earth, which is where the concept of Special Regions initially came from."

In the 2020 conference **"*Mars extant life: what's next?*"** (Carrier et al, 2020) a significant fraction of the participants thought that there is a possibility Mars has extant life.

"Primary conclusions are as follows: A significant subset of conference attendees concluded that there is a realistic possibility that Mars hosts indigenous microbial life. A powerful theme that permeated the conference is that the key to the search for martian extant life lies in identifying and exploring refugia ("oases"), where conditions are either permanently or episodically significantly more hospitable than average. Based on our existing knowledge of Mars, conference participants highlighted four potential martian refugium (not listed in priority order): Caves, Deep Subsurface, Ices, and Salts."

For more example quotes from the literature, see section in my paper:

- Views of astrobiologists on the possibility of present-day life on or near the surface

NASA make statements that contradict important conclusions from previous studies by the National Research Council and others - and as a result fail to properly consider the weight of the impacts under review

NASA don't cite the European Space Foundation study from 2012, or the US's National Research Council study. What's more, their submitted documents don't have any cites.

Not only that, the submitted documents make statements that go against the conclusions of the peer reviewed literature on the topic which suggests they haven't read it or they ignore it.

Example, let's look at this passage from the MSR safety fact sheet from this page,

Draft Environmental Impact Statement:

The question of whether samples from Mars could present a hazard to Earth's biosphere has been studied by several different panels of scientific experts from the United States and elsewhere over the past several decades.

[this much is true]

The reports from these panels have found an extremely low likelihood that samples collected from areas on Mars like those being explored by Perseverance could possibly contain a biological hazard to our biosphere.

The most recent of the thorough Mars sample return studies, from the European Space Foundation in 2012:

"The risks of environmental disruption resulting from the inadvertent contamination of Earth with putative martian microbes are still considered to be low. But since the risk cannot be demonstrated to be zero, due care and caution must be exercised in handling any martian materials returned to Earth"

NASA's Draft Environmental Impact Statement again

The evidence includes the absence of any observed harm to Earth's environment from Martian rocks that frequently fall to Earth in the form of meteorites,

National Research Council report in 2009 said [(Board et al, 2009: 48).]:

Section: Potential for large scale effects [of a Mars Sample Return]
"The potential hazards posed for Earth by viable organisms surviving in samples is significantly greater with a Mars sample return than if the same organisms were brought to Earth via impact-mediated ejection from Mars

…Certainly in the modern era, there is no evidence for large-scale or other negative effects that are attributable to the frequent deliveries to Earth of essentially unaltered Martian rocks. However the possibility that such effects occurred in the distant past cannot be discounted."

NASA's Draft Environmental Impact Statement again

and the fact that the Mars samples being gathered by NASA's Perseverance Mars rover are from the frst few inches of a planetary surface that is very dry and highly irradiated naturally by the Sun, which would sterilize all known active biology.

The Review from 2015: ([Board, 2015)]

There are many examples of small-scale and microscale environments on Earth … that can host microbial communities, including biofilms, which may only be a few cell layers thick. The biofilm mode of growth, as noted previously, can provide affordable conditions for microbial propagation despite adverse and extreme conditions in the surroundings.

So, let’s go into this in more detail

In 2009, the National Research Council examine the possibility of life transferred on meteorites and say they can’t rule out the possibility of large scale effects in the past due to life from Mars, and say potential hazards are significantly greater with a sample return – in their EIS, NASA don’t mention this and may be either unaware of it or ignore it

Let’s look at the first of these two statements NASA use to support their conclusion that the activity is very low risk, from the MSR safety fact sheet from this page:

> The evidence includes the absence of any observed harm to Earth’s environment from Martian rocks that frequently fall to Earth in the form of meteorites,

The National Research Council DID look into this question in their "Assessment of Planetary Protection Requirements for a Mars Sample Return". However their conclusion was the opposite of the NASA summary.

They were unable to rule out the possibility that life from Mars could have caused past mass extinctions on Earth

The NRC found that most of the meteorites that get to Mars are sterilized during transit. But about 1% get here within 16,000 years and 0.01 percent within 100 years (note none of the meteoirites we have from Mars left the planet less than hundreds of thousands of years ago)

This is from Earth (Board et al, 2009: 48).

> "*Transit to Earth may present the greatest hazard to the survival of any microbial hitchhikers. Cosmic-ray-exposure ages of the meteorites in current collections indicate transit times of 350,000 to 16 million years. However theoretical modeling suggests that about 1 percent of the materials ejected from Mars are captured by Earth within 16,000 years and that 0.01 percent reach Earth within 100 years.*

NRC continue that survival of organisms in meteorites is plausible. If they can be shown to survive ejection, entry and impact they can be expected to transfer from Mars to Earth.

> *“Thus, survival of organisms in meteorites, where they are largely protected from radiation, appears plausible. If microorganisms could be shown to survive conditions of ejection and subsequent entry and impact, there would be little reason to doubt that natural interplanetary transfer of organisms is possible and has, in all likelihood, already occurred.*

However that is the big unknown. Can life from present day Mars get onto the meteorites, be ejected from Mars, and then survive the fireball of re-entry to Earth.

The meteorites we have on Earth all came from at least 3 meters below the surface of Mars. The proposed habitats for present day Mars are on the surface in dust and brine layers. How is life in those layers going to get into a rock at least 3 meters below the surface? Then there's the shock of ejection and the fireball of re-entry to Earth.

I go into that in my paper in the section:

- **Could Martian life have got to Earth on meteorites? Our Martian meteorites come from at least 3 m below the surface in high altitude regions of Mars Error! Bookmark not defined.**

The NRC continue that any microbes in the martian materials transported to Earth in a sample return mission face very different conditions from those in meteorites.

> *It should be noted that martian materials transported to Earth via a sample return mission will spend a relatively short time (less than a year) in space - all the while protected in containers. (Note that researchers have yet to discover compelling evidence of life in any meteorite, martian or otherwise.) Thus the potential hazards posed for Earth by viable organisms surviving in samples is significantly greater with a Mars sample return than if the same organisms were brought to Earth via impact-mediated ejection from Mars.*"

They go on to say that it is simply not possible to determine whether viable Martian life forms have already been delivered to Earth.

They also say that though there is no evidence of large scale or other negative effects (such as extinctions) in the modern era due to the frequent deliveries of Martian rocks, that it is not possible to discount such effects in the distant past.

