Space agencies must keep Earth safe from microbes in Martian dirt – a review of the planetary protection literature with new worst case mirror life scenarios

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[Mid edit, some cites to be added]

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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# Abstract

In the late 2020s to 2030s, China, NASA / ESA and Japan plan to return samples from Mars. We need to keep Earth’s biosphere safe from any Martian microbes. Japan’s agency JAXA has the simplest mission, to return samples from the top few centimeters of Mars’s innermost moon Phobos.

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.

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”.

This is a short review of central results in planetary protection literature, with a new worst case scenario of mirror life, to encourage space agencies to ensure Earth’s biosphere is adequately protected when they return samples from Mars.

# Review of central results in the planetary protection literature for Mars Sample Return missions for attention of space agencies

This review focuses on NASA’s draft EIS only because it is the first environmental impact statement for a Mars sample return ever published. If NASA and ESA can make mistakes of this order, when they paid so much attention to planetary protection in the past, other space agencies could easily do the same.

## The meteorite argument can’t be used for potential life in surface dust, salts and dirt

Let’s start with the meteorite argument. NASA argues that ([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.*

However, the NRC Mars Sample Return study in 2009 said ([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*

The NRC goes on to say, in its discussion of large scale effects:

*... 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.*

So, how did NASA come to such a different conclusion?

NASA’s EIS reasons:

First, potential Mars microbes would be expected to survive ejection forces and pressure (National Academies of Sciences, …, 2019), …

Their cite is a study of planetary protection for the Japanese space agency JAXA mission to return samples from Phobos. It does indeed conclude there is no need for JAXA to take special precautions because (amongst other reasons) their samples will have already survived ejection from Mars.

However their cite specifically say their argument for the JAXA mission does ***not*** apply to Mars sample return missions ([SSB, 2019](#b_Board_2019) :[2](https://nap.nationalacademies.org/read/25357/chapter/2#5))

*MSR material might come from sites that mechanically cannot survive ejection from Mars and thus any putative life-forms would de facto not be able to survive impact ejection and transport to space. Such mechanical limitations do not apply for material collected on Mars.*

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

Martian surface dust, salts, and dirt couldn’t mechanically survive ejection, as they would burn up in the atmosphere before reaching escape velocity.

NASA’s EIS get their conclusion through mistaken citing, as they don’t mention this caveat, or the NRC statement.

### For planetary protection, what matters are the species that can’t get to Earth, similarly to starlings that can’t fly across the Atlantic and the freshwater diatom Didymo that can’t cross seas to New Zealand

NASA’s cites do say some very hardy terrestrial microbes such as b. subtilis might rarely survive transfer from Mars to Earth in a meteorite. However, this doesn’t prove all or even any martian life ever got to Earth from Mars, as we don’t know its capabilities, if it exists. European Barn swallows were in the Americas already but European starlings are an invasive species in the USA which can’t fly across the Atlantic.

Text on graphic: Some microbes may be able to get from Mars to Earth – what matters for invasive species are the ones that can’t.
Barn swallow - can cross Atlantic
Starling - invasive species in the Americas
Didymosphenia geminatum invasive diatom in Great Lakes and New Zealand, can’t even cross oceans.


Starling photo from: ([Johnstone, 2017](#b_Johnstone_2017))

Barn swallow photo from ([Batbander, 2017](#b_Batbander_2020))

Didymosphenia geminata (Lyngb.) from [(Schmidt, n.d.)](#b_Schmidt_nd)

For a microbial example, the invasive freshwater diatom "Didymo" (*Didymosphenia geminatum)* in New Zealand can't get from one freshwater lake to another on the same island without human help [(Spaulding et al, 2010)](#b_Spaulding_2010). It could never get from Mars to Earth. Any diatoms on Mars, perhaps in the lakes beneath the polar ice ([Davis, 2018](#b_Davis_2018)), may well be unable to tolerate six months of vacuum or the extreme shock of ejection from Mars, and if so, likely evolved independently from terrestrial diatoms.

To take an example here, Mars has very cold brines which form in the late evening / early morning on and just below the surface in Gale crater [(Martin-Torres et al, 2015)](#kix.c1m7hhbhkmn1). These should be stable for longer in Jezero crater [(Chevrier et al, 2020: figure 7)](#kix.odnzqwswkobn). Nilton Renno suggested they could be habitable by life in biofilms ([Pires, 2015)](#kix.yo5n6xsddztt), a strategy often used by terrestrial life to make deserts more habitable ([SSB, 2015](#kix.oax6src83tdc) :[11](https://nap.nationalacademies.org/read/21816/chapter/4#11)).

Microbes in these biofilms might grow slowly with doubling times of decades to millennia and transfer to other seeps, perhaps attached to a dust grain and shielded from UV in dust storms, with one microbe succeeding every few millennia.

These would have no evolutionary pressure to withstand extreme shock, life below the surface of a rock, extended periods of vacuum, and so on, and similarly to Didymo, might have no way to get to Earth on a meteorite. For them, a sealed sample tube is like a miniature spaceship complete with dust, shielding from UV, and a small amount of martian atmosphere, much less dessicating than a vacuum.

### It is safe for Japan to return unsterilized samples from Phobos without any special precautions because they already survived ejection from Mars – and it may be safe to send humans to Phobos if they sterilize any materials before contact from deep below the surface

JAXA did establish it is safe to return their samples from Phobos because

1. Our martian meteorites left Mars at least 700,000 years ago. See table S4 of [(Udry et al, 2020)](#b_Udry_2020) ejection ages range from EETA 79001A at 0.7 million years to Dho 019 / 1668 / 1674 at 18.5 million years.
2. the top few centimeters on Phobos had similar levels of ionizing radiation to meteorites currently arriving at Earth from that most recent impact.
3. Meanwhile life that survives ejection from Mars and travels directly to Earth is protected from the fireball of re-entry so long as it isn't in the surface layers.

JAXA’s analysis may have a slight oversight on the re-entry fireball. They argue microbes ejected from Mars wouldn’t need to be far below the surface of the rock to survive. This is normally valid, but it doesn't work exactly as stated for photosynthetic life which tends to live on or near the surface of rocks.

The astrobiologist Charles Cockell found not only chroococcidiopsis but all associated organics were destroyed on re-entry, when he attached it at a typical growing depth on a re-entry aeroshell. He concluded [(Cockell, 2008)](#kix.jztdleevmtmy)

... Thus, the planetary exchange of photosynthesis might not be impossible, but quite specific physical situations and/or evolutionary innovations are required to create conditions where a photosynthetic organism happens to be buried deep within a rock during ejection to survive atmospheric transit.

However, our martian meteorites were thrown into space by glancing collisions into the high altitude southern uplands [(Tornabene et al, 2006)](#kix.a4ip5t4d8249), where the thin atmosphere makes ejection to Earth easier. They also come from at least 3 meters below the surface [(Head et al, 2002:1355)](#4ut9kfm5zz3j),  and anywhere below 12 centimetres has a uniform temperature of around -73°C ([Möhlmann, 2005:figure 2](#b_Möhlmann_2005)).

Perhaps life is possible there in rare geothermal hot spots. If so, it’s unlikely to use photosynthesis. There’s one possible exception, life using the thermal radiation from a hydrothermal vent for photosynthesis ([Beatty et al, 2005](#Beatty_2005)), but it’s an unlikely scenario for Mars. Then in addition, photosynthetic life in the ejected rocks is also likely to be sterilized or destroyed by the fireball of exit from Mars, as rocks have to leave at Mars escape velocity of 5.03 km / sec [(NASA, n.d.)](#b_NASA_ndmfs)

This may need closer attention, but it seems the JAXA argument is valid at least back to when our earliest meteorites left Mars. Meanwhile, life deposited on Phobos over 18.5 million years ago has had over 22.5% of many of its amino acids destroyed (calculated in discussion of sterilization dose below). So the analysis seems correct with this minor tweak to account for photosynthetic life.

By a similar argument it may be safe to send astronauts to Phobos so long as they sterilize any materials before contact from deep below the surface. There may be viable life on Phobos buried deep after ancient larger impacts on Mars which can’t get to Earth currently.

### Jezero crater seems uninhabited from orbit – but so do terrestrial Mars analogue deserts – the 2015 MEPAG review which the EIS omits overturned all the conclusions relevant to Jezero crater that NASA’s EIS relies on

NASA say the Martian surface is too inhospitable for life in Jezero crater where Perseverance is collecting samples even if there is life elsewhere and say. ([NASA, 2022s](#b_NASA_2022eis): S-4)

*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 (Rummel et al. 2014, Grant et al. 2018).*

NASA’s draft EIS refers to SR-SAG2 [(Rummel et al , 2014)](#kix.im73nfot8zt5), but don't cite the 2015 review ([SSB, 2015](#kix.oax6src83tdc)), which modified all its main conclusions relevant to Jezero crater.

Jezero crater seems uninhabited from orbit, but polyextremophiles in terrestrial Mars analogue deserts live in biofilms and microhabitats you only discover by close examination. Also dust storms transfer terrestrial life over large distances, with life from the Gobi desert detected in Japan and the same may be possible on Mars  [(Maki et al, 2019)](#kix.1thbwj2w2qtd).

In these reports, “Special regions” mean regions where potentially terrestrial life could spread to colonize Mars.

So first, the MEPAG review says that the SR-SAG2 report doesn’t discuss transport of material in the atmosphere (e.g. dust storms). ([SSB, 2015](#kix.oax6src83tdc) : [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."

That last point is that if terrestrial life can actually be transported in dust storms, once introduced anywhere, it could potentially spread to anywhere else on the planet. Applied in reverse, if viable martian life can be transported in the dust, it can potentially get from anywhere on Mars to Jezero crater.

Then the 2015 MEPAG review says SR-SAG2 only briefly considered the implications of our lack of knowledge of micrenvironments which can be habitable in regions that seem uninhabitable on larger scales ([SSB, 2015](#kix.oax6src83tdc) :[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.*

For an example microenvironment relevant to Mars, microbes can use micropores in salt deposits for humidity when the air is otherwise too dry [(Vítek et al, 2010)](#b_Vitek_2010). Cassie Conley [(Conley, 2016)](#kix.8vsd5bxcvoe2) and separately Paul Davies [(Davies, 2014)](#kix.t7ig6ibvcei5) have suggested these micropores as potential habitats on present day Mars. Jezero crater doesn’t have the large bright salt deposits of Mount Sharp [(Lerner, 2019)](#y398t7inp5j), but micropores in a small deposit could still be a potential microhabitat. Microbes can use micropores in gypsum too. In one study of the hyperarid core of the Atacama desert, microbes imbibed water when the external humidity was above 60% and gradually became more desiccated when it was below that [(Wierzchos et al, 2011: figure 1)](#b_Wierzchos_2011).

