We must contain any life in Mars dirt that can’t get into meteorites

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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. Any recently deposited microbes there 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.

So, JAXA don’t need to take any special precautions. JAXA warned against using their meteorite argument for samples from the martian surface which never had to withstand ejection from Mars. But, NASA’s draft EIS says any life from Jezero crater can get here faster and better protected in a meteorite.

Which is right? JAXA. NASA shouldn’t use this meteorite argument.

NASA’s EIS proposes to return its samples to a Biosafety Level 4 facility. However, the European Space Foundation study in 2012 set size limits well beyond the capabilities of a BSL-4 and indeed beyond 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 makes almost no difference to astrobilogy value.

For a far more interesting mission we can return bonus samples in a sterile container 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 the planetary protection literature to encourage space agencies to take more care 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.

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.

Their 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 has 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. If there are diatoms on Mars, perhaps in the lakes beneath the polar ice ([Davis, 2018](#b_Davis_2018)), they 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)). They 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, vacuum, life below the surface of a rock, and so on, and similarly to diatoms, might have no way to get to Earth on a meteorite. The diatoms need wet conditions, the Martian microbes might need dust. For them, a sealed sample tube is like a miniature spaceship complete with dust, shielding from UV, and a small amount of martian atmosphere.

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.

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 they contact deep below the surface. There may be viable life on Phobos buried deep after ancient larger impacts on Mars.

However, we can't apply this argument to the Martian surface at this time. 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  [(Maki et al, 2019)](#kix.1thbwj2w2qtd).

The MEPAG review of 2015 raises these issues, first the 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."

“Special regions” here means regions where potentially terrestrial life could spread to colonize Mars. If it can be transported as viable spores in the dust, terrestrial life introduced anywhere could potentially spread to anywhere on the planet. Applied in reverse, viable martian life from anywhere could get to Jezero crater.

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

The other main finding the 2015 MEPAG review overrode was about microenvironments, which can be habitable in regions that seem to be 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.

As an example, 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 a small deposit could still be a potential microhabitat.

They can use micropores in gypsum too. In one study 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))

Diagram

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**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, for instance by looking for Nilton Renno’s biofilms ([Pires, 2015)](#kix.yo5n6xsddztt) or searching for micropores in salt or gypsum [(Conley, 2016)](#kix.8vsd5bxcvoe2) [(Davies, 2014)](#kix.t7ig6ibvcei5) or other potential local habitats.

We have an example already of how our knowledge of a landing site can change after a rover lands. NASA 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, with a tentative decision that it could approach within a couple of kilometers to image them but not study close up ([Witze, 2016](#Witzer_2015)). It 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).

The MEPAG and MEPAG review studied forwards rather than backwards contamination. Extant martian life may be more capable than terrestrial life after billions of years of evolution to survive transit in dust storms or may be better adapted to colder temperatures. It 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 could speed up chemical processes and can reduce the lowest temperatures for cell division for many microbial species [(Rummel et al , 2014:897)](#kix.im73nfot8zt5), and it might reproduce very slowly at first in such cold conditions (until the biofilm is established) with generation times of decades to millennia or more.

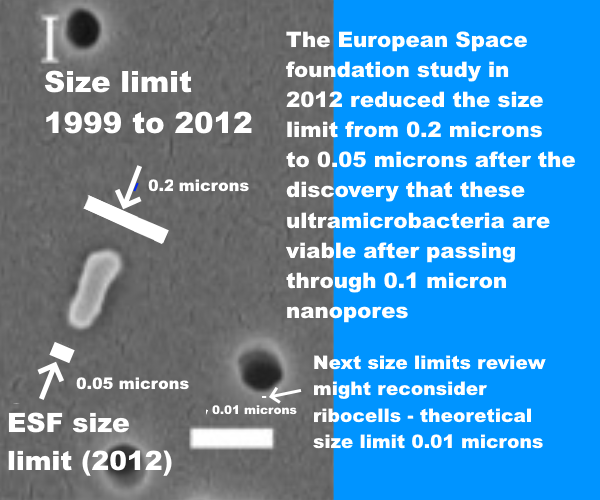
One of NASA’s major omissions is the European Space Foundation study in 2012 which reduced the size of particle we need to contain at the 1 in a million level from 0.2 microns to 0.01 microns. This was motivated by the discovery of fast horizontal gene transfer to distantly related archaea in sea water 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 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”***

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)).