> *"Despite suggestions to the contrary, it is simply not possible, on the basis of current knowledge, to determine whether viable Martian life forms have already been delivered to Earth. Certainly in the modern era, there is no evidence for large-scale or other negative effects that are attributable to the frequent deliveries to Earth of essentially unaltered Martian rocks. However the possibility that such effects occurred in the distant past cannot be discounted."*

That's in their section 5, Potential for Large Scale Effects, page 48:

NASA summarize this INCORRECTLY as

> The reports from these panels have found an extremely low likelihood that samples collected from areas on Mars like those being explored by Perseverance could possibly contain a biological hazard to our biosphere.
>
> …
>
> The evidence includes the absence of any observed harm to Earth's environment from Martian rocks that frequently fall to Earth in the form of meteorites

NASA fail to consider the potential for microhabitats in Jezero crater not detectable from orbit

It's the same for the second half of that INCORRECT paragraph.

> **, and the fact that the Mars samples being gathered by NASA's Perseverance Mars rover are from the first few inches of a planetary surface that is very dry and highly irradiated naturally by the Sun, which would sterilize all known active biology.**

Microbes can make use of habitats with small amounts of water and they may be able to modify them to make them habitable. The surface is indeed very dry but not totally dry. Curiosity found that brines form there regularly in the early morning or late in the evening.

The UV from sunlight is blocked by a few millimeters of dust and the ionizing radiation is only an issue for microbes that are dormant for millennia. Life in surface habitats would likely revive every year at the appropriate season for growth.

Curiosity has already found a cold brine layer in equatorial sand dunes (Martin-Torres et al, 2015) a few cm below the surface. Nilton Renno has suggested this could be habitable to a biofilm that can regulate its microhabitat, for instance, retain the water through to warmer conditions in daytime (Nilton Renno cited in Pires, 2015).

Then some think the Viking lander found life on Mars already in the 1970s. This was revived with the discovery of rhythms that resemble arcadian rhythms in the carbon emission in gases (CO2 or methane) when the old data was re-analysed. They were offset by two hours, too much to explain easily with simple chemistry. It is either very complex and not well understood chemistry or biology. Either way it needs further study.

I go into some of the proposed habitats that could occur in Jezero crater in in my paper under

- **Suggested sources for native life in equatorial regions such as Jezero crater include local microhabitats such as salty brines, and spores in windblown dust –**

while the dust and salts are not likely to be transferred to Earth via asteroid impacts

- **Puzzles from the Viking landers – why some think Viking detected life already in the 1970s – evolved gases in the labelled release experiment offset from temperature fluctuations by as much as two hours, more typical of a circadian rhythm than a chemical reaction**

The 2015 review overturned the suggestion from the 2014 review that areas not of Planetary Protection concern can be delineated using maps. A similar situation arose with the 2020 review which overtunred the suggestion from the 2019 review that these areas can be deliniated using maps.

These studies weren't looking at Martian life particularly but rather at whether terrestrial life could survive on Mars. But Martian life if anything is likely to be more adapted to Martian conditions than terrestrial life.

I go into this in in my paper under:

- **2020 Review committee modified recommendations of 2019 report, saying our knowledge is not yet sufficient to classify parts of Mars as suitable for an unsterilized Category II mission in the forward direction – agrees on need to protect Earth in backwards direction**

And

- **Similar situation in 2014 / 2015: 2014 report said maps can identify areas of Mars of planetary protection concern in the forwards direction then 2015 review modified those recommendations, saying maps can't yet be used – due to knowledge gaps on survival of terrestrial life in dust storms and potential for life to survive in microhabitats hard to detect from orbit**

This is what the 2015 study says

First that terrestrial life could transfer to dispersed small-scale habitats on Mars. They might also be able to alter the local environmental parameters (this would include retaining water from night to day time as it gets warmer) and be able to get transferred to other parts of Mars. Microbes could also form communities where they exchange metabolites cooperatively to increase their survival. (Board, 2015)

> *In particular, the issues of translocation of terrestrial contamination and the behavior of multispecies populations in extreme environments, produce uncertainty in the*

determination of Special Regions, because such regions might not be isolated from the rest of the planet (translocation), because microbial communities could occupy dispersed, small-scale habitats or might be able to alter local environmental parameters and syntrophic consortial interactions

[**syntrophic interactions:** where microbes exchange metabolites in an overall combined metabolism that wouldn't be feasible for either species individually (Seiber at al, 2010)

These issues, together with the present lack of knowledge about the limits of life on Earth and the uncertainty of the relationship between the large-scale and micro-scale environments at any given place make the definition of Special Regions difficult.

They also say that these potential small scale microbial habitats may not be detectable from orbit. They may be only a few cell layers thick in a biofilm, even with adverse and extreme conditions that surround the biofilm.

Detectability of Potential Small Scale Microbial Habitats

There are many examples of small-scale and microscale environments on Earth … that can host microbial communities, including biofilms, which may only be a few cell layers thick. The biofilm mode of growth, as noted previously, can provide affordable conditions for microbial propagation despite adverse and extreme conditions in the surroundings. On Earth, the heterogeneity of microbial colonization in extreme environments has become more obvious in recent years.

Also we need a better understanding of temperature and water activity of potential microenvironments. We still have very limited data on this, as the emphasis has been on study of geology, not microhabitats.

To identify Special Regions across the full range of spatial scales relevant to microorganisms, a better understanding of the temperature and water activity of potential microenvironments on Mars is necessary.

…

Craters, and even microenvironments underneath and on the underside of rocks, could potentially provide favorable conditions for the establishment of life on Mars, potentially leading to the recognition of Special Regions where landscape-scale temperature and humidity conditions would not enable it.

NASA fail to consider potential for dust storms to transfer life to Jezero crater

Continuing to comment on the second half of that INCORRECT paragraph.

, and the fact that the Mars samples being gathered by NASA's Perseverance Mars rover are from the first few inches of a planetary surface that is very dry and highly irradiated naturally by the Sun, which would sterilize all known active biology.

NASA don't mention that the sample tubes will also be covered in dust – indeed this is considered to be part of the sample return. NASA originally planned a dust sample, but instead decided to just rely on whatever dust gets attached to the outside of the sample tubes before collection.

The dust may come from distant parts of Mars and potentially might contain viable spores. The sample tubes are left on the surface for the sample fetch rover to pick up which means they will have at least one side in shadow not sterilized by the UV light. The windblown dust is protected from UV especially during dust storms as well as any microbes that are imbedded in cracks in the dust which is made of iron oxide and blocks out UV.

The 2015 study considers various ways that microbes could be transferred to distant regions of Mars. The most likely is through the dust (Board, 2015)

A potential problem with designating Special Regions on Mars is that viable microorganisms that survive the trip to Mars could be transported into a distant Special Region by atmospheric processes, landslides, avalanches (although this risk is considered minimal), meteorite impact ejecta, and lander impact ejecta. In addition to dilution effects, the flux of ultraviolet radiation within the martian atmosphere would be deleterious to most airborne microbes and spores.

The dust attenuates UV radiation (this is especially true during a dust strom when it can turn day into night).