The 2015 MEPAG review also discusses how microbes in biofilms modify microhabitats by surrounding themselves with “extrapolymeric substances” - proteins, polysaccharides, lipids, DNA and other molecules.These can make microenvironments far more habitable for microbes and help them cope with environmental stressors ([SSB, 2015](#kix.oax6src83tdc) :[11](https://nap.nationalacademies.org/read/21816/chapter/4#11))

Text on graphic: How EPS (extrapolymeric substances) can make a “home” of the hostile Martian surface.
Some of the environment stressors
100% humidity varies to 0%
Heat, cold, UV, dust storms
Oxidants, nutrients
Algae may add oxygen
Retains moisture from night to daytime when temperature soars from -70°C to above 0°C.
Cryoprotectants - protects from cold shock
Extrapolymeric substances (EPS): proteins, DNA, lipids, polysaccharides, other large organic molecules.


A biofilm is like a microbe's "house" which
can keep it warm, wet, protected from UV, 
and which it shares with other microbes

Graphic adapted from figure 2 of ([Sabater et al., 2016](#b_Sabater_2016))

So, we can’t know Jezero crater is uninhabitable everywhere without detailed local study, searching for

* Nilton Renno’s biofilms ([Pires, 2015)](#kix.yo5n6xsddztt)
* micropores in salt or gypsum [(Conley, 2016)](#kix.8vsd5bxcvoe2) [(Davies, 2014)](#kix.t7ig6ibvcei5),
* and other potential local habitats, some of which could be new to science so we don’t yet know to look for them.

### NASA discovered potential habitats for terrestrial life in Gale crater AFTER Curiosity’s landing

We have an example already of how our knowledge of a landing site can change after a rover lands. Like Perseverance, Curiosity is not sufficiently sterilized to visit regions where terrestrial life could spread. NASA thought Gale Crater had no risk for forward contamination. But then they discovered potential habitats for terrestrial life in Gale Crater after Curiosity’s landing [(JPL, 2016)](#kix.j93rpoj9e4ep).

These may be RSLs, features that grow in spring, expand through the summer and fade away in the autumn on sun facing slopes on Mars  [(McEwen, 2011)](#kix.ww6o6l5aa7a). There are two models for them, dry formation by dust flows and a wet formation by brine seeps. Neither model explains them fully. Stillman in 2018, suggests some of these features may be caused by dry granular flow, and others by a wet-dominated mechanism [(Stillman, E., 2018:81)](#kix.4r1byain9c9g).

Although the features close to the rover were ambiguous and not definitely RSLs, mission planners were concerned that Curiosity was not sufficiently sterilized to approach them because of the risk of forward contamination. After discussion they made a tentative decision that it could approach within a couple of kilometers to image them but not study close up ([Witze, 2016](#Witzer_2015)). Curiosity is currently exploring the region of the possible RSLs but doesn’t seem to have approached any of them close up ([NASA, n.d.)](#b_NASA_2022eis).

### 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

Another central argument in NASA’s draft EIS is that Mars is lifeless anyway. The 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).

Yet their most recent source there is about searches for currently habitable environments on Mars! ([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]  
  
(cited by NASA as National Research Council 2022)

Once more, NASA got to this conclusion through a citing error.

This is a surprising error given that NASA itself was involved in extensive discussions about whether to divert Curiosity away from a potential current habitat for terrestrial life in Gale crater as we just saw [(JPL, 2016)](#kix.j93rpoj9e4ep). However, NASA is a large organization involving many people. Those involved in one aspect of its operations may not know about other things it does.

### Martian life could also be more capable of coping with Martian conditions than terrestrial life

The MEPAG and MEPAG review studied forwards contamination, so didn’t look at potentially more capable martian life. Any life on Mars has had billions of years to evolve to survive transfer better in dust storms or to adapt to colder temperatures.

Martian life might also use novel biochemistry [(Schulze-Makuch et al, 2010a)](#kix.pi3n4jm5lyn5) [(Houtkooper et al, 2006)](#kix.13jd6ghwsika), or use the abundant martian “chaotropic agents” such as the perchlorates, which speed up a cell’s chemical processes at low temperatures and can reduce the lowest temperatures for cell division for many microbial species [(Rummel et al , 2014:897)](#kix.im73nfot8zt5).

Also the Martian surface changes slowly over millions of years, so martian surface life may be adapted to reproduce very slowly at first in such cold conditions (until the biofilm is established) with generation times of decades to millennia or more.

There is evidence that species of lichens and mosses are still in the process of recolonizing Antarctica since the last ice age, with the species diversity dependent on the distance from the nearest geothermally active sites that provided refuges during the ice ages [[(Fraser et al, 2014)](#kix.6g31hz3cb55x).](https://doi.pangaea.de/10.1594/PANGAEA.837185)

## The European Space Foundation study in 2012 reduced the size of particle to contain at 1 in a million from 0.2 microns to 0.01 microns, well beyond the capability of a BSL-4 and NASA’s recommendation is based on the science of 1999

Another of NASA’s major omissions is the European Space Foundation study in 2012 which reduced the size of particle we need to contain at the 1 in a million level from 0.2 microns to 0.01 microns. They made this change after a discovery of fast horizontal gene transfer to distantly related archaea in sea water via Gene Transfer Agents (GTA) [(Ammann et al, 2012:19)](#qa4nethlmcdw):

***Surprisingly, it is now estimated that GTA transduction rates are more than a million times higher than previously reported for viral transduction rates in marine environments. Clearly, GTAs are a major source of genetic diversity in marine bacteria.***

The researchers found that archaea can readily transfer novel capabilities to unrelated species of archaea overnight in sea water [(Maxmen, 2010)](#kix.ixvz10mxikde) ([McDaniel, 2010](#b_McDaniel_2010)).

The ESF also said a particle of 0.05 microns or larger shouldn’t be released under any circumstances because of the discovery that ultramicrobacteria remain viable after passing through 0.1 micron nanopores [(Ammann et al, 2012:21)](#qa4nethlmcdw):

***“the release of a particle larger than 0.05 μm in diameter is not acceptable in any circumstances”***

This is a visual comparison of the change in the size limit. The 0.01 microns is shown as the potential theoretical size limit a future review might decide on to contain early life ribocells is also the size limit for the GTAs.

Size limit 1999 to 2012: 0.2 microns
ESF Size limit (2012): 0.05 microns
The European Space Foundation study in 2012 reduced the limit from 0.2 microns to 0.05 microns after the discovery that these ultramicrobacteria are viable after passing through 0.1 micron nanopores
Next size limits review might reconsider ribocells – theoretical size limit 0.01 microns


SEM of a bacterium that passed through a 100 nm filter (0.1 microns), larger white bar is 200 nm in length [(Liu et al, 2019)](#kix.fceop15m75fz).

A BSL-4 doesn’t need this level of containment, to contain gene transfer agents, ultramicrobacteria, or hypothetical early life. Indeed, recent air filter technology reviews don’t mention any attempts to achieve 100% containment at all sizes above 0.05 microns or a 1 in a million chance of releasing a single particle in the lifetime of a facility at all sizes above 0.01 microns ([Borojeni et al, 2022:7](#b_borojeni_2022)).

The ESF study says theirs is the first size limit review since 1999 and needs to be revisited periodically. The next review may examine new research into extremely small early life cells such as ribocells with enzymes made from fragments of RNA instead of proteins ([Kun, Á., 2021](#b_Kun_2021)). Steven Benner and Paul Davies say the small structures in the martian meteorite ALH84001 are consistent with RNA world cells ([Benner et al, 2010](#kix.7xkeg482reap): [37](https://books.google.co.uk/books?id=OscgAwAAQBAJ&pg=PA37)) as did Panel 4 for the 1999 workshop ([Space Studies Board, 1999](#kix.onye7oc8xdfg): [117](https://www.nap.edu/read/9638/chapter/6#117)).

## The planetary protection literature warns of likely low but not demonstrably zero potential for 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

Another major change made by NASA’s EIS is a finding of no significant risk of environmental effects for life returned from Mars ([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.**

The National Research Council’s 2009 study said it is not possible to assess the potential for negative impacts.

The NRC also said the potential for [even] large-scale negative effects appears to be low but is not demonstrably zero [(Space Studies Board, 2009: 48).](#kix.xed3c1hm3p4k)

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.

In this case the discrepancy is based on an assessment by NASA’s sterilizing subcommittee [(Craven et al., 2021)](#b_Craven_et_al_2021). The EIS doesn’t alert the reader to the discrepancy between the sterilizing subcommittee’s conclusions and the conclusions of the National Research Council study in 2009, and many papers in the planetary protection literature coming to similar conclusions to the NRC study, and the views of Joshua Lederberg and Carl Sagan that in the worst case terrestrial life might have no defences against an independently evolved biology from Mars.

### The argument about harmlessness of martian life was presented in a non peer reviewed op ed by Zubrin along with the meteorite argument, with an immediate response from planetary protection experts that his recommendation to take no precautions with Mars sample returns is like building a house without smoke detectors

The view that there is no significant risk from life returned from Mars seems to represent a minority view amongst microbiologists [(MacGregor et al, 2001)](#b_MacGregor_2001) . I don’t know of any recently published published papers that say this, except that the space engineer and Mars colonization proponent Robert Zubrin presented these arguments about harmlessness of martian life and the meteorite argument in a non peer reviewed op ed in 2000 [(Zubrin, 2000)](#kix.s0r7xw2fjr42). He got an immediate response in the next edition of the planetary report from planetary protection officers that it’s like building a house without smoke detectors [(Rummel et al., 2000)](#b_Rummel_2000).

Text on graphic: We need to install “smoke detectors” to protect Earth.
The risk of large scale effects from NASA’s mission is likely very low - indeed unlikely it returns life at all but it’s not demonstrably zero.
The risk of a fire to your house is also low.
We need the smoke detectors just in case. Especially for a “house” for billions of people.
Especially as we likely have many future missions like this from many countries.


*Background graphics:*

*Smoke detector* [*(Rockmelder, 2007)*](#b_Rookmelder_2007) *House on fire* [*(LAFD, 2018)*](#B_LAFD_2018)

I work (on my own initiative) as a voluntary fact checker for scared people. For anyone who might read this paper and panic and expect the worst, and perhaps instantly jump to fear of human extinction, it’s more like installing smoke detectors in your house. Most people will never get their house burnt down, but it is still wise to install smoke detectors.

This particular mission hasn’t got life detectors and won’t approach any regions thought likely to have life. Unless life is very common on Mars, perhaps as spores in the dust or in the dirt, it is unlikely to return life at all. Also life on Mars may be harmless or even beneficial, or there may be no life there or early or prebiotic life. But many experts say we don’t know any life on Mars is safe, and also we don’t know that Jezero crater is lifeless, or that there is no life in the samples taken by Perseverance.