A BSL-4 doesn’t need to contain gene transfer agents, ultramicrobacteria, or hypothetical early life. 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)).

NASA’s draft EIS also contradicts the planetary protection literature with its finding of no significant risk of environmental effects for life returned from Mars ([NASA, 2022](#b_NASA_2022eis): 3-3):

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 says it is not possible to assess the potential for negative impacts, and says 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.

NASA’s conclusion in this EIS that the potential environmental impacts would not be significant can be traced back to an assessment by its sterilizing subcommittee [(Craven et al., 2021)](#b_Craven_et_al_2021). This seems to represent a minority view amongst microbiologists [(MacGregor et al, 2001)](#b_MacGregor_2001)

First, arguing from many examples of pathogens adapted to humans, this 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 omits discussion of “opportunistic pathogens” not adapted to humans. Legionnaire’s disease, a disease of biofilms and protozoa infects human lungs and sometimes can kill us, without any human specific adaptations. For the microbe that causes Legionnaire’s disease, Legionnella, human lungs must seem like biofilms, and the macrophages in our lungs like large protozoa [*(Alberts et al 2002)*](#kix.dceso8baikzv).

It’s not likely these samples return an exact analogue of Legionnella, as it needs an oxygen rich aquatic environment to survive, can’t survive drying and can’t form spores. However, the way it invades the lungs could be relevant for a possible pathogen of martian biofilms, and 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 [(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 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, which can cause acute gastrointestinal disease in humans ([Cornelius et al, 2012](#b_Cornelius_2012)).

Perhaps it may help to add another example, opportunistic fungal infections. Opportunistic fungi kill an estimated 1.5 million people worldwide every year [(Brown et al, 2012)](#kix.jjb1r3cr4sax).

Fungi are potential Martian life analogues, especially the black fungi from Antarctica [(Selbmann et al, 2015)](#b_Selbmann_2015). One of them 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, and sometimes a serious pathogen for immunocompromised individuals. It is also naturally resistant to most antifungals on the market [(Urbaniakt al, 2019).](#kix.54k04aufndc2)

We have separate genus specific protections in our immune systems targeting each of the three main genera of human opportunistic pathogens, Candida, Aspergillus, and Cryptococcus [(Kumar et al, 2018)](#b_Kumar_et_al_2018). Perhaps without genus specific protections, we might all be immunocompromised against a new genus of fungi from Mars.

Some astrobiologists say that there is a possibility that more generally, 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.*

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 blue-green algae chroococcidiopsis, which can 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 it survives on just rock, water, and light, fixing CO2 and nitrogen from the atmosphere. It is an ancient polyextremophile with numerous alternative metabolic pathways it can utilize, including nitrogen fixation, methanotrophy, sulfate reduction, nitrate reduction etc [(KEGG, n.d.)](#kix.pj8o7osp4x21), 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 it can get energy by oxidising hydrogen produced in the rocks by various abiotic processes ([Puente-Sánchez et al., 2018](#b_Puente_sanchez_2018)).

Chroococcidiopsis is one of the best terrestrial candidates to flourish on Mars as it is one of the few organisms with the remarkable ability to repair even multiple double strand breaks in its DNA, for instance, when exposed to cosmic radiation on the exterior of the ISS ([Li et al, 2022](#b_Li_2022)).

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.

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):

A picture containing map

Description automatically generated

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)).

This issue becomes especially acute if mirror life obtains enzymes (isomerases) that transform ordinary organic molecules into their mirror form. A few rare terrestrial microbes can use this method in reverse to eat mirror organics [(Pikuta et al, 2016)](#kix.dx5amqll2t52). In the worst case scenario, mirror life consumes 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..*

If there is life on Mars, mirror or normal, it likely already has isomerases to metabolize organics of opposite sense - because nearly all martian organics are either made abiotically locally, or are infall from comets, asteroids and interplanetary dust, with organics of both senses.