Also microbes often grow in cell changes, clusters or aggregates and inner cells are protected against UV.

However, dust could attenuate this radiation and enhance microbial viability. In addition, for microbes growing not as single cells but as tetrades or larger cell chains, clusters, or aggregates, the inner cells are protected against ultraviolet radiation. Examples are methanogenic archaea like Methanosarcina, halophilic archaea like Halococcus, or cyanobacteria like Gloeocapsa. This is certainly something that could be studied and confirmed or rejected in terrestrial Mars simulation chambers where such transport processes for microbes (e.g., by dust storms) are investigated. The SR-SAG2 report does not adequately discuss the transport of material in the martian atmosphere.

These studies on transfer of microbial life in Martian dust storms in Mars simulation chambers don't seem to have been done. At least I found almost nothing in my literature search and what I found has nothing new by way of citations. This seems to remain a recommendation to follow up in the future.

It is not easy to simulate a dust storm. Also it will be hard to do this accurately until we have samples of the dust to examine closely either on Mars in situ or nearer to home.

Also this is just for terrestrial life. Martian life may have developed special adaptations to spread in dust storms.

In in my paper, I look into this in the sections:

- Could Martian life be transported in dust storms or dust devils, and if so, could any of it still be viable when it reaches Perseverance?
- Native Martian propagules of up to half a millimeter in diameter (including spore aggregates and hyphal fragments) could travel long distances with repeated bounces (saltation) - if they can withstand the impacts of the bounces
- Martian spores could evolve extra protection such as a shell of agglutinated iron oxide particles to protect themselves from UV
- Martian life could also use iron oxides from the dust for protection from the impact stresses of the saltation bounces - or it might use chitin - a biomaterial which is extremely hard and also elastic and is found in terrestrial fungi and lichens

NASA plan to use a biosafety level 4 facility to handle the samples – but how can they know that a BSL-4 facility designed to contain infectious diseases of humans will work to protect Earth's biosphere from extraterrestrial ultramicrobacteria or the potentially even smaller nanobes such as ribocells that may have preceded terrestrial life? The answer is they don't – they seem unaware of the research saying a higher standard is needed

From the Mars Sample Return Planning Group 2 MSPG2 (Meyer et al, 2022) the design and construction of the Sample Receiving Facility is considered to be complete when it is certified to BSL-4 standard.

> SRF commissioning (at least 2 years prior to Earth Return) –the design and construction of the SRF as a biocontainment facility ends with Biosafety Level 4 (BSL-4) certification; start of test and training phase for the SRF functionalities not related to the biocontainment function

There is no mention of the European Space Foundation report in their list of references or any justification for using BSL-4 to handle extraterrestrial samples. Just argument by analogy that it's used for infectious diseases. Which is a very different situation from having to contain possibly starvation limited ultramicroabacteria and possibly even riobocells, RNA world cells with a different biology from terrestrial life.

It is clear that this is something that needs to be looked at. Whether extraterrestrial life needs better than BSL-4. The European Space Foundation did look at this. But it doesn’t have any discussion of how their requirements compare with the requirements for a BSL-4 laboroatory.

But a closer look reveals that the ESF requirement is not only well beyond BSL-4 standards. It is beyond the standards of any currently available technology. New technology will need to be developed to handle its requirements.

NASA don’t seem aware of the 2012 ESF study’s size limit requiring 100% containment at 0.05 microns or the need for regular review

This seems to extend to theh Mars Sample

The European Space Foundation study summarizes their conclusions in this figure (Ammann et al, 2012:14ff). :

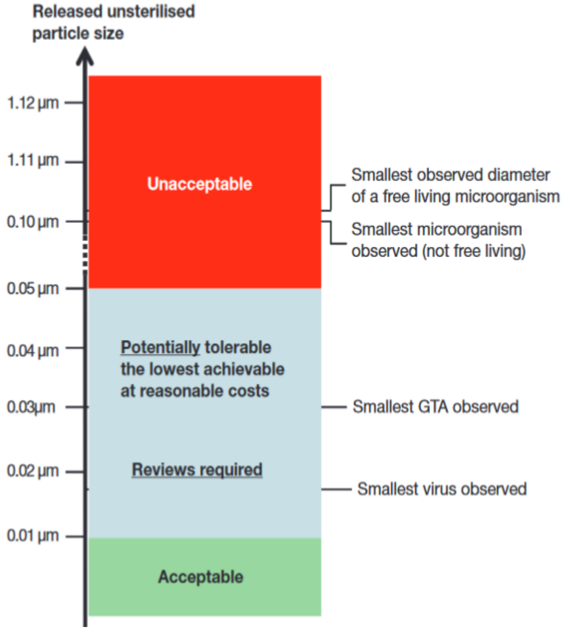

Figure 5: ESF summary of containment requirements

The report concluded that

> *"the release of a particle larger than 0.05 µm in diameter is not acceptable in any circumstances"* (Ammann et al, 2012:21).

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}.

If the size requirement cannot be met without decreasing the overall level of assurance for the non-release of such a particle, the release of a single unsterilised particle of up to 0.05 µm can be considered as a potentially tolerable systems-level adjustment, assuming that it has been demonstrated that this size is the lowest achievable at a reasonable cost.

In such a case, the actual maximum particle size potentially released (as planned from design) would have to be independently reviewed by interdisciplinary groups of international experts to determine:

- whether this size value is the best reasonably achievable at a reasonable cost,

And, if yes:

- taking into consideration the latest scientific developments in the fields of astrobiology, microbiology, virology and any other relevant discipline, whether the release of such a particle can be considered as tolerable.

The release of a single unsterilised particle larger than 0,05 µm is not acceptable under any circumstance.

Figure 9: screenshot from the ESF report

"The probability that a single unsterilized particle of 0.01 micron diameter or greater is released into the Earth's environment shall be less than one in a million"

"Release of a single unsterilized particle at 0.05 microns is not acceptable under any circumstances"

Note, the ESF defines their one in a million as the probability of release of A SINGLE UNSTERILIZED PARTICLE of 0.01 microns. This means over the ENTIRE LIFETIME of the facility.

We don't have the technology to do this yet in any of our filters. I go into this in detail in in my paper under:

- **Example of best available nanofilter technology from 2020, not yet commercially available, filters out 88% of ambient aerosol particles at 0.05 microns - far short of the ESF requirement to filter out 100% at this size – though the ESF requirement at 0.05 microns can be met with nanoparticles in water under high pressure**

By the ESF study NASA or ESA should have required a new size limits review by now, and they haven't. Even though ESA is a full partner in the mission now, NASA don't seem to be aware even of the headline requirement of the ESF study that no particle of 0.05 microns should be released under any circumstances. I say this because they say that a BSL-4 facility is sufficient to handle the samples.