So we have to take precautions. We also need to take precautions as a precedent for future potentially more risky samples returned from other areas of Mars. Just as it is wise to install smoke detectors in your house.

Since many in the space exploration / colonization community have been convinced by Zubrin’s arguments, it may help to go into some detail on this point, why the arguments don’t work.

The basic arguments are the same for Zubrin and for the sterilizing sub committee though the subcommittee present them with more sophistication. The main ones are that

* Martian life didn’t co-evolve with humans so it can’t harm us  
  [This argument works by ignoring opportunistic pathogens of humans such as Legionaires' disease and opportunistic fungal infections that didn’t co-evolve with us]
* Martian life would be extremophile, only able to survive in the extreme conditions on Mars  
  [This works by ignoring many polyextremophiles such as radiodurans able to withstand high levels of ionizing radiation and first isolated in cans of corned beef]

## Argument by sterilizing subcommittee that martian pathogens wouldn’t be adapted to humans or other Earth hosts doesn’t cite discussions of opportunistic pathogens such as legionnaire’s disease as well as diseases caused by accidental exotoxins such as botulism

First, arguing from many examples of pathogens adapted to humans, the sterilizing subcommittee’s assessment says the risk of a direct pathogen of humans is near-zero [(Craven et al., 2021)](#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.***

This argument omits discussion of “opportunistic pathogens” not adapted to humans. One example is Legionnaire’s disease, a disease of biofilms and protozoa. It also infects human lungs and sometimes can kill us, yet it’s not evolved to attack humans. For the microbe Legionnella pneumophila, human lungs must seem like biofilms, and the macrophages in our lungs must seem like large protozoa [*(Alberts et al 2002)*](#kix.dceso8baikzv).

It’s not likely these samples return an exact analogue of Legionnella pneumophila, as it needs an oxygen rich aquatic environment to survive, can’t survive drying and can’t form spores. However, the way it invades our lungs could be relevant for a possible pathogen of martian biofilms, and perhaps martian protozoa. Anaerobic protozoa can reach up to a quarter of the growth efficiency of aerobic protozoa ([Priya et al, 2008](#b_Priya_2008)). Also, Stamenković showed cold martian brines can in principle take up oxygen to a surprising degree so there may be aerobes in them too [(Stamenković et al, 2018)](#kix.b5k93sevqv0j)

Warmflash used Legionnaire’s 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 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.*

Warmflash also mentions various diseases that harm us indirectly through exotoxins, accidental toxins secreted by the microbe, such as tetanus, botulism, and ergot disease, not adapted to humans [(Warmflash, 2007)](#inpazll45dhz).

The 2009 NRC review which NASA refers to elsewhere also adds an example ([SSB, 2009](#b_SSB_2009): [46](https://nap.nationalacademies.org/read/12576/chapter/7#46)) of hydrothermal vent organisms ([Nakagawa et al, 2007](#b_Nakagawa_2007)) that though not pathogenic themselves, share many virulence genes with epsilon-Proteobacteria, a pathogen which can cause acute gastrointestinal disease in humans ([Cornelius et al, 2012](#b_Cornelius_2012)).

### New example of opportunistic fungal pathogens which can sometimes be deadly especially for immunocompromised people and kill 1.5 million people a year – we might all be immunocompromised to a new genus of fungi from Mars

We will see in the next section that several astrobiologists have warned that one worst case scenario is that we could be in effect immunocompromised to life based on a different biology. It may help to start with a simpler example, opportunistic fungi from a new genus that could evade our immune system.

Opportunistic fungi kill an estimated 1.5 million people worldwide every year [(Brown et al, 2012)](#kix.jjb1r3cr4sax) and fungi are potential Martian life analogues, especially the black fungi from Antarctica [(Selbmann et al, 2015)](#b_Selbmann_2015). One of these black fungi, Cryomyces antarcti, tested in Mars simulation conditions in the BIOMEX experiment, exterior to the ISS, survived, still viable, with only slight damage too fine to see with optical microscopy [(Pacelli et al, 2017)](#b_Pacelli_2017). Another of these black fungi, Exophiala jeanselmei, which showed promise in the Mars simulation chamber of the German aerospace center [(Zakharova et al, 2014)](#kix.ojnjic4hyuz0), is pathogenic for humans on rare occasions. Exophiala jeanselmei sometimes is a serious pathogen for immunocompromised individuals, and is also naturally resistant to most antifungals on the market [(Urbaniakt al, 2019).](#kix.54k04aufndc2)

Our immune system probably stops many fungal infections by recognizing particular patterns, the pathogen-associated molecular patterns (PAMPs). It likely does this using pattern recognition receptors (PRRs) which then trigger the immune response. These are targeted to the molecular patterns from the most common fungi that attack humans, species from three genera: Candida, Aspergillus, and Cryptococcus with different molecular patterns specific to each genera [(Kumar et al, 2018](#b_Kumar_et_al_2018) : [table 1](https://link.springer.com/article/10.1186/s13073-018-0553-2/tables/1))

Our immune system wouldn’t have these genus specific pattern recognition receptors for a martian fungus with an alien biochemistry. It may not have them even for related martian fungal species in a different genus from any terrestrial biology.

Also, we have only a few effective antifungal medicines, making antifungal resistant microbes a problem [(Cowen et al, 2015)](#kix.zg2yugivuqil). Alien life might be naturally antifungal resistant, if they don’t have the biochemistry targeted by antifungal medicines.

Perhaps we might all be immunocompromised against a fourth accidentally pathogenic genus of fungi from Mars.

### 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

Some astrobiologists say that there is a possibility that more generally, in a worst case scenario, we might all be in effect immunocompromised to an entire exobiology from Mars. Joshua Lederberg, a key figure in early work on planetary protection [(Scharf, 2016)](#kix.t6u255axqlml) put it like this [(Lederberg, 1999)](#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*

Lederberg argues our immune system and defenses are keyed to various chemicals produced by Earth life such as peptides and carbohydrates. Mars life might use different chemicals.

***Joshua Lederberg:*** *Thus, although the hypothetical parasite from Mars is not adapted to live in a host from Earth, our immune systems are not equipped to cope with totally alien parasites: a conceptual impasse."*

He considers two possibilities, that martian life is mystified by us, or in the worst case, our immune system doesn’t recognize the attackers as life, and does nothing to stop them. Perhaps microplastics would be a useful analogy for that second possibility. At 10 microns or less in diameter, they can potentially cross into the blood stream, for instance through the submicron barrier in the lungs, and access all organs [(Campanale et al, 2020)](#kix.k9ynqems2czp) so our bodies are to some extent permeable to small particles that our immune system ignores.

In the forward direction, Claudius Gros warns introducing terrestrial life to another planet perhaps orbiting a distant star could eliminate nearly all higher life in a reset to Precambrian times. He presumes biological defense mechanisms evolve only to respond to threats actually present, not to never encountered theoretical possibilities [(Gros, 2016)](#kix.hwnfjqjxs7me).

Carl Sagan put it like this [(Sagan, 1973)](#kix.urfjjsuep509)

***Carl Sagan:*** *On the one hand, we can argue that Martian organisms cannot cause any serious problems to terrestrial organisms, because there has been no biological contact for 4.5 billion years between Martian and terrestrial organisms. On the other hand, we can argue equally well that terrestrial organisms have evolved no defenses against potential Martian pathogens, precisely because there has been no such contact for 4.5 billion years.*

## Sterilizing subcommittee’s discussion of potential for extremophiles from Mars that can’t live in normal terrestrial conditions omits mention of polyextreomophiles such as radiodurans that can live in normal terrestrial conditions, found in corned beef yet able to withstand 100 double strand breaks of DNA per chromosome

The sterilizing subcommittee also looks into whether martian life might transform the environment of Earth and uses examples of extremophiles that can’t live in our normal habitat to argue it’s plausible any martian microbe would not be viable on Earth [(Craven et al., 2021)](#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.*

This omits polyextremophiles that live in a wide range of both extreme and normal environments such as the ionizing radiation resistant Deinococcus radiodurans, which was first discoverednd in radiation sterilized cans of corned beef in 1956 [(Krisko et al, 2013)](#b_Krisko_2013). Radiodurans can repair 100 double strand breaks per chromosome without any loss of viability or mutation of its genome [(Minton, 1994)](#kix.x8t13x4jipmy). Indeed the day night variations in temperature, pressure and humidity on Mars seem likely to encourage polyextremophiles.

### Although martian life is likely to be better able to withstand various stressers than terrestrial life it’s not likely to depend on them, and variability of martian conditions would favour polyextremophiles also able to withstand terrestrial conditions

Martian life is likely to be better able to withstand UV, and ionizing radiation than terrestrial life but it’s not likely to depend on UV or ionizing radiation. Indeed these capabilities may make it more desiccation resistant than most terrestrial life.

Martian life is likely to be able to withstand extreme changes of temperature from below -70 C to above 0 C in the same day. But this ability is not likely to make it unable to withstand conditions of more stable temperature. It seems more likely to encourage polyextremophiles able to withstand both cold and warm temperatures.

The humidity on Mars is also very variable from close to 100% at night to close to 0% in daytime, and the pressure also varies greatly from day to night. This again seems likely to encourage polyextremophiles rather than extremophiles adjusted to near constant extreme conditions.

Martian nitrogen levels are just on the borderline of what may be possible for nitrogen fixation. If there are nitrogen fixers on Mars they may be better able to fix nitrogen than terrestrial life – the abundant nitrogen on Earth would not be likely to be a problem for them.

Some cold tolerant microbes from Antarctica are able to fix nitrogen at a partial pressure of 0.2 mbar similarly to the partial pressures on modern Mars, as reported in unpublished research [(Mancinelli, 1993)](#b_Mancinelli_1993) following [(Klingler et al, 1989)](#kix.oghzd67ddprx). Sakon et al also found that some cold tolerant life (psychrophiles) can still fix nitrogen at these low partial pressures when the temperature and UV flux of Mars is simulated [(Sakon et al, 2005)](#kix.bhtbxpj204qz) [(Sakon et al, 2006)](#kix.pn1ad4sgqwr4). These experiments involve a partial pressure of nitrogen, in an atmosphere of other gases at normal terrestrial atmospheric pressures. Follow up experiments are needed to duplicate the Martian atmospheric pressure in a Mars simulation chamber and find out if these microbes from Antarctica can still fixate nitrogen at the same partial pressure of 0.2% at a total pressure of 0.6% [(Sakon et al, 2006)](#kix.pn1ad4sgqwr4).