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. We could enclose large areas of Earth with its tropical jungles, coral reefs etc (like the confusingly similarly named Biosphere II). But it would be a severely diminished world to leave to the next generation.

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.

There are numerous legal ramifications if a space agency takes on board the assessment of the National Research Council, 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.

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), with an immediate response in the next edition of the planetary report that it’s like building a house without smoke detectors [(Rummel et al., 2000)](#b_Rummel_2000).

Text

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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)) (Which they cite as National Research Council 2022)

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]

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

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

*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.

The main issues I identified were out of date science (like the BSL-4 recommendation), arguments overturned by their own cites, and that they didn’t consider the alternative of sterilizing samples before they reach Earth [(Walker, 2022a)](#b_Walker_2022). Several other commentators raised significant issues including some of the ones already mentioned as well as new ones ([Dehel, T., 2022](#b_Dehel_2022)) [(DiGregorio, 2022)](#b_DiGregorio_2022) ([Everline, C., 2022](#b_everline_2022))

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

However this is a matter that goes beyond the capabilities of engineers and scientists to make decisions for us. It raises many novel ethical and legislative questions.

As the NRC said we can’t actually assess the current level of risk. Experts may say in their opinion it is likely very low but they can’t know. It could be higher than we realize or lower than we realize.

If later we find only prebiotic synthesis on Mars, or slowly and imperfectly reproducing life with a biochemistry compatible with terrestrial predators, this means the current level of risk from back contamination is and always has been zero. The risk is only in the forwards direction, that we might lose the chance to discover and investigate early life or prebiotic synthesis on Mars.

On the other hand, if later we discover the scenario of a mirror life analogue of chroococcidiopsis on Mars, the current level of potential harm for martian life escaped from the facility is far higher than we currently assess it to be.

The 1 in a million threshold for a BSL-4 has become the "gold standard" for risk management through custom. That was in effect an ethical decision by regulators about levels of acceptable risk, though the actual origins of this figure are obscure. There is no way to derive this figure through engineering or science, but it’s become accepted by legislators, decision makers and the general public [(Ammann et al, 2012:27)](#qa4nethlmcdw):.

*While it is almost impossible to find a justification for it, it appears that the 10-6 value has been accepted and is now considered by regulators as being the ‘gold standard’ to be met to demonstrate excellence in risk management*

Although theoretically the risk of escape from a biosafety lab should never exceed 1 in a million, in practice there are far more escapes than that, often because of human error. To add some examples, one SARS outbreak in 2003 in Taiwan 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).

Escapes can also happen because of 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).

Once there is potential for novel large-scale harm, even if it’s likely a low chance, all this needs especially close scrutiny including other issues such as accidents, a fire at the facility or criminal actions.

The very worst case scenarios for martian life such as mirror life also introduce novel ethical and legal questions about how we handle situations where there is a potential for not just novel harm, but an unprecedented level of novel public harm. We can’t rely on the same one in a million 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.

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.*

This leads to novel ethical and legislative questions about how we assess such situations which aren’t covered by our prior decisions to accept a 1 in a million chance for escape from a BSL-4.

Another complication is that since we don’t yet know what is or isn’t on Mars, this 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).

This is an ethical decision for the public and legislators about whether to return unsterilized samples at all.

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)*

Carl Sagan wrote [(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.****.*

Dehel in his public comment on the draft EIS conveyed a warning from a video he recorded by Gill Levin who died shortly before the EIS ([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 [(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).

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.***

The public comments on an EIS are not a poll so we can’t derive a % for concerns, but they do show many members of the public concerned that this is a qualitatively different situation from a known pathogen in a BSL-4 lab.

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)

It continues in a similar vein through most of the remaining comments. These are just the ones concerned about 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))

That’s a total of 25 out of 76 comments (including mine this time) that 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 test first doesn’t work. The only options available for those who want to ensure no appreciable risk of harm, are sterilize first or stop the mission..

Several said sterilize first.

* [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)

So that’s 12 said to sterilize first if the samples are returned to Earth. Many more might say to sterilize first if an EIS mentions it as an option.

NASA’s proposed action may be stopped at various points. First NASA could withdraw the EIS.