A BSL-4 facility doesn't comply with this limit – and the technology to filter out 100% of aerosol particles at 0.05 microns doesn't yet exist except for nanoparticles in water under high pressure

A BSL-4 facility can't comply with these requirements.

I cover this in my paper under

- HEPA and ULPA filters are not tested for such small particles as 0.05 microns and not required to contain them
- Example of best available nanofilter technology from 2020, not yet commercially available, filters out 88% of ambient aerosol particles at 0.05 microns - far short of the ESF requirement to filter out 100% at this size – though this standard can be met with nanoparticles in water under high pressure

The size limit needs to be reviewed regularly – and in 2022 it is definitely necessary to review a limit set in 2012

The ESF study said that future reductions in the size limit are possible. They expected later reductions to happen at a slower pace, but say the size limit will need to be reviewed in the future, adding (Ammann et al, 2012:21):

> *Based on our current knowledge and techniques (especially genomics), one can assume that if the expected minimum size for viruses, GTAs or free-living microorganisms decreases in the future, and this is indeed possible, it will be at a slower pace than over the past 15 years*
>
> *However, no one can disregard the possibility that future discoveries of new agents, entities and mechanisms may shatter our current understanding on minimum size for biological entities. As a consequence,* ***it is recommended that the size requirement as presented above is reviewed and reconsidered on a regular basis.***
> *[bolding as in original cited text]*

The minimum size for filters to contain Marian biology was reduced from 0.25 microns to 0.05 microns / 0.01 microns in just three years from 2009 to 2012.

By 2020, eight years later, another review is certainly required.

NASA’s Environmental Impact Statement is vulnerable to litigation on the basis that it doesn’t consider impacts of a sample return properly, doesn’t take account of the main issues mentioned by the Sample Return Studies and say things that contradict their conclusions – potential remedies include stopping the mission altogether or an injunction, e.g. to sterilize all samples before they contact Earth’s biosphere

NEPA doesn’t provide for judicial review directly. But it’s often a ground for litigation on the basis that the process hasn’t been carried out properly, For instance judicial review can be requested because

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

During the litigation the court can issue injunctions that

- bar all or part of a proposed action

The result of the court case is usually

- referred back to the agency (such as NASA) for further proceedings - and the court can say what those are
- It can order equitable relief which vacates the action - i.e. stops the project going ahead
- Or issue some other action.

National Environmental Policy Act: Judicial Review and Remedies

The courts can just stop the whole thing - or they could require some injunction on NASA.

In the case of the NASA proposals, if they don’t do a proper assessment, one likely injunction might be that NASA have to sterilize all samples returned to Earth until proven to be safe, if they assess that NASA haven't taken account of all possible impacts or they haven't sufficiently considered the weight of the impacts.

Then there is a similar process in Europe, which ESA will have to go through for their sample fetch rover. That starts with the Directive 2001/42/EC of the European Commission.

However I haven't seen any academic papers on how the Mars sample return legal process would work out in Europe.

Generally it wouldn't stop in the USA. If all domestic agencies were satisfied, and if the European Comission are satisfied, there are still many international treaties that are relevant.

I go into this in much more detail in my paper.

I have copied over some of the sections here,

The legal process is likely to extend well beyond 6 years with involvement of CDC, DOA , NOAA, OSHA etc., legislation of EU and members of ESA, international treaties, and international organizations like the World Health Organization – NASA don't seem to be prepared for this or even mention potential international ramifications

There is potential for many delays in the legal process. Six years from filing the EIS is the bare minimum. The legal process in the USA starts with the EIS (EPA, n.d.). First, since there is a potential for damage to Earth's environment, various executive orders mandate NASA itself, as a federal agency, to consider such matters as (NASA, 2012fdg):

- impact on the environment,
- impact on the oceans,
- impact on the great lakes,
- escape of invasive species,
- lab biosecurity against theft

After the environmental impact statement is filed, Uhran et al mention many other agencies likely to declare an interest such as the (Uhran et al, 2019) (Meltzer, 2012:454)

- CDC (for potential impact on human health),
- Department of Agriculture (for potential impact on livestock and crops),
- NOAA (for potential impact on oceans and fisheries after a splashdown in the sea)
- Occupational Safety and Health Administration, to consider questions of quarantine if a scientist or technician gets contaminated by a sample

- Department of Homeland Security,
- Federal Aviation Administration because the sample returns through the atmosphere
- Department of Transportation for bringing the sample to the receiving laboratory from where it touches down and to distribute to other laboratories
- Occupational Safety and Health Administration - for any rules about quarantine for technicians working at the facility
- U.S. Customs and Border Protection and the Coast Guard to bring back sample in case of an water landing or the Department of Defense if it lands on land, likely the Utah Test & Training Ranges
- Department of the Interior which is the steward for public land and wild animals which could be affected by release of Martian microbes
- Fish and Wildlife Service for the DoI who maintain an invasive species containment program and may see back contamination as a possible source of invasive species
- National Oceanic and Atmospheric Administration (NOAA)'s fishery program for sea landing in case it could affect marine life and NOAA fisheries
- Integrated Consortium of Laboratory Networks (ICLN) for laboratories that respond to disasters - a partnership of the Department of Agriculture, Department of Defense, Department of Energy, Department of Health and Human Services, Department of Homeland Security, Department of the Interior, Department of Justice, Department of State, and Environmental Protection Agency
- The state where the receiving laboratory is stationed may have regulations on invasive species, environmental impacts, disposal of waste, and possession of pathogens, similarly also for any states the sample may have to transit to from the landing site to the facility

As the process continues it is possible to stop the activity. It's the same process that is used for instance. to stop oil pipelines across tribal lands in the USA or almost any US environmental legal action.

The Congressional Research Service explains (Congressional Research Service, 2021) that NEPA doesn't provide for judicial review directly. But it's often a ground for litigation on the basis that the process hasn't been carried out properly.

For instance judicial review can be requested because

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

During the litigation the court can issue injunctions that

- bar all or part of a proposed action

The result of the court case is usually

- referred back to the agency (such as NASA) for further proceedings - and the court can say what those are
- It can order equitable relief which vacates the action - i.e. stops the project going ahead
- Or issue some other action.

The “ordinary” remedy is to just vacate the Federal action so it can’t go ahead, but the courts consider the “seriousness” of the deficiencies in the EIS and the “disruptive consequences” of vacating the action (Congressional Research Service, 2021).

So the courts can just stop the whole thing - or they could require some injunction on NASA. In this case, one example injunction might be that NASA have to sterilize all samples returned to Earth until proven to be safe, if they assess that NASA haven’t taken account of all possible impacts or they haven’t sufficiently considered the weight of the impacts.