Martian life is not likely to have problems with the oxygen in Earth’s atmosphere. It may have photosynthetic life that produces oxygen when it converts CO2 to organics. Curiosity discovered seasonal oxygen in Gale crater, 30% higher than expected in spring to summer. It could be produced abiotically or by low levels of present day life. [(Trainer et al, 2019:3021)](#kix.6c37lp2f20m) [(Shekhtman, 2019)](#kix.rbmxa8jo44b0)

Martian life indeed would be adapted to conditions of superoxygenation. The Martian salts include chlorides and sulfides as on Earth but also chlorates, sulfates and perchlorates and we also find hydrogen peroxide on Mars. All this would make Martian life better adjusted to oxygen stress than terrestrial life and as for capabilities to cope with ionizing radiation, this doesn’t mean it is dependent on perchlorates or hydrogen peroxide.

Makuch et al did hypothesize a possible martian lifeform that depends on perchlorates and hydrogen peroxide for a faster metabolism in very cold conditions which wouldn’t survive being warmed up above 0 C for long [(Schulze-Makuch et al, 2010a)](#kix.pi3n4jm5lyn5) [(Houtkooper et al, 2006)](#kix.13jd6ghwsika). Such life could survive on Mars and not easily survive on Earth. But even on Mars it could co-exist with other polyextremophiles able to withstand the warmer surface conditions. Proving potential for life on Mars that wouldn’t be able to survive on Earth is very different from showing that no life on Mars can survive on Earth.

### The remarkable polyextremophile blue green algae chroococcidiopsis, one of our top candidate Mars analogue organisms with strains found in many terrestrial habitats, and sometimes in the human microbiome

This remarkable ability to repair multiple double strand breaks of DNA is also shared by one of our top candidates for a terrestrial microbe to survive on Mars, dessication resistant desert strains of the blue green algae chroococcidiopsis. The BIOMEX experiment on the exterior of the ISS tested Chroococcidiopsis sp. ASB-02, a species isolated from the Urad Middle Banner desert in inner Mongolia, and it remained viable after exposure to cosmic radiation in Mars simulation conditions ([Li et al, 2022](#b_Li_2022)).

A microbe from Mars only needs to find a niche somewhere on Earth that it can survive in, then it can evolve and adapt and proliferate to other habitats. Species of chroococcidiopsis flourish from Antarctic cliffs to the Atacama desert [(Bahl et al, 2011)](#kix.axc3vj9odk3) or from Sri Lankan reservoirs [(Magana-Arachchi et al, 2013)](#kix.ejspgahn01jm) to the Chinese sea [(Xu et al, 2016:111)](#kix.2o5rxmoxb588). As a prime producer chroococcidiopsis survives on just rock, water, and light, fixing CO2 and nitrogen from the atmosphere.

Chroococcidiopsis is an ancient polyextremophile with numerous alternative metabolic pathways it can use, including nitrogen fixation, methanotrophy, sulfate reduction, nitrate reduction etc [(KEGG, n.d.)](#kix.pj8o7osp4x21), with strains of chroococcidiopsis even able to grow in complete darkness with viable populations 750 meters below the Atlantic sea bed [(Li et al, 2020)](#kix.xaj0jr23elda). In this habitat chroococcidiopsis strains can get energy by oxidising hydrogen produced in the rocks by various abiotic processes ([Puente-Sánchez et al., 2018](#b_Puente_sanchez_2018)).

Species of chroococcidiopsis are also sometimes found in the human microbiome ([Ventero et al, 2022](#b_Venetero_2022)) ([Lackey et al, 2019](#b_Lackey_2019)).

### Example of an accidental neurotoxin, chroococcidiopsis indica produces BMAA, misincorporated in place of the amino acid serine and may be a contributing cause to neurodenerative diseases such as ALS through protein misfolding – extraterrestrial biology could use many more amino acids that could be misincorporated

The chroococcidiopsis genus also has examples of accidental toxins. The species chroococcidiopsis indica produces BMAA [(Cox et al., 2005:fig 2)](#b_Cox_2005), which may be a contributing cause to neurodegenerative diseases such as ALS which Steven Hawking suffered from, as it can bind to serine transfer RNA and so get misincorporated into proteins in place of serine, which then leads to protein misfolding and these misfolded proteins have been found in nerve cells of people with ALS [(Holtcamp, 2012)](#b_Holtcamp_2012).

An extraterrestrial biology could use many more amino acids than the 20 encoded in RNA. There are 140 that occur naturally in terrestrial biology, but not in proteins [(Ambrogelly et al., 2007)](#kix.9ywn5yi42yte). 52 amino acids have been identified in the Murchison meteorite [(Cronin, 1983)](#kix.l8slghbnpbwa). A computer search turned up nearly 4,000 biologically reasonable amino acids [(Meringer, 2013)](#kix.qubfew9c9gv) [(Doyle, 2014)](#kix.19tf8efo9qks). Many of those won’t occur in nature, but terrestrial biology also includes non natural amino acids. Meanwhile also many of the natural amino acids don’t occur in terrestrial biology and might potentially be used in extraterrestrial biology.

Proteobacteria in our gut may provide some protection against BMAA by removing it [(Baugh et al, 2017)](#kix.i91b5ab1axfq). However there might be no helpful microbes to protect us by removing similarly close analogs of our amino acids from an alien biochemistry.

More generally, other blue green algae can produce accidental liver toxins (hepatotoxins) that can harm or kill cattle and dogs that eat the algal mats that often cover parts of the Great Lakes [(Hoff et al, 2007)](#kix.plnxi9y5lg0). These heptatoxins may also rarely harm humans [(Zhang et al, 2015)](#b_Zhang_2015).

### Martian life could be better at photosynthesis than terrestrial life since terrestrial photosynthesis works at well below its theoretical peak efficiency

Photosynthetic life on Earth operates at well below its theoretical peak efficiency for photosynthesis. Bains et al suggest this may be a many pathways event. Perhaps oxygenic photosynthesis could evolve in many ways, but with very low probability of achieving all the necessary steps so terrestrial life only happened to evolve it once. As a perhaps more plausible alternative, that it could be a "pulling up the ladder" event where once the niche was filled, a photosynthesizer not limited by the need for an electron donor such as sulfide, Fe(II) or hydrogen it was hard for a new photosynthesizer to evolve again [(Bains et al, 2016)](#whomxsyo94yn).

Terrestrial photosynthesis rejects 50% of the incoming sunlight, mainly in the red part of the spectrum, leading to the distinctive “red edge”. The purple bacteria and lichens don’t have this “red edge” and Martian life would be likely to use red light like the purple bacteria, because of the high absorption of blue light by dust [(Kiang, 2007)](#kix.3cbxwf1wrteo).

Oxygenic photosynthesis goes through two photosystems, 1 and 2, and both use the same frequencies of light. The efficiency could be doubled by using red light for one of the two systems [(Blankenship et al, 2011:808)](#kix.pigu57k8z2kz).

Martian life might also be able to use the full range of the spectrum. Terrestrial seaweeds are dark brown in colour because they use accessory pigments like fucoxanthin to gather the blue-green component of light rejected by chlorophyll. These then transfer the energy to the chlorophyll and so to the photosynthetic reaction centers. They do this so that they can use sunlight at only 1% of surface levels so it helps to use the blue-green light that passes through seawater [(Caron et al, 2001)](#kix.yvuehebdansk).

A hypothetical Martian microbe with faster photosynthesis might find it useful to capture the full spectrum, especially in the low light levels on Mars. This would double its theoretical efficiency compared to terrestrial life.

According to Mellis, it would be possible to increase the typical 3% efficiency of green algae three fold, close to the theoretical maximum of 8 to 10% by truncating the light-harvesting chlorophyll antenna size [(Mellis, 2009).](#kix.icq8wh8vwj1a) Experiments back this up, though with smaller improvements (instead of tripling, they achieve modest increases of 55% to 60%) [(Kirst, 2014)](#kix.q4yfvw1zs2e7). Terrestrial life likely uses a larger antenna than is needed to block out light from competitors, or because it allows it to capture more light at lower light levels with lower cell densities [(Ort et al, 2015:8530)](#kix.5mxlf05z0e9a) [(Negi et al, 2020:15)](#kix.rh6eayh1dl2y).

Although terrestrial life uses a fixed antenna size, cells have been designed that adjust the antenna size depending on the light intensity so that they achieve high efficiency both at low and high light levels compared to wild-type strains, doubling and even tripling the yields of the wild-type strains [(Negi et al, 2020:15)](#kix.rh6eayh1dl2y).A Martian photosynthetic organism would experience large changes in light levels with a need to capture light during dust storms if possible, and also to capture as much as possible during conditions of bright sunlight, so it might already have an adjustable antenna size and so have the advantages of both small and large antennas.

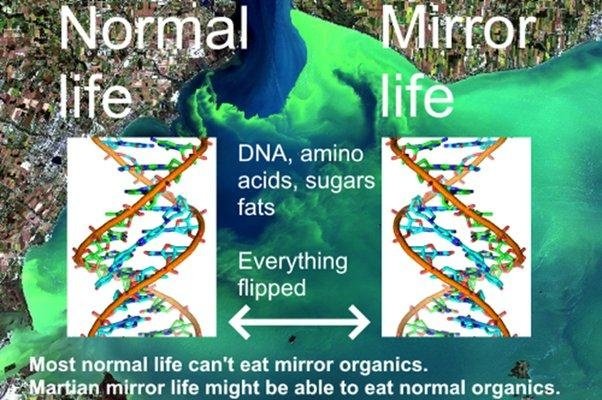
A Martian photoautotroph would only need a small improvement in efficiency compared to terrestrial life to be competitive with our photoautotrophs in the oceans, and there seem to be possibilities for major increases in efficiency. This Martian photoautotroph then might replace the natural species in our oceans.

## New worst case scenario of a mirror life chroococcidiopsis analogue from Mars which could gradually convert organics in ecosystems into indigestible mirror organics

The planetary protection literature doesn’t cover many scenarios in depth. In a search for new scenarios, I found many ways life from Mars can harm humans, our crops or ecosystems – as well as many ways it can be harmless or beneficial. These are for a future paper ([Walker, 2022b](#b_Walkker_2022b)). However, it may help to briefly mention one detailed worst case scenario, which as far as I know is new to the topic, to encourage space agencies to treat planetary protection more rigorously. This is a mirror-life analogue of Chroococcidiopsis, or indeed a mirror analogue with more efficient photosynthesis than chroococcidiopsis, from the previous section.

All terrestrial DNA spirals the same way and most of the organics that make up terrestrial life such as our amino acids only occur in one form (the amino acid glycine is an example exception as it is symmetrical). When a molecule can occur in two mirror forms, it’s called chiral. Terrestrial life is homochiral as nearly all chiral molecules occur in only one form.