Assuming they don’t do that, it can be stopped by a court case. NEPA doesn’t provide for judicial review directly. But it’s often a ground for litigation on the basis that the process hasn’t been carried out properly, For instance judicial review can be requested because ([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

This depends on someone with standing challenging it, which has to be someone who raised the issues as a public comment or during public debate and potentially directly affected by the proposed action. NEPA environmental cases are nuanced with complex legal decisions. Agencies sometimes prevent them getting to the courts by saying the petitioner is no more affected than anyone else, or saying that in their view there is no risk ([Birnbach, 1997](#b_Birnbach_1997)).

During the litigation the court can issue injunctions that ([Congressional Research Service, 2021](#b_CRS_2021))

* bar all or part of a proposed action

The result of the court case is usually ([Congressional Research Service, 2021](#b_CRS_2021))

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

After that, it could be stopped by the presidential directive NSC-25, which requires a review of large scale effects which could be reasonably expected to result in allegations of major or protracted effects even if the agency feels confident that such allegations are false. This is done after the NEPA process is completed [(Race, 1996)](#kix.7grd10futt6o). This directive says [(Whitehouse, 1977):](#b_WhiteHouse_1977)

“experiments which by their nature could be reasonably expected to result in domestic or foreign allegations that they might have major or protracted effects on the physical or biological environment … are to be included under this policy even though the sponsoring agency feels confident that such allegations would in fact prove to be unfounded.”

The worst case for NASA may be if it gets past all those hurdles with little public awareness until the samples are on their way to Earth, and then mounting public concern leads to Congress and the president acting to tell NASA to divert the mission away from Earth. NASA may then need to devise an ad hoc alternative plan for the diverted samples.

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

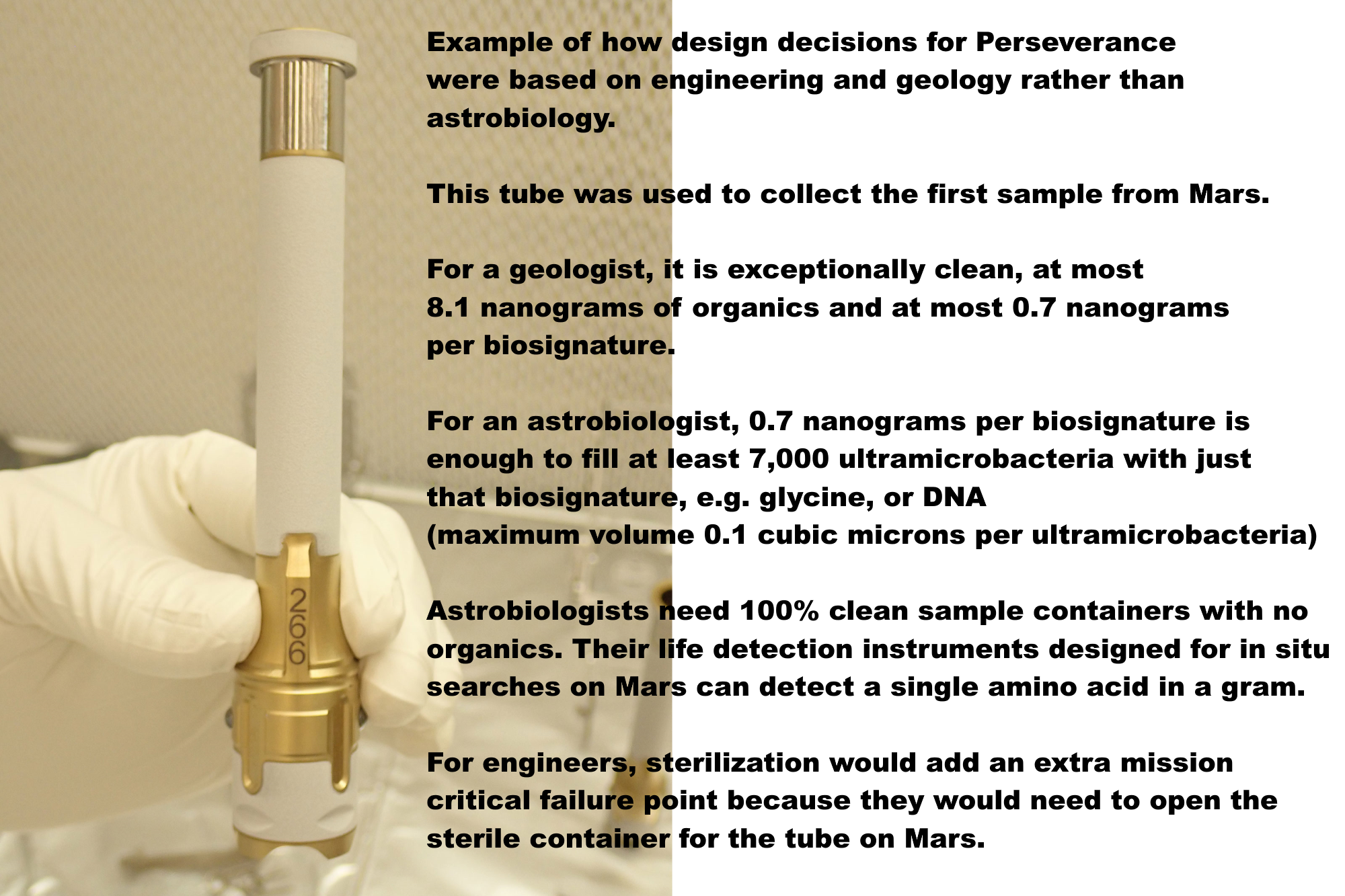
*“Broad acceptance at both lay public and scientific levels is essential to the overall success of this research effort.”*