Meanwhile, since this is a joint NASA / ESA mission, it involves ESA. Most of the ESA member states are in the EU (ESA, n.d.MS) so the EU will get involved.

This leads to a separate legal process in Europe, starting with the Directive 2001/42/EC (EU, 2001). I haven’t located any academic reviews for the European process, but as for the case in the USA, this would spin off other investigations which would involve the European Commission (Race, 1996).

The UK, as a member of ESA but not in the EU, might also be involved in a separate process with its domestic laws. Canada also sits on the governing council of ESA, so perhaps may get involved. These countries are all members of ESA and also all potentially impacted by an adverse outcome.

However it wouldn’t stop at the USA and ESA. All other countries are potentially impacted in the worst case. These potential impacts on the environment of Earth, and on human health world-wide bring many international treaties into play (Uhran et al, 2019),

> ***In an address given to the Space Studies Board Task Group on Issues in Sample Return in 1996, attorney George Robinson presented a list of 19 treaties or international conventions and 10 domestic categories of law, including the rights of individual states and municipalities to quarantine, that may affect return missions***

[Need to find out more details here]

Also several international organizations are likely to be involved such as the WHO (Uhran et al, 2019).

We will see below that the very worst case scenarios involve degradation of Earth’s environment (such as by mirror life).

It seems unlikely that these worst case scenarios would be ignored as the legal proceedings continue. If the legal discussions expand to focus on these scenarios, this could involve many other organizations.

The Food and Agriculture Organization (UN, 1945) could become involved, especially if the potential for alien exobiology such as mirror life is considered, because of potential impact on agriculture and fisheries and global food supplies, and the World Health Organization because of effects on human health globally if a new organism is returned that can be spread to other countries.

In the USA, the Environmental Protection Agency partners with the United Nations Environment Program (UNEP), and Arctic Council, so they'd likely get involved (EPA, n.d.pwio).

Indeed, there would be few aspects of human life that would not be relevant in some way in discussions of the very worst case scenarios. As the legal process continues, surely there would be open public debate about these scenarios, and if the discussion expands in this way, potentially it might lead to much wider involvement in the international community. It would be necessary to convince the public, and interested experts in all these agencies that this is a safe mission and that all their concerns have been answered.

Race (Race, 1996) says that experts will have challenges deciding in advance whether the sample should be classified as potentially:

- an infectious agent
- an exotic species outside its normal range
- a truly novel organism (as for genetic engineering)
- a hazardous material

The choices here would change which laws and agencies would be involved.

Presidential directive NSC-25 requires a review of large scale effects which is done after the NEPA process is completed. (Race, 1996)

There are numerous treaties conventions and international agreements relating to environmental protection or health that could apply.

Including those to do with (Race, 1996)

- protection of living resources of the sea
- air pollution (long range pollution that crosses country boundaries)
- world health, etc

Individual groups in other countries could invoke domestic laws such as laws on accidents at sea or on land if they argue back contamination of Earth can cause measurable damage. (Race, 1996)

Race says scientists are likely to focus on (Race, 1996)

- technical details
- mission requirements
- engineering details
- costs of the space operations and hardware

General public are likely to focus on

- risks and accidents
- whether NASA and other institutions can be trusted to do the mission
- worst case scenarios
- whether the methods of handing the sample, quarantine and containment of any Martian life are adequate

Six to seven years seems a bare minimum to complete all this. Any addition to the legal process would push the sample return date further back than 2039.

Uhran et al recommend an advanced planning and oversight agency set up two years before the start of the legal process – similarly Rummel et al recommend it should include experts in legal, ethical and social issues – and the ESF recommends an international framework should be set up, open to representatives from all countries - NASA don't seem to have done any of this yet

NASA and ESA clearly didn't 'do this or they would have produced a much more thorough EIS and would have engaged in far more outreach to the general public before submitting the EIS.

With so much to be sorted out, Uhran et al recommended that an oversight agency should be set up long before the legal process starts. Uhran et al recommend this is done two years before filing the environmental impact statement to develop a consensus position on the margin of safety for sample containment (Uhran et al, 2019).

Since the aim is to develop a consensus position, this would need to be based on up to date information. So it would need to include the review of the size limits required in the ESF sample return study (Ammann et al, 2012:PG). The current paper suggests the need to review filter technology and provide a preliminary study of the technological advances needed to achieve the specified size limits, since the technology doesn't seem to exist yet.

Similarly Rummel et al advise that clear communication with the public is essential from an early stage, for success of the mission. They recommend that this should avoid a NASA centric focus and include links with other government agencies and international partners and external organizations (Rummel et al, 2002).

Rummel et al warn that the mission might attract viral sharing of misinformation, a concern that now seems similar to the "infodemic" for COVID19. Potentially the sample return mission, and the facility, could also attract intentionally disruptive events, by bioterrorists, or by members of the public opposed to sample return (Rummel et al, 2002). Perhaps this may need to be managed based on the emerging discipline of infodemiology (WHO, 2020wic).

Rummel et al say that the oversight committee would need to contain experts in legal, ethical and social issues in addition to the experts in astrobiology, space engineering and mission planning. It should conduct ethical and public reviews. Broad acceptance by the public is essential at an early stage for success of the mission (Rummel et al, 2002).

Similarly the ESF recommends that since negative consequences from an unintended release could be borne by countries not involved in the program, a framework should be set up at the international level open to representatives of all countries, with mechanisms and fora dedicated to ethical and social issues of the risks and benefits from a sample return (Ammann et al, 2012:59). This again would be best done before the start of the legal process to make sure everyone is on the same page before it starts.

NASA did set up a review board for sample return missions on August 14th 2020 (NASA, 2020nebmsr). However, it is not clear yet what its scope is. It is not clear whether it will consider these wide ranging issues, or include experts in legal, ethical and social issues, as recommended by Rummel et al.

From the content of the draft EIS and the reactions in comment replies, it seems unlikely that these issues have been considered.

The legal process and public debate for NASA's mission as precedent for China's mission to return a sample too – perhaps as soon as 2030 – with sterilization a likely solution for a country that wants to be first to return a sample

China currently plans to launch a mission possibly as soon as 2028, to return a sample by 2030. It would consist of two rockets, one with a lander and ascent vehicle, and the other with an orbiter and reentry capsule to return the sample to Earth, using two Long March rockets (Jones, 2021)

China had one of the most rigorous of all responses to the COVID pandemic. Professor Bruce Aylward, leader of the joint team that studied their response (McNeil, 2020) put it like this in the press briefing about their findings (United Nations, 2020)

> ***They [the Chinese] approached a brand new virus [that] has never been seen before that was escalating and quite frightening in January … and they have taken***

very basic public health tools … and applied these with a rigor and an innovation of approach on a scale that we've never seen in history

If China considers the Mars sample return to be potentially hazardous it is likely to be especially careful just as it has been especially careful with COVID.