We don’t know how terrestrial life became homochiral, with many proposed mechanisms [(Blackmond, 2019)](#kix.n0rgprjmenzc). Some experts say it is *“luck of the draw”*  [(Brazil, 2015)](#kix.2grzq8c9tonv). The theory of punctuated chirality suggests any initial chiral bias could be erased by local self reinforcing chiral networks of chemicals which expand, and flip chirality on an environmental scale, with these flips perhaps frequent in Early Earth. If so, life on Mars could have the opposite chiral bias to Earth [(Gleiser et al, 2008)](#b_Gleiser_2008):



Background image from [(NOAA, n.d.cwcu),](#kix.73mkfspkv7qy) DNA spiral from [(Pusey, 2012)](#kix.5wke44plkdgc)

If we could flip a cake in 3D, like reflecting it in a mirror, our metabolism couldn’t do anything with the flipped starches or proteins, and many fats would also be inaccessible [(Dinan et al, 2007)](#kix.8ecw6j7s9pbi)

Synthetic biologists plan to gradually flip ordinary to mirror life over a period of a decade or so – and will make sure synthetic mirror life is engineered to depend on chemicals only available in the laboratory. They warn escape of mirror life could cause major transformations of the terrestrial biosphere by locking up organics in unusable mirror forms ([Bohannon, 2010](#msx5f5igvnly)).

The biggest risk here is if mirror life gets enzymes (isomerases) that transform ordinary organic molecules into their mirror form. A few rare terrestrial microbes already use this in reverse to eat mirror organics [(Pikuta et al, 2016)](#kix.dx5amqll2t52). In the worst case scenario, mirror life has the enzymes to let it consume ordinary organics, but terrestrial life can’t make anything of the mirror organics ([Bohannon, 2010](#msx5f5igvnly))..

***Kasting:*** *“It would quickly consume all the available nutrients,” he says. “This would leave fewer or perhaps no nutrients for normal organisms.” …. As the CO₂ in the ocean was incorporated into inedible mirror cells, they would “draw down” CO₂ from the atmosphere … in about 300 years the bugs would suck down half of Earth’s atmospheric CO₂. Photosynthesis of most land plants would fail. “All agricultural crops other than corn and sugar cane would die,” … “People might be able to subsist for a few hundred years, but things would be getting pretty grim much more quickly than that.” After 600 years, we’d be in the midst of a global ice age. It would be a total evolutionary reboot—both Kasting and Church think mirror predators would evolve, but whatever life existed on Earth by that point wouldn’t include us..*

Any life on Mars, mirror or normal, likely has those isomerases because it needs to be able to eat both types of organics. That’s because nearly all martian organic is infall from comets, asteroids and interplanetary dust or made locally abiotic. Non biotic organics nearly always come in both normal and mirror forms.

Eventually many terrestrial microbes are likely to develop the necessary isomerases to eat it, but higher life couldn’t evolve so quickly. The outcome is a mix of normal and mirror organics. Kasting and Church’s worst case scenario is that mirror life retains the edge over normal life in this evolutionary race.

I think we would survive. We have already designed almost self-sustaining space habitats like the early Russian BIOS-3 based on plants grown for food, and oxygen, which in turn take up carbon dioxide and water from humans which should work in space, a more challenging situation [(Salisbury et al, 1997)](#kix.z752zjh2x4aq) [(Johansson, 2006)](#b_johansson_2006) .

We could enclose large areas of Earth with its tropical jungles, coral reefs etc, like Biosphere 2 [(UA, n.d.)](#b_UA_nd). But it would be a severely diminished world to leave to the next generation.

### Closely related worst case scenario of a shadow biosphere of mirror life nanobes that produce indigestible mirror life biofilms on Earth

For a closely related scenario, Earth and Mars exchange normal life, but Mars has a shadow biosphere with a different biochemistry that never got here like the hypothesis of a terrestrial shadow biosphere of nanobes ([Cleland, 2019](#kix.isfv99lfhkt8), pp [213](https://books.google.co.uk/books?id=eqCsDwAAQBAJ&pg=PA213)- [214](https://books.google.co.uk/books?id=eqCsDwAAQBAJ&pg=PA214)) which could co-exist with modern life. Earth doesn’t seem to have one (yet) but small cells have an advantage in an environment with low nutrient concentrations, as they have a larger surface to volume ratio, and so take up nutrients more efficiently. They would also avoid protozoan grazing [(Ghuneim et al, 2018)](#kix.6av2wm9nvy6g).

In this second mirror life scenario, Martian mirror life cells have a less sophisticated biology, but compete in a shadow biosphere on Earth because of their small size, with the extra advantage that they form mirror organics biofilms. These shadow biosphere biofilms are inedible to most terrestrial life and expand.

In these worst case mirror life scenarios, we may be able to reduce impacts, perhaps with engineered normal life predators of mirror life, or if Mars has both forms of life, we may be able to import these predators from Mars. However, these are scenarios to avoid, with consequences hard to predict.

## Many legal ramifications if a space agency takes on board the NRC study’s assessment that the risk of minor or major global harm from life from Mars is not demonstrably zero

There are numerous legal ramifications if a space agency takes on board the assessment of the National Research Council’s study, that the risk from martian life of minor or major global harm to humans or the environment can’t be assessed, and though likely low is not demonstrably zero. In the US, this means that other agencies such as the CDC, NOAA etc will need to look at the proposals. At some stage, international agencies like the FAO and WHO will get involved, international treaties triggered and domestic laws of other countries are also likely to be triggered. In short, great care is taken to make sure that Earth is kept safe [(Uhran et al, 2019)](#5ubwr36nczvc) [(Race, 1996)](#kix.7grd10futt6o).

In the other direction, if a space agency passes their sample as safe based on a claim of no potential for large scale harm to other countries, this may make it hard to object should another agency approve a riskier sample return from Mars based only on their internal legislation and a claim that they also assess that there is no risk of large scale harm.

## NASA’s draft EIS fails central requirements for a valid NEPA Environmental Impact Statement

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 omits important studies that overturn results it relies on. It also uses cites that contradict the sentences they are attached to without alerting the reader to this discrepancy.

*(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.

*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)

This wasn’t done and the public weren't given the opportunity to comment on a scientifically valid EIS. I hope NASA 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 the it should include the possibility of delaying the return until the risks are better understood

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*

### NEPA say to contact the agency to resolve issues, however NASA is not responding to attempts to contact them on this topic

NEPA say the first step is to contact the agency to resolve issues. However, the comments section of the draft EIS didn’t include responses to substantial issues I raised in May [(Walker, 2022a)](#b_Walker_2022) and NASA’s planetary protection office hasn’t responded to my attempt to contact them via email about issues I raised after the draft EIS was published. 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.

## 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

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?

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

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.

### 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

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

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).

### 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

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 shouldn’t take even a low level of risk

The public comments on 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 said variations on:

* test before the samples contact our biosphere, or
* stop the mission.
* 5 out of the first 24 specifically mentioned concerns about unprecedented harm (excluding my own comment here)

The first 25 comments summarized are:

* [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) – [(my comment)](https://www.regulations.gov/comment/NASA-2022-0002-0195) – [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-2022-0002-0197) – [test first](https://www.regulations.gov/comment/NASA-2022-0002-0204) – [test first](https://www.regulations.gov/comment/NASA-2022-0002-0203) – [could be very dangerous](https://www.regulations.gov/comment/NASA-2022-0002-0206)

Here are just the ones that mention unknown or unprecedented harm from then on:

* [unknown harm](https://www.regulations.gov/comment/NASA-2022-0002-0210) – [unknown harm](https://www.regulations.gov/comment/NASA-2022-0002-0214) – [unprecedented harm](https://www.regulations.gov/comment/NASA-2022-0002-0221) – [unprecedented harm](https://www.regulations.gov/comment/NASA-2022-0002-0223) – [unprecedented harm](https://www.regulations.gov/comment/NASA-2022-0002-0219)
* [unprecedented harm](https://www.regulations.gov/comment/NASA-2022-0002-0229) – [unprecedented harm](https://www.regulations.gov/comment/NASA-2022-0002-0232) – [unprecedented harm](https://www.regulations.gov/comment/NASA-2022-0002-0251) – [unprecedented harm](https://www.regulations.gov/comment/NASA-2022-0002-0245) – [unprecedented harm](https://www.regulations.gov/comment/NASA-2022-0002-0243)
* [unprecedented harm](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))

25 comments (including mine this time) specifically mention issues with unprecedented or unknown harm. Most of the remaining comments say stop mission or test first, and may be based on similar concerns.

We’ll see that the idea to test first before returning unsterilized samples doesn’t work. But sterilizing first would work. 12 said sterilize first, even though it’s not listed as an alternative action in the EIS.

* [sterilize first](https://www.regulations.gov/comment/NASA-2022-0002-0246) – [sterilize first](https://www.regulations.gov/comment/NASA-2022-0002-0217) – [sterilize first](https://www.regulations.gov/comment/NASA-2022-0002-0216) – [sterilize first](https://www.regulations.gov/comment/NASA-2022-0002-0218) – [sterilize first](https://www.regulations.gov/comment/NASA-2022-0002-0220) – [sterilize first](https://www.regulations.gov/comment/NASA-2022-0002-0251) – [sterilize first](https://www.regulations.gov/comment/NASA-2022-0002-0222) – [ensure safe or sterilize first](https://www.regulations.gov/comment/NASA-2022-0002-0210) – [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 comment on the last day of public discussion just says that in their review of the draft PEIS they didn’t identify significant environmental concerns

EPA posted on the last day of public comments. It 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 these comments by the general public. [(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.

### It’s essential for this mission to have broad acceptance at both lay public and scientific levels to succeed and this doesn’t look like broad acceptance - if NASA continues with this action it is vulnerable to being stopped at various future stages

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. Or 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 100% safe mission could cause problems if the general public aren’t convinced it’s safe. So this is by far the best outcome.

Assuming NASA continue with the EIS, it can be stopped 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. Environmental cases often depend 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
* 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?).

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).

The worst case for NASA may be if it gets past all those hurdles with little public awareness and then with samples already on their way to Earth, mounting global public concern leads to Congress and the president acting to tell NASA to divert the mission away from Earth. This could lead to many issues, infodemic, confusion, misleading statements about what NASA is doing and when the inadequate EIS is unearthed at this point it could cause many problems for NASA’s credibility.

## We can forestall all these issues and make the mission 100% safe by sterilizing samples before they reach Earth

We can forestall all these issues, and make the mission 100% safe from the outset by sterilizing samples before they reach Earth. What’s more we’ll see this has virtually no impact on either the geological or the astrobiological interest of the mission.