We can forestall all these issues, and make the mission 100% safe from the outset by sterilizing samples before they reach Earth. One way to sterilize it with minimal impact on the geological studies is to duplicate surface ionizing radiation. Curiosity measured 76 milligrays a year on the Martian surface [(Hassler, 2014).](#b_Hassler_2014) Kminek et al [(Kminek et al, 2006:4)](#59niufgu58xk): assumed a yearly dose of 200 milligrays, and found that 500 million years at that dose, or 100 megagrays is enough to reduce many amino acids to a millionth of the original concentration. Adjusting to half the yearly dose, 500 million years of surface radiation at 100 milligrays a year, 50 megagrays reduces many amino acids 1000 fold, with only one milligram left of every original gram of amino acids.

Based on those figures, the dose x for an n-fold reduction is 50 \* log(n) / 3. So, a four-fold reduction corresponds to 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. Radiodurans when dessicated and frozen can survive 0.14 megagrays [([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 find the % destroyed = 100 - 100/ n = 100 - 100 / (10^(3\*x/50)) for the dose x in megagrays. So for instance for samples from the JAXA mission that reached Phobos over 18.5 million years ago, with a dose of over 1.85 megagrays, 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.

Even the equivalent of 500 million years of surface radiation could be allowed for and 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. After 3 billion years of ionizing radiation any remaining amino acids in any surface layers are 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). This is also 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. On Mars, even if there was abundant life in the past and widespread slowly growing extant life in microhabitats, 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).

As for 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)



With these levels of forward contamination, Perseverance is unlikely to detect life, past or present, even if by chance it returns it. Present day life is not likely to be present at more than a few cells per gram or a few picograms (thousandths of a nanogram) per gram even with the most optimistic projections unless Perseverance serendipitously samples a biofilm.

So, sterilization preserves virtually all geological interest with minimal impact on astrobiological interest.

The NASA draft EIS adds another reason for returning unsterilized samples. They say that they need to be returned to Earth for “safety testing”. But this isn’t needed for a sterilized sample return.

Even for an unsterilized sample return, their “safety testing” is guaranteed to find false positives. 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.*

They go on to discuss how to test for life by checking for biosignatures. However, with Perseverance they are guaranteed a false positive. The next stage is that the samples all go to “hold and critical review”.

Their cite doesn’t say what would happen next, but there is no way at present to 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 the presence of viable martian life by attempting to cultivate it. Even terrestrial life is often impossible to cultivate in laboratory conditions. It may need nutrient poor conditions, 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).