The debate that is sure to happen with the NASA mission will help bring widespread awareness of the issues of a sample return and the need to be careful.

China’s mission is far simpler than the NASA one and similar to the proposal for NASA by the astrobiologist Chris McKay for a mission that does no more than land, gather a scoop of dirt and immediately return, see Sample return as a valuable technology demo for astrobiology – and proposals to keep the first sample returns simple, a scoop of dirt or skimming the atmosphere to return micron sized dust samples

China's first mission may have a higher chance of returning present day life than the NASA mission as currently envisioned - because they plan to scoop up some dirt which could have viable spores from dust storms, or the life that Viking detected (if it did find life).

Perhaps China may be able to accelerate their legal process or bypass elements of it though they would still have the international treaties and responses of international organizations and other countries to deal with.

However, once this topic enters public debate widely, the public can be expected to raise many issues as NASA has already seen with the comments so far on their draft environmental impact statement (NASA, 2022msrc).

The general public in Chinese likely raise similar issues, which would get the attention of leaders in China, given their recent experience of COVID and the high level of importance they assign to matters of public health.

NASA can’t accelerate the legal process to achieve an unsterilized sample return before 2039 – but it could “win” this race with a sterilized return or unsterilized return to a safe orbit with sterilized subsamples returned to Earth – inspiring China and other nations to do the same

It’s possible this could turn into a space race similarly to the races between the Soviet Union and USA in the 1960s, but with an easy win available to China due to the complexity of the NASA mission and the comparative simplicity of the Chinese mission.

If this turns into a space race with NASA competing with China, NASA can't accelerate the legal process to “win the race” with an unsterilized return before 2030.

However, NASA can accelerate its timeline if they do a sterilized return or a return to a safe orbit and sterilized subsamples, as that has almost no legal process.

They could do that by 2033 with their current timetable.

Another way that NASA could “win” the race to return a sample of Mars would be to do a separate low cost sample return such as SCIM skimming the Mars atmosphere to return micron sized “Mars rocks” from dust storms, or Chris McKay’s “grab a sample of dirt and return”. NASA could have done either of those a decade ago or more.

It would likely be hard for NASA to find the budget for an extra sample return mission in competition with existing programs, but if Congress authorized the expenditure, they could do such a mission very quickly, and with their previous experience and expertise, surely faster than China, if they see China as “winning” the race to be first to return a sample.

See:

- Sample return as a valuable technology demo for astrobiology – and proposals to keep the first sample returns simple, a scoop of dirt or skimming the atmosphere to return micron sized dust samples

A fast sterilized sample return, or return to a safe orbit, might lead to China doing the same.

As a response to public concerns, China could use either of the solutions suggested here:

- to sterilize the sample during the return mission.
- to return it to a remotely operated satellite in a safe orbit, and sterilize some of the dirt to return to Earth for immediate study while the rest is tested for signs of life in orbit.

These wouldn't significantly impact on the prestige value of returning the first samples from Mars and they are well within China's capabilities.

For details see

- Sterilized sample return as aspirational technology demonstration for a future astrobiology mission
- **Recommendation** to return a sample for teleoperated 'in situ' study above Geosynchronous Equatorial Orbit (GEO)

If they do this, it could then become the norm for samples returned from another planet – that when you don't know if there is life in them or what form of biochemistry or exobiology might be involved, you return the samples to a safe orbit for preliminary study first, or sterilize them.

Both missions are likely to be of most interest as a technology demo to show we can return a sample from Mars, at a later stage, once we know how to select the samples intelligently. But it's not impossible either mission might return viable present day life.

Sterilization or return to a safe orbit is the simplest solution both from a practical point of view and legally.

However, we need to look in more detail into the challenges involved in an unsterilized return, since that is NASA's current proposal.

I cover this in my paper under:

- Public health challenges responding to release of an extraterrestrial pathogen of unfamiliar biology
    - Failure modes for sample containment
    - Complexities of quarantine for technicians accidentally exposed to sample materials
    - Vexing issue of authorizations to remove technicians from quarantine to treat life threatening medical incidents in hospital
    - Example of a technician in quarantine with acute respiratory distress and symptoms similar to Legionnaires' disease – a disease of biofilms and amoebae that adventitiously infects humans – and sometimes mentioned in planetary protection discussions

- Arbitrariness of technician's quarantine period for an unknown pathogen – Carl Sagan gives the example of leprosy which can take 20 years or more to show symptoms
- How do you quarantine a technician who could be a life-long symptomless super-spreader of an unknown Martian pathogen?
- Martian microbes could participate harmlessly or even beneficially in the human microbiome but harm other terrestrial organisms when the technician exits quarantine - example of wilting Zinnia on the ISS
- What if mirror life becomes part of the technician's microbiome?
- Potential for mirror life on Mars and survival advantages of mirror life competing with terrestrial life that can't metabolize mirror organics
- Similar considerations apply to astronauts returning from Mars - in some scenarios such as mirror Martian life, astronaut quarantine would be insufficient to protect Earth's biosphere
- A laboratory with the samples handled telerobotically as a solution to all these human quarantine issues – however the other problems remain and the safest way to do telerobotics is in an orbital facility with the robotics controlled remotely from Earth

NASA can greatly increase the astrobiological interest by using 100% sterile sample containers for bonus samples of atmosphere, dust and dirt on the ESA fetch rover

The result will be of far greater astrobiological interest if NASA return samples of dust, dirt and the atmosphere in sterile containers.

It is understandable that engineers were concerned about enclosing the sample tubes in some airtight sterile container that needed to be opened on Mars. If this failed then it would make the entire mission impossible.

However adding sterile containers for dust, dirt and atmospheric samples to the ESA fetch rover will have no impact on its capability to return those geological samples. For the geologists, this is a bonus sample. For astrobiologists, the returned dust, gas and dirt is of such greatly reduced interest in a non sterile container that it is worth the small risk to engineer for 100% sterility.

Also the far simpler sample collection system, especially the methods to collect a sample of atmosphere and dust, should make a sterile sample return container easier.

Perseverance's sample tubes weren't sterilized 100% leading to risk of false positives that may prevent distribution of unsterilized samples from containment – estimated 8.1 nanograms maximum organic contamination per sample tube are equivalent to 81,000 ultramicrobacteria or 160 million hypothetical RNA world mirror nanobes

Whether the unsterilized samples are returned to a safe location unconnected to Earth's biosphere, or to a laboratory on Earth, the hope is that the samples eventually can be proved to not contain life. Once proven safe, they could be distributed to laboratories with no need for containment just as for the lunar samples.