One way to sterilize it with minimal impact on geological studies is to duplicate surface ionizing radiation. Even the equivalent of 500 million years of surface radiation would have virtually no impact on geological interest, as rock samples from the ancient delta are 3 billion years old, and Perseverance can't drill to layers protected from surface ionizing radiation.

### Sterilization with 500 million years equivalent of surface ionizing radiation will have virtually no effect on geological studies

Allen et al tested the effect of sterilization of simulated Mars samples [(Allen et al, 1999)](#iaznka4yiw0c) with a gamma ray dose equivalent to 3 megagrays. There was no effect on radiometric dating, rock composition, crystal structure, no dehydration of gypsum, no changes in the spectra of the components of the Mars soil simulant. No effect on the basal spacing of montmorillonite, which is extremely sensitive to temperature and degree of hydration. The only change they found was a change in the colour of quartz (clear to deep brown) and halite crystals (to blue) and a change in their thermoluminescence properties. If the rocks have already had 3 billion years of ionizing radiation, these changes have likely already happened to Mars surface deposits.

### 500 million years of ionizing radiation would reduce a gram of amino acids to a milligram

By [(Kminek et al, 2006:4)](#59niufgu58xk) 500 million years at 200 milligrays per year reduces many amino acids to a millionth of the original concentration, however, that’s more than double the dose measured by Curiosity of 76 milligrays a year on the Martian surface [(Hassler, 2014)](#b_Hassler_2014) . Half the dose means a 1000 fold instead of a million fold reduction.

So, 500 million years of surface radiation at 100 milligrays a year, or 50 megagrays total, reduces many amino acids 1000 fold, with only one milligram left of every original gram of amino acids.

In the same way we can calculate the dose for an n-fold reduction as

x = 50 \* log(n) / log(1000) = 50 \* log(n) / 3.

n = 10^(3\*x/50) and the % destroyed for the dose x in megagrays is 100 - 100/ n.

So, a 4-fold reduction in amino acids needs around [10 megagrays](https://www.google.com/search?q=50+*+log(n)+%2F+3&oq=50+*+log(n)+%2F+3&) or around 100 million years of surface radiation. That might be more than enough since Radiodurans can only survive 0.14 megagrays when dessicated and frozen [([Horne et al, 2022](#b_Home_2022))](https://www.liebertpub.com/doi/pdf/10.1089/AST.2022.0065?fbclid=IwAR3b2cGbAu_2Wu9bFHYTfUblARsZRIkFExalSwY5gSMDa2ubEGei7uNPobc) which works out as an approximately [1.02](https://www.google.com/search?q=10%5E(3*0.14%2F50)&oq=10%5E(3*0.14%2F50) fold reduction in amino acids, destroying around 2% of the amino acids.

We can also calculate the figure for the JAXA samples mentioned earlier. Any that got to Phobos over 18.5 million years ago had a dose of over 1.85 megagrays, so at least [22.5%](https://www.google.com/search?q=100-100+%2F+(10%5E(3*1.85%2F50))) of many of the amino acids are destroyed.

This sterilization would reduce the amounts of past organics in the samples, but there is likely so little left of past organics after 3 billion years of surface ionizing radiation that even a small amount of forward contamination will overwhelm it.

### Amino acids exposed to 3 billion years of surface radiation have been reduced from grams to attograms, a billionth of a billionth of a gram – meanwhile infall from space adds about 60 micrograms per gram but is constantly destroyed by surface processes

Using the same calculation, amino acids that have been on the surface for 3 billion years got reduced by leaving only one attogram for every original gram of amino acids (a billionth of a nanogram, which in turn is a billionth of a gram).

These minute traces of past organics may also be mixed with infall from space [(Frantseva et al, 2018)](#kix.43cshwr9iept). Many processes degrade the surface organics, but without them, Mars would have around 60 ppm or 60 micrograms per gram of organics infall, averaged over its entire surface to a depth of a hundred meters ([Goetz et al, 2016:247](#kix.5ee0degz9iqz)) as well as indigenous abiotic synthesis.

Even if Mars had abundant life in the past and has slowly growing extant life in microhabitats almost everywhere at lower latitudes, still, nearly all the organics will be infall from meteorites, comets, interplanetary dust and in situ abiotic processes .[(Mulkidjanian, 2015)](#kix.m9ljf4kqi22z) [(Westall et al, 2015)](#kix.lndwqsud7oy4) [(Franz et al, 2020)](#kix.sakk9guw1dxu).

This is why astrobiologists devised ultra sensitive instruments such as astrobionibbler able to detect just a single amino acid in a gram [(Schirber, 2013)](#kix.yjlj3rortisy) [(Noell et al, 2016)](#kix.p67mg41cwbkw).

### 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 a few cells per gram of present day life even if viable

Given these figures, sadly, Perseverance’s permitted levels of forward contamination are too high for the samples to be likely to be of much astrobiological interest, Perseverance’s engineers believe they achieved a maximum of  0.7 ppb or 0.7 nanograms per gram for their most abundant biosignatures  [(Boeder et al, 2020: table 6),](#b_Boeder_2020)

Text on image: Example of how design decisions for Perseverance were based on engineering and geology rather than astrobiology.

This tube was used to collect the first sample from Mars.

For a geologist, it is exceptionally clean, at most 8.1 nanograms of organics and at most 0.7 nanograms per biosignature.

For an astrobiologist, 0.7 nanograms per biosignature is enough to fill at least 7,000 ultramicrobacteria with just that biosignature, e.g. glycine, or DNA (maximum volume 0.1 cubic microns per ultramicrobacteria)

Astrobiologists need 100% clean sample containers with no organics. Their life detection instruments designed for in situ searches on Mrs can detect a single amino acid in a gram.

For engineers, sterilization would add an extra mission critical failure point because they would need to open the sterile container for the tube on Mars. 


Sample tube photo from [(NASA, n.d.pst)](#b_NASA_nd_pst)

That’s well above the attograms that might remain for past life if lucky enough to sample it. Meanwhile present day life might not be present at more than a few ultramicrobacteria per gram, so a few picograms (thousandths of a nanogram) per gram unless Perseverance serendipitously samples a biofilm. So, Perseverance seems unlikely to be able to detect martian life, past or present in its sample tubes, even if by chance it returns it.

## 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”

So in short, sterilization preserves virtually all geological interest, and because of the forward contamination of the samples, it will have minimal impact on astrobiological interest.

NASA’s draft EIS wouldn’t permit this alternative because it says unsterilized samples need to be returned to Earth for “safety testing” in its Purpose and Need ([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.**

However if samples are sterilized before they reach Earth they don’t need safety testing. This requirement seems to improperly exclude a reasonable alternative. By the U.S. Court of Appeals for the Seventh Circuit in Simmons v. U.S. Army Corps of Engineers [(7th Circuit, 1997)](#b_7th_circuit_1997), it is contrary to NEPA for agencies to

“contrive a purpose so slender as to define competing `reasonable alternatives' out of consideration (and even out of existence).”

### Even if sample are returned unsterilized this “safety testing” seems to serve no useful purpose as all the samples would test positive for life and we have no way to distinguish terrestrial from potential martian life from the biosignatures or to reliably cultivate even terrestrial life in a lab

Meanwhile if samples are returned unsterilized, NASA’s “safety testing” seems to serve no useful purpose. By their own cite [(Kminek et al., 2022)](#b_Kminek_2022) it is practically impossible to assess the environmental impact if life is found, so the only testing they can do is for presence of life or not.

*During the Working Group’s deliberations, it became clear that a comprehensive assessment to predict the effects of introducing life in new environments or ecologies is difficult and practically impossible, even for terrestrial life and certainly more so for unknown extraterrestrial life.*

This cite goes on to discuss how to test for life by checking for biosignatures. However, by Perseverance’s permitted levels of forward contamination, they are guaranteed to generate false positives for all the samples tested. The next stage is that the samples all go to “hold and critical review”.

This cite doesn’t say what would happen next, but we currently have no way to reliably distinguish terrestrial from potential martian biosignatures. Swabs of Perseverance’s clean room found many microbes only detected through their 16S RNA ribosome subunit, with four not closely resembling any known terrestrial life ([Hendrickson et al., 2021](#b_Hendrickson_2021)). It would be impossible to use sequencing to prove they aren’t martian after taking them to Mars and back again.

Also we can’t reliably test for viable martian life by attempting to cultivate it. Even terrestrial life is often impossible to cultivate in laboratory conditions. It may need a nutrient poor medium, have generation times of 6 months or more, or depend on other microbes in biofilms for amino acids or even nucleotides, yet be widespread outside the laboratory ([Solden et al, 2015](#b_Solden_2016)). The vast majority of microbial species haven’t been characterized or sequenced or cultivated in the laboratory. This is the problem of “microbial dark matter” [(Dance,2020)](#kix.41z9kctjpkl7).

### Too early for any form of safety testing 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

It's actually too early to do ***any*** form of safety testing, even with samples returned in sterile containers, at least, not at the level of assurance needed when there is potential for large scale harm.

We could destructively test 10,000 grains of uncontaminated dust individually – and perhaps the 10,001th grain has a viable microbe which we can’t detect without destroying it. We could destructively test 10 grams for biosignatures, and the next milligram contains a viable microbe.

From simulated wind blown Martian dust, microbes can indeed get attached to a dust particle and blown in the winds [(van Heereveld et al, 2017)](#kix.jrn9ywlbx47r) [(Osman et al 2008)](#kix.l7ygxnpz1coq). A viable microorganism could be imbedded in a dust grain [(Sagan et al, 1968)](#kix.fpa6qyxsabjo). The iron oxides shield the microbe from UV but also hide a microbe from non destructive tests, such as Raman spectroscopy or autofluorescence which in any case are also less reliable, and then there’s the issue that we don’t know for sure what to look for by way of biochemistry.

### So “safety testing” is not feasible at present, and sterilization keeps Earth 100% safe with likely virtually no difference to the science return

In short, this “safety testing” for unsterilized samples isn’t feasible at present. It may be possible later once we know more about Mars, how to identify the life and what harmful capabilities it has if any.

Meanwhile sterilization keeps Earth 100% safe with virtually no difference to the geological or astrobiological science return.

So, how practically can we sterilize samples before they reach Earth while still maintaining effectively zero risk of harm?

## Samples can be sterilized in a satellite similar to those for Geostationary orbit, but above GEO – and the spacecraft can be returned through low energy ballistic transfer without aerobraking or even flybys of the Earth or Moon

We might be able to use nanoscale x-ray emitters on the return journey [(Kim et al, 2016)](#kix.rrf3whc22g), but if not, we can return it to a larger satellite similar to a geostationary satellite for sterilization.