However sadly Perseverance's sample tubes weren't sterilized sufficiently for this objective. As stated in the NASA guide Planetary protection provisions for robotic extraterrestrial missions (NASA, 2005ppp):

> ***A "false positive" could prevent distribution of the sample from containment and could lead to unnecessary increased rigor in the requirements for all later Mars missions.***

This seems likely to be the case for the Perseverance samples. The achieved levels of biosignatures and organics in the sample tubes are high enough to make it challenging for an astrobiologist to prove definitively that there is no viable life in the sample. See:

- Limitations on cleanliness of the Mars sample tubes - estimated 0.7 nanograms contamination per tube each for DNA, glycine, alanine, and 17 other biosignatures, 8.1 nanograms total organics, and a roughly 0.02% possibility of a viable microbe in at least one of the tubes – higher levels of sterilization needed to detect life unless Perseverance returns exceptionally well preserved life

- Perseverance's estimated achieved levels of 8.1 nanograms of organic contamination per sample tube equals the amount of organics in 81,000 ultramicrobacteria, 160 million hypothetical minimal volume RNA world nanobes and between 2 trillion and 5.6 trillion terrestrial amino acids

For more about this see also:

- Permitted levels of contamination could make it impossible to prove absence of Martian life in Perseverance's sample tubes – leading to an unnecessary requirement to sterilize Perseverance's samples indefinitely

It is hard to see how these samples could be certified by experts to be free of any Martian life.

We might later be able to deduce that the samples are lifeless, as our understanding of Mars develops, but it would be challenging to prove this by direct measurement of the samples.

From this it seems that unlike the situation for the lunar samples, NASA and ESA need to plan for the Martian samples to be sterilized before distribution to normal laboratories for the indefinite future.

For all these options, most likely the end result of any legal process would be that the samples are only be permitted to be handled unsterilized in laboratories equipped to contain 0.05 ultramicrobacteria – or 0.01 micron diameter mirror life nanobes if that is considered to be a possibility - until we know more about Mars and whether there is any potential for viable native life in samples from Jezero crater.

Permitted levels of contamination could make it impossible to prove absence of Martian life in Perseverance's sample tubes – leading to an unnecessary requirement to sterilize Perseverance's samples indefinitely

Sadly, the Curiosity sample tubes are not 100% sterile. Their measurements to test success of their procedures to reduce contamination suggest they achieved a maximum of

- 8.1 nanograms of organics per tube
- 0.7 nanograms for each of the biosignatures they tested (e.g. DNA)
- 0.00048% chance of a single viable microbe per tube – this means a 0.02% chance that at least one tube has a viable terrestrial microbe in it.

For details see

- Limitations on cleanliness of the Mars sample tubes - estimated 0.7 nanograms contamination per tube each for DNA, glycine, alanine, and 17 other biosignatures, 8.1 nanograms total organics, and a roughly 0.02% possibility of a viable microbe in at least one of the tubes – higher levels of sterilization needed to detect life unless Perseverance returns exceptionally well preserved life

This is enough to make it challenging to prove that there is no viable life in the sample. See:

- Perseverance's estimated achieved levels of 8.1 nanograms of organic contamination per sample tube equals the amount of organics in 81,000 ultramicrobacteria, 160 million hypothetical minimal volume RNA world nanobes and between 2 trillion and 5.6 trillion terrestrial amino acids

As stated in the NASA guide Planetary protection provisions for robotic extraterrestrial missions (NASA, 2005ppp):

> ***A "false positive" could prevent distribution of the sample from containment and could lead to unnecessary increased rigor in the requirements for all later Mars missions.***

There seems a significant possibility of a false positive which could delay certifying the samples as safe for Earth, or make it necessary to sterilize all samples returned indefinitely.

The level of contamination in the samples, though low, may still be high enough to make it hard to prove that there is no Martian life in the samples.

Proposals to modify the ESF lander and sample selections to increase potential for returning viable present day or identifiable past life with samples of the dirt, dust from the air during dust storms, and compressed large samples of Martian air collected in 100% sterile containers by the fetch lander – and to use Marscopters to search for freshly excavated young craters for Perseverance to sample

If there is extant life on Mars, is there a chance we can detect it using this sample return mission, perhaps modified in some way? One major improvement would be to return an additional sample in a 100% sterile container so that it is not confused by the permitted organics in the Perseverance sample tubes.

The current paper suggests we may spot life in Martian dust. Martian propagules adapted to the Martian conditions could be up to half a millimeter in diameter carried through the process of saltation - repeated bounces across the Martian sand-dunes similarly to motion of dust in desert sand dunes on Earth.

- Native Martian propagules of up to half a millimeter in diameter (including spore aggregates and hyphal fragments) could travel long distances with repeated bounces (saltation) - if they can withstand the impacts of the bounces

Martian propagules may have evolved coatings of hard chitin-like substances or agglutinated particles of the iron oxide dust, to protect from UV and collisions with the Martian surface during saltation. Chitin is a hard substance common in fungi and in the fungal component of lichens, and also in insect exoskeletons and jaws. See

- Martian life could also use iron oxides from the dust for protection from the impact stresses of the saltation bounces - or it might use chitin - a biomaterial which is extremely hard and also elastic and is found in terrestrial fungi and lichens

The current paper finds that if there are small regions within reach of the dust storms as productive of spores as the coldest driest terrestrial deserts, small samples from the Martian dust could potentially contain detectable amounts of viable spores. Since the dust storms are sometimes global, it's possible a dust sample could collect propagules that originated almost anywhere on Mars. On Earth, spores and fungal hyphal fragments from distant deserts can be detected thousands of miles away, for instance spores and propagules from the Gobi desert are detected in Japan.

Spores could be carried for similar long distances on Mars. It's also possible that spores adapted to Mars could remain viable after transport for long distances in the dust storms, which block out most of the UV from the sun.

- Potential for spores and other propagules from nearby or distant regions of Mars similarly to transfer of spores from the Gobi desert to Japan

The original plans for the Perseverance rover included a dust sample but this capability was later removed. The current paper recommends that the ESA fetch rover takes an extra sample tube to collect dust. Or better, it could use a rotary air sampler to collect and compress a sample of air.

A dust sample is of interest for human missions too, to have a sample of Martian dust to test with terrestrial spores to check the potential for terrestrial life to spread in Martian dust storms - for forward contamination risk evaluation. It is also useful to study chemical hazards in the dust that could impact on astronauts such as the chlorites, chlorates and perchlorates.

Such a sample also has some geological interest as a random sampling of wind-eroded rock fragments from distant parts of Mars.

See:

- **Recommendation:** Extra sample of air and airfall dust to search for Martian life, assess forward contamination issues for terrestrial microbes, dust dangers for astronauts, and to return a random sample of wind-eroded rock from distant parts of Mars
- **Proposal:** magnets could be used to enhance dust collection
- **Proposal:** to use the sample return capsule as a dust collector – keep it open to the atmosphere before adding the sample tubes

The plans for Perseverance also originally included an atmospheric sample, another capability later dropped from the mission. Dust collection can be combined with an atmospheric sample which would be valuable for studying trace gases in the atmosphere.

As a capability dropped by Perseverance, it is in the scope of the mission. An atmospheric sample can't be added to Perseverance now, but it can still be added to the ESA fetch rover or the Mars Ascent Vehicle.

Perserverance's In Situ Resource Utilization experiment Moxie collects carbon dioxide in the air to split it into oxygen, which may be useful for fuel on Mars in the future. To collect the carbon dioxide it uses an atmospheric compressor.

Jakovsky et al propose sending a similar atmospheric compressor for Mars to the one already on Perseverance, but this time use it to collect an atmospheric sample and a dust sample to return to Earth. The compressor makes it possible to gather a much larger sample of air in the same size of sample container, and the dust is collected in a filter used to filter out dust from the atmospheric sample, which can then be run in an alternative mode venting back to the atmosphere to continue to collect dust once the atmospheric sample is complete.

This paper also recommends modifications to the ESA fetch rover to add an extra sample of dirt since this is of special interest to astrobiologists. Ideally this would include the brine layers at a temperature of -73°C (200°K) observed indirectly by Curiosity, which form in sand dunes at night - which might perhaps shed light on the puzzling Viking observations.

These brines could potentially be habitable to a native Martian biofilm if it can retain the liquid through to the warmer daytime temperatures, which reach temperatures above 0°C, to modify habitability of the layers at a microscale.

Another way they could be habitable to Martian life is if it can tolerate lower temperatures than terrestrial life using chaotropic agents such as the Martian perchlorates or chlorides to speed up metabolic processes by disrupting hydrogen bonding, or ice binding agents to keep the water liquid at higher temperatures, or novel biochemistry adapted to lower temperatures than terrestrial life. See:

- How Martian life could make perchlorate brines habitable when they only have enough water activity at -70 °C – biofilms retaining water at higher temperatures - chaotropic agents permitting normal life processes at lower temperatures – and novel biochemistry for ultra low temperatures

They could also be of interest for novel chemistry in the Martian conditions.

- **Recommendation:** modify ESA's sample fetch rover to grab a sample of the near surface temporary brine layers from sand dunes - perhaps Perseverance may be able to do this too with its regolith bit

These recommendations are all in the spirit of the mission as extra sample returns and are different from the "mission creep" of adding new instruments for other purposes.

The current paper also has a recommendation to increase the possibility for finding recognizable traces of early life. This doesn't require any new instruments. It is a suggestion for a new way of using the Marscopter, if it remains operational, combined with satellite observations of the area.

Any ancient organics in surface layers are likely to be seriously degraded by cosmic radiation to the point where traces of life would be hard to recognize. The current paper suggests searching for young craters near to the Perseverance rover in Jezero crater.

We find that there is a near certainty of young craters within travel distance of Perseverance less than 50,000 years old which are also deep enough to excavate the subsurface to a depth of several meters. This could let us return organics exposed to no more than a few tens of thousands of years of surface levels of cosmic radiation. This would increase the possibility of finding clear signals of past life.

Also it's possible that the preserved organics could make such layers more habitable to present day life.

They could be identified as targets from orbit and the Marscopter used to study them more closely if any are close enough to be photographed – this would involve driving the rover up to a high place and then flying the Marscopter as high as it can fly to photograph a large area of the landscape from above.

- **Recommendation:** use of Marscopter and Perseverance to help identify young craters with sharp rims to help sample subsurface organics excavated by meteorites

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5, Potential for Large Scale Effects

> *"Despite suggestions to the contrary, it is simply not possible, on the basis of current knowledge, to determine whether viable Martian life forms have already been delivered to Earth. Certainly in the modern era, there is no evidence for large-scale or other negative effects that are attributable to the frequent deliveries to Earth of essentially unaltered Martian rocks. However the possibility that such effects occurred in the distant past cannot be discounted."*

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> 10: *"**SR-SAG2 Finding 3-1:** Cell division by Earth microbes has not been reported below –18°C (255K).*
>
> ***"Revised Finding 3-1:** Cell division by Earth microbes has not been reported below –18°C (255K). The very low rate of metabolic reactions at low temperature result in doubling times ranging from several months to year(s). Current experiments have not been conducted on sufficiently long timescales to study extremely slow-growing microorganisms."*

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> *802: Future missions would therefore benefit from the development of instruments capable of direct and unambiguous detection of extant life in situ, and improvements are needed in capabilities for sample preparation to optimize biosignature detection. Spacecraft resources should support a sufficient number of sample analyses to support replicate analyses, positive and negative controls. Contamination control should be coupled with contamination knowledge so that Earth-sourced material can be eliminated as a possible source of any biological material discovered in Martian samples.*

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> *“We have discovered the substance calcium perchlorate in the soil and, under the right conditions, it absorbs water vapour from the atmosphere. Our measurements from the Curiosity rover’s weather monitoring station show that these conditions exist at night and just after sunrise in the winter. Based on measurements of humidity and the temperature at a height of 1.6 meters and at the surface of the planet, we can estimate the amount of water that is absorbed. When night falls, some of the water vapour in the atmosphere condenses on the planet surface as frost, but calcium perchlorate is very absorbent and it forms a brine with the water, so the freezing point is lowered and the frost can turn into a liquid. The soil is porous, so what we are seeing is that the water seeps down through the soil. Over time, other salts may also dissolve in the soil and now that they are liquid, they can move and precipitate elsewhere under the surface,” explains Morten Bo Madsen, associate professor and head of the Mars Group at the Niels Bohr Institute at the University of Copenhagen.*

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Plans should be developed well in advance in order to avoid a frenzied, reactive mode of communications between government officials, the scientific community, the mass media, and the public. Any plan that is developed should avoid a NASA-centric focus by including linkages with other government agencies, international partners, and external organizations, as appropriate. It will also be advisable to anticipate the kinds of questions the public might ask, and to disclose information early and often to address their concerns, whether scientific or non-scientific.
...

Evaluations of the proposal should be conducted both internal and external to NASA and Centre National d’Etudes Spatiale (CNES) and the space research communities in the nations participating in the mission. An ethical review should be conducted at least at the level of the Agencies participating and these reviews made public early in the process (in France, the national bioethics committee, Comité Consultatif National d'Ethique pour les Sciences de la Vie et de la Santé, CCNE, is the appropriate organization). The final protocol should be announced broadly to the scientific community with a request for comments and input from scientific societies and other interested organizations. Broad acceptance at both lay public and scientific levels is essential to the overall success of this research effort.

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