We need to avoid aerobraking and we can do that using “ballistic capture”, also known as “weak stability boundary transfers” [(Topputo et al, 2015)](#kix.y6m27dagydba), the low delta v, fuel efficient, three or four body transfer orbits first used for the Japanese Hiten mission in 1990 [(Belbruno, 2018)](#kix.1k2em0jzw5rw). The ESA Earth Return Orbiter will use continuous low thrust transfer [(Huesing et al, 2019)](#b_Huesing_2019), ideal for such an orbit.

One way to avoid aerobraking is to return the sample via a lunar retrograde orbit (actually a prograde orbit around Earth but retrograde around the Moon) [(Lock et al, 2014)](#kix.5ndcbcm6dzkm).

However, an especially promising low energy trajectory avoids even flybys of Earth or the Moon. This is the reverse of the trajectory in figure 13 from [(Kakoi et al, 2014](#kix.nbfharykgi6q)). It uses a halo orbit manifold to spiral from ballistic capture to a halo orbit around Sun Earth L2, the unstable gravitational point of balance between Earth and sun, which is on the far side of Earth from the sun as well outside the orbit of the Moon.

This then dovetails to another manifold to spiral down to a halo orbit around Earth Moon L2 point of gravitational equilibrium above the far side of the Moon, which dovetails to a low energy transfer to an Earth Moon L1 halo above the near side, and then the spacecraft slowly reduces the size of its orbit around Earth and circularize it in an orbit well above GEO.

We can then target the Laplace plane inclined at approximately 7.2° from the equatorial plane. This is a proposed “graveyard orbit” for GEO satellites at end of lifetime as even large light fragments of cladding from the satellites stay trapped well away from GEO, through the balance of the light pressure from the sun and gravity ([Rosengren et al, 2013](#27jnhf5eskov)). It’s where ring particles would orbit if Earth had a ring system. The sterilizing sample could be placed, say, 100,000 km above this proposed GEO disposal orbit. This is very safe as the delta V is over 1 km / second to both Earth and the Moon.

### This keeps Earth 100% safe with virtually no loss to science and little change in NASA’s budget – since they save the cost of a Sample Receiving Facility – estimated at $471 million in 2015 US dollars for the 1999 technology specifications

Launch costs to above GEO wouldn’t be prohibitive for NASA as the Falcon Heavy can already deliver over 25 tons to GEO at a cost of $150 million and launch costs are sure to go down. The satellite could be less than a ton in mass even including the mass of a sterilizer unit.

In this way we keep Earth 100% safe, with virtually no loss to science and little change in overall budget. NASA add the cost of the sterilizing satellite, but they save other costs including the cost of a sample receiving facility on Earth, estimated at $471 million in 2015 dollars [(Mattingly, 2010:20)](#kix.725l5y4f81l7) based on the 1999 size limit. There are no designs available or costs for the 2012 ESF size limit review but it would likely cost more if it is feasible at all. They also save on the mass of the aeroshell, and the fuel budget to take it to Mars and back again.

## We could transform this into a much more interesting mission for astrobiology with little change in the overall budget by adding bonus samples collected in a STERILE container sent on the ESF fetch rover of dust, dirt, atmosphere and some pebbles for a technology demo of a rock sample return

With more ambition, and not much change in the budget, we could transform this into a much more interesting mission for astrobiology.

Perseverance’s geology focus dates back to an oversight present from the mission’s inception a decade ago. The decadal review in its summing up said [(Space Studies Board, 2012:17)](#kix.3x8s1sakyp9f).

***Mars science has reached a level of sophistication such that fundamental advances in addressing the important questions above will come only from analysis of returned samples.***

They relied on a 2002 paper, Safe on Mars from a time with a much simpler understanding of Mars and less capable instruments for in situ studies ([Space Studies Board, 2002a](#kix.fph6gak1xp10), chapter [5](https://www.nap.edu/read/10360/chapter/7):[38](https://www.nap.edu/read/10360/chapter/7#38)) and even then it said that:

***"If such capabilities were to become available, one advantage is that the experiment would not be limited by the small amount of material that a Mars sample return mission would provide. What is more, with the use of rovers, an in situ experiment could be conducted over a wide range of locations."***

A white paper submitted to the decadal review by astrobiologists emphasized the need to be able to detect life in situ before we can intelligently decide which samples to return [(Bada et al, 2009:7)](https://mail.google.com/mail/u/1/?ui=2&ik=5fe299b9b7&view=lg&permmsgid=msg-a:r7390408788637707510#m_2869046682696390255_m_-1972427842941295334_m_-7564448782541179972_m_20121669073991):

***We feel that organic detection efforts over the next two decades via investment into advanced in situ robotic instrumentation are fundamental in support of a future intelligent MSR mission.***

*Currently, MSR is regarded by much of the scientific community as largely weighted towards a technology demonstration as the rationale for good astrobiology will not be apparent until we discover more about our neighboring planet.*

Other studies came to the same conclusion [(Paige, 2000)](#kix.jbi8mnfxz305) [(Davila et al, 2010](#kix.ngzkl9svh8bg)).

Since then astrobiological instruments continued to get smaller and more capable, while our understanding of past and present day habitability of Mars gets more complex. The now overwhelming case for in situ study for astrobiology continues to get stronger.

That is for future missions.

However one thing astrobiologists are sure to do is to study the dirt and dust in situ on Mars. The dust is like a collection of tiny rocks from the rest of Mars. If we are lucky it might snag some life along with the dust. The dirt can help us understand conditions on the surface of Mars. We already were surprised by the perchlorates in the dirt, and can’t know what other surprises we might find that may lead to new research directions [(David, 2015).](#b_David_L_2015)

These studies could also resolve the puzzle of the Viking labelled release. Did it find life or complex chemistry? Miller’s discovery that the Viking evolved gases were offset 2 hours after the temperature maximum [(Miller et al, 2002)](#kix.s9xdd9f9w2d6) raises intriguing questions that need answers. If Viking found life these samples might return viable or dead propagules in the dust or dirt, and if instead we find complex chemistry, this would make Mars surface simulation experiments and studies more accurate – and perhaps be of interest for prebiotic synthesis?

We might also find subtle abiotic processes such as abiotic photosynthesis, or abiotic nitrogen fixation. Mars could have an abiotic nitrogen cycle with photochemically produced HNO₃ fixed in thin (0.2 to 5 nm) pure water metastable interfacial films, potentially supporting up to one kilogram of fixed nitrogen per square meter [(Boxe et al, 2012)](#kix.bv2a2sn74414)

To make a start on these questions, we could add a STERILE container to send to Mars on the ESF fetch rover to return bonus samples of dirt, dust and atmosphere without forward contamination.

**Diagram

Description automatically generated**We have already sent 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 connected with the sampling experiments. Jakosky et al propose sending a similar experiment to Mars in a small sample tube sized container or alternatively a larger container to return 100 cc of atmosphere. This is how it works.

First it uses the getter to remove evolved gases from the container wall. Then it closes one microvalve and opens another to get an atmospheric sample. Finally it closes both microvalves to the gas container and opens the vent to run more atmosphere through the compressor to collect dust in the filter [(Jakosky et al, 2021)](#kix.c8nc02yubaxs)

Assuming a volume of, say, 50 cc of dust, and a dust density of 0.5 grams per cc, it could return up to 25 grams of dust.

This is enough to detect life at around one cell per gram or less. This is also a useful first upper bound of the amount of life in the dust if none is returned.

We can then add a scoop of dirt and return it all in a separate small sealed sterile container which goes to Mars on the ESF fetch rover.

We could also make Perseverance into a far better rock sample return technology demo for astrobiology by returning CLEAN rock samples. The ESA fetch rover could use a sterilized scoop and pick up a sample of dirt along with a few small pebbles / rocks. This would demonstrate the capability to return rock samples without forwards contamination, and by returning a clean rock, could help with fine details of surface chemical / abiotic processes

### These clean samples can be studied above geostationary orbit in Mars simulation conditions with a Martian gravity centrifuge – not for safety testing, humans never go near the satellite – it’s the first try out for the supersensitive instruments that astrobiologists have developed to send to Mars to find life in situ

These clean samples could be studied above geostationary orbit, in Mars simulation conditions with a centrifuge for artificial martian gravity – which would make it unique as a facility, as we can’t simulate martian gravity accurately on Earth.

These samples would be returned to a small robotic satellite and NOT a human occupied space station like the ISS. In the backwards direction, quarantine can’t protect Earth from mirror life or indeed fungal diseases. Two zinnia plants on the ISS died of a fungal disease fusarium oxysporum [(NASA, 2016)](#b_NASA_2016) probably brought there on an astronaut’s microbiome [(Urbaniak et al, 2018)](#kix.nlri9gi4x7wt). It is also an occasional opportunistic pathogen of humans [(Urbaniakt al, 2019)](#kix.54k04aufndc2). As we mentioned, chroococcidiopsis species are sometimes found in the human microbiome including in the nasopharyngeal microbiota ([Ventero et al, 2022](#b_Venetero_2022)), and in human milk from Gambia ([Lackey et al, 2019](#b_Lackey_2019)), so it’s unlikely a mirror life chroococcidiopsis analogue could be kept out of Earth’s biosphere by human quarantine of technicians or astronauts.

In the forward direction, an unmanned satellite let’s us study martian life in far cleaner conditions than a human occupied space station, as ultramicrobacteria can get through HEPA filters both ways.

This orbital lab is still not for “safety testing”. Suppose we successfully cultivate life from the sample, and detect familiar life, a novel strain of a familiar microbe such as chroococcidiopsis. Even then, this could bring new capabilities to Earth acquired from billions of years of evolution in Martian conditions. It would also be hard to prove that there is no other life in the sample.

The dust and dirt samples are just a start. There is likely no shortcut alternative to Sagan’s “*exhaustive program of unmanned biological exploration of Mars”.*

This orbiting astrobiology lab is the equivalent of one geostationary satellite far above GEO. Humans can study the dust, dirt and atmosphere as they would on Mars using exquisitely sensitive in situ instruments designed for end to end sample preparation to analysis - these already exist such as LDChip300 (antibodies) almost sent on Exomars but descoped [(Parro et al, 2011)](#kix.2d65a8o2aygj)., the gene sequencer SETG [(Mojarro et al, 2016)](#kix.2ip74fxhqd30)., astrobionibbler able to detect a single amino acid in a gram  [(Schirber, 2013)](#kix.yjlj3rortisy) [(Noell et al, 2016)](#kix.p67mg41cwbkw), a chiral version of the Viking labelled release experiment [(Anbar et al, 2012)](#kix.eugxrcbmglly), and many others.

Bonus samples in STERILE containers returned to satellite perhaps 50,000 or 100,000 km above GEO in what would be Earth’s ring plane if it had a ring system.

NOT for safety testing

Returned for astrobiological study – nexus of expanding off-planet astrobiology lab.

Minimal forward contamination.
Humans nowhere near this.

Centrifuge to replicate martian gravity.
Many instruments placed in centrifuge along with the dust and operated remotely from Earth.
Chiral labelled release.
SETG from sample acquisition through to DNA sequence all automated in 2 units, each can be held in palm of hand.

Astrobionibbler microfluidics can detect a single amino acid in a gram of sample



Graphic shows:

GEOS17 ([Clark,, 2018](#b_Clark_2018)) just to have an image of a geostationary satellite, not that it would be a $2.5 billion dollar satellite.

SETG from [(Mojarro et al, 2016)](#kix.2ip74fxhqd30)

Astrobionibbler from ([Elleman, 2014](#b_elleman_2014))

ISS centrifugal motor for plant experiments, diaable to any level from microgravity to 2 g [(NASA, n.d.)](#b_NASA_nd_cr)

[need to turn those links into cites]

The Moon may seem a better place to return the samples if we have a continuous human presence in a base on the Moon by the 2030s. Humans close by could reduce latency for teleoperation and might make it easier to add or remove equipment and supplies.

However, latency for telerobotics from Earth would remain reasonably low above GEO, we can send multiple ton missions up there at low cost, and COSPAR guidelines for category 5 (sample return) missions currently say that [(COSPAR, 2011)](#kix.9np6swoargx) [(Debus, 2004)](#kix.90rfza76n8fi)

*"(The Moon must be protected from back contamination to retain freedom from planetary protection requirements on Earth-Moon travel)".*

### With yet more ambition we can search for past organics using a Marscopter to return pebbles excavated by a recent crater to a depth of 2 meters or more – as a technology demo and first look at organics from 3 billion years ago though unlikely to return life with the first sample found

With yet more ambition, we could search for past organics. It might be enough to sterilize a separate sample collector which is lifted by the Marscopter and used to acquire a rock sample.

We could search for a crater recently excavated to 2 meters and the marscopter could search for an exposed pebble which by the geological context was exposed from 2 meters depth, and with minimally degraded organics. This is not likely to return recognizable past life unless the marscopter has in situ multiple biosignature detection, but this could be a start towards investigating organics from 3 billion years ago in Jezero crater, and how it’s been chemically altered since then, to use to help plan future in situ studies and later sample returns.

A typical small crater of 16 to 32 meters in diameter can excavate the surface of Mars to more than 2 meters. An observational study by Daubar et al found that this size of crater excavated the surface to depths of between 2 and 9 meters (based on seven newly formed craters at this size in Figure 4 of [Daubar et al, 2014](#kix.1cyurw3kmey)).

This is deep enough to find organics not significantly damaged by cosmic radiation even after three billion years. It may also be able to penetrate below the average depth of impact gardening by meteorites. The fines dominated regolith in Jezero crater is estimated as 2 to 5 meters thick [(Schuyler et al, 2020)](#kix.h9af5ssvjett). In the size range 16 to 32 meters the crater rate is about 2.57 craters per square kilometer every ten million years (1.9 + 0.67 for first two rows in table 1 of [Hartmann et al, 2017](#kix.ipone8p2y1m1)). For more on this and some of the other suggestions here see my draft for a future paper ([Walker, 2022b](#b_Walkker_2022b)).

### With even more ambition we could make a 100% sterile marscopter by specifying components able to resist heating at 300 C for several hours – which can be flown to sensitive locations with no risk of forward contamination and retrieve samples with no risk of backwards contamination

With even more ambition, we could make a 100% sterile marscopter by specifying components that are not affected by preheating to a few hours at 300 C. It could be flown to nearby RSLs or other sensitive locations with no risk of forward contamination, and it could be used to return contamination free rock samples such as pebbles or rock fragments from crater rims or crater floors. Our technology has advanced since the Viking landers which were baked for 112 °C for 30 hours, enough for a million-fold reduction of the originally low population [(Beauchamp, 2012)](#kix.kebgt1qylud6).

We now have high temperature microprocessors and memory devices for oil wells, aviation and electric cars. Their heat resilience means they don't have to be cooled, and they can be placed closer to heat sources such as engines. This helps with cost, weight and most important, reliability [(Watson et al, 2012)](#kix.zqrftage3yi).

At 250 °C the half life of the RNA bases under hydrolysis is between 1 and 35 minutes, and at 350 °C the half-lives are between 2 and  15 seconds  [(Levy et al, 1998)](#b_Levy_1998). Eight of the 20 amino acids have been proven to not just evaporate or liquify but to decompose at temperatures between 185 for Q (Glutamine) to 280 for H (Histamine)  [(Weiss et al, 2018)](https://docs.google.com/document/d/1QJgApnOW88OXgjuC7ktzaYiiE7UQHay2ihBWC9TARKw/edit#bookmark=kix.xj8cvvlk7n1d) There might be other more recalcitrant organics remaining but it seems that this should be sufficient to eliminate both forwards and backwards contamination.

The Venus lander teams sketched out a design for a largely mechanical rover with minimal onboard electronics capable of functioning at Venus surface temperatures of around 500 C, as part of Venus Rover studies. The researchers proposed that the same approach could be useful for planetary protection [(Sauder et al, 2017, section 6.2)](#kix.n59cqt9s3mjo).

Since then, temperature technology continued to improve. NASA’s HOTTECH program has developed sensors, imagers, solar arrays, batteries, electric motors, actuators, and other technologies that work even at 500 C for at least 60 days for a Venus surface lander [(NASA, n.d.)](#b_NASA_nd_hottech). The Long-lived in-Situ solar system explorer (LLISSE) is a design for a complete in situ Venus surface probe that can meet this specification with no active cooling ([Kremic et al, 2021](#b_Kremic_2021)).

By using some of that technology plus commercial off the shelf components we could achieve specifications for a Marscopter that is essentially the same machine, except that it can be heated to 300 C for a few hours, finally perhaps cleaned with carbon dioxide snow – and shipped to Mars in a container only opened on the surface – which could then be flown to nearby sensitive sites such as the RSLs with no risk of forwards contamination, and be used to collect samples for return for analysis in the automated lab above GEO. This could be the first of many 100% sterile rovers we could use in the future to explore sensitive areas of Mars.

### NASA have an opportunity to set precedent for future missions to keep Earth 100% safe – and if we find life on Mars that can never be returned safely it may stimulate rather than discourage space exploration and settlement

NASA have an opportunity to set a precedent to keep Earth safe. Other countries are likely to follow its example, or indeed, collaborate in a multi-national astrobiology sample handling and pre-processing lab above GEO – in a similar spirit to the ISS but far lower cost.

If we do find life on Mars that can never be returned safely, this may stimulate rather than discourage vigorous space exploration and settlement. The first astronauts to Mars might study the surface remotely in a spectacular orbit that flies near to both poles twice a day and skims in close over a different part of Mars on the opposite sides of the planet twice a day.

[](https://www.youtube.com/embed/BftmbvBd5m4?feature=oembed)

Video: [One Orbit Flyby, Time 100x: Mars Molniya Orbit Telerobotic Exploration in HERRO Mission](https://www.youtube.com/embed/BftmbvBd5m4?feature=oembed)

Early astronaut explorers would likely use two spacecraft joined via tethers for artificial gravity to stay healthy, simulating mars gravity perhaps, and then operate surface marscopters, rovers and other surface assets, similarly to avatars in a computer game.

In the scenario where Mars has mirror life or other life that can never be returned to Earth, settlers in orbital settlements or on the Martian moons could make 100% sterile rovers in surface factories controlled as in the game of civilization. It would be similar to exploring the Venus surface, or the Jupiter cloud decks or other parts of the solar system where humans can’t go safely.

A picture containing transport, satellite

Description automatically generated

Main image: [NASA, 2012](#NASa_2012tchh) “Safely tucked inside orbiting habitat, space explorers use telepresence to operate machinery on Mars, even lobbing a sample of the Red Planet to the outpost for detailed study."

Inset image of a tele-operated Centaur as an insert. Carter Emmart / NASA Ames research center [(Mann, 2012)](#b_Mann_2012)

### We might later be able to return even mirror life to Earth – sketch for a potentially 100% safe lab even with the prohibitory version of the precautionary principle

Even if we use the prohibitory version of the precautionary principle and find mirror life on Mars, it might be possible to return it to a future sample receiving laboratory on Earth with appropriate precautions. I sketch out an idea for a way this could be done in my preprint ([Walker, 2022b](#b_Walkker_2022b)) using a titanium sphere surrounded by a Whipple shield for containment during re-entry, black box flight recorder technology for protection during transport, then final analysis in a telerobotic facility accessed via a sump filled with vacuum stable light oil sterilized with ionizing radiation and heated at high temperatures, and the whole thing inside a large externally maintained oven in a nuclear fallout shelter for end of life sterilization. This is just a sketch of basic scientific ideas not an engineering proposal.

There might be simpler ways to do it but this sketch may be enough to establish the possibility to achieve the high standard of “no appreciable risk” for the prohibitory version of the precautionary principle.

However, by then it may be preferrable to return it to a laboratory on the Moon or indeed on Phobos, for telerobotic study, if we have a scientific human outpost there.

### We can explore and exploit Mars without humans on the surface, as part of a vigorous program of exploration and perhaps settlement throughout the solar system

We can explore and exploit Mars without humans on the surface, settling the Martian moons and orbital space habitats, as part of vigorous exploration and perhaps settlement throughout the solar system. Humans and robots work together each doing what it does best. Torrence Johnson, Galileo Chief Scientist, put it like this in the foreword to Meltzer’s “Mission to Jupiter” [(Meltzer, 2007)](#kix.nfbetjdd3vdc)

***Torrence Johnson:*** *What we call robotic exploration is in fact human exploration. The crews sitting in the control room at Jet Propulsion Laboratory as well as everyone out there who can log on to the Internet can take a look at what’s going on. So, in effect, we are all standing on the bridge of Starship Enterprise*

My aim with this review is to do everything I can to help make sure voices and concerns of the public are heard, and that space agencies do a rigorous scientific review with full public involvement. I am sure somehow, the public will get their say, though I don’t yet see clearly how exactly it will happen.

# Titles of sections – for an outline of this paper

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

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*…*

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* [Comment posted December 5](https://www.regulations.gov/comment/NASA-2022-0002-0228)[th](https://www.regulations.gov/comment/NASA-2022-0002-0228)
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* [Comment posted December 20th](https://www.regulations.gov/comment/NASA-2022-0002-0254)

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*Indeed, not even all infectious human pathogens—let alone non-infectious pathogens— on Earth require a multicellular, macroscopic host to evolve harmful capabilities.*

*July, 1976, the month that VL1 [Viking Lander 1] landed on theMartian 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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