Even if we can return samples without contamination, it is still not possible to certify samples of dust, say, as free of life to the level of assurance we may need when there is potential for large scale harm. A viable microorganism could be imbedded in a dust grain shielded from UV by iron oxides in the dust [(Sagan et al, 1968)](#kix.fpa6qyxsabjo). Research with simulated wind blown Martian dust suggests microbes can indeed get attached to a dust particle and get blown in the winds [(van Heereveld et al, 2017)](#kix.jrn9ywlbx47r) [(Osman et al 2008)](#kix.l7ygxnpz1coq). The iron oxides would hide a microbe from non destructive tests, such as Raman spectroscopy or autofluorescence which 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.

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.

In short, until we know what to look for, there is no way to prove unsterilized samples are safe. This “safety testing” isn’t feasible at present, though it may be possible later once we know more about Mars and the capacities of any life there.

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?

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

Using the same criterion to aim for effectively zero risk of any contamination of Earth, the samples can be returned to a sterilizing satellite in the Laplace plane inclined at approximately 7.2° from the equatorial plane. This suggestion is based on a proposed disposal orbit for GEO satellites at end of lifetime. Even if the satellites explode or collide or fragment the fragments can’t harm satellites in GEO ([Rosengren et al, 2013](#27jnhf5eskov)). It’s where ring particles would orbit if Earth had a ring system. Samples could be returned to, say, 100,000 km above this proposed GEO disposal orbit. The delta V is over 1 km / second to both Earth and the Moon.

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. Meanwhile this saves the cost of a sample receiving facility on Earth, which the 2010 decadal review estimated at $471 million in 2015 dollars [(Mattingly, 2010:20)](#kix.725l5y4f81l7). That cost estimate is based on the 1999 size limit. There are no designs available or costs for the 2012 size limit review but it would likely cost more if it is feasible at all.

In this way we keep Earth 100% safe, with virtually no loss to science and little change in overall costs. It might be a cost saving for NASA.

However we could transform this into a much more interesting mission for astrobiology.

Several studies by astrobiologists concluded we need to be able to identify life in situ, and drill, for a reasonable chance to resolve central questions of astrobiology [(Paige, 2000)](#kix.jbi8mnfxz305), [(Bada et al, 2009)](#kix.b77th2810md), [(Davila et al, 2010](#kix.ngzkl9svh8bg)).

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 [(Board et al., 2012:17)](https://mail.google.com/mail/u/1/?ui=2&ik=5fe299b9b7&view=lg&permmsgid=msg-a:r7390408788637707510#m_2869046682696390255_m_-1972427842941295334_kix.3x8s1sakyp9f)

*The Mars community, in their inputs to the decadal survey, was emphatic in their view that a sample return mission is the logical next step in Mars exploration.*

***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.***

Board, S.S. and National Research Council, 2012. *[Vision and voyages for planetary science in the decade 2013-2022](https://solarsystem.nasa.gov/resources/598/vision-and-voyages-for-planetary-science-in-the-decade-2013-2022/" \t "_blank)*. National Academies Press.

For geologists that may be true. However, the only white paper submitted to the decadal survey by astrobiologists said the opposite, emphasizing the need for in situ studies before we know what to return to Earth [(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.*

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

However any in situ astrobiology mission would also analyse the dirt and dust it finds on Mars, and this much can be done with a returned sample. The mission could be made far more interesting by sending a STERILE container on the ESF fetch rover to return bonus samples of dirt, dust and atmosphere without forward contamination.

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. 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. At the high end of the range of views of astrobiologists on the habitability of Mars for extant life, these samples might find viable or dead propagules in the dust or dirt, and if instead they find complex chemistry, this could help make Mars surface simulation studies more accurate. Also (speculation), if we do find complex chemical reactions resembling circadian rhythms, might they be of interest for prebiotic synthesis?

We could also pick up a bonus rock sample too, as a technology demo for returning CLEAN rock samples, and it could help understand surface chemical / abiotic processes. The ESA fetch rover could use a sterilized scoop – and pick up a sample of dirt along with a few small pebbles / rocks.

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). Chroococcidiopsis is 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. 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.

Diagram

Description automatically generated with medium confidence

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 more ambition, we could do a technology demo for returning CLEAN rock samples using a presterilized marscopter. It might be enough to sterilize sampling handling components or we could sterilize the whole marscopter.

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 are now at the stage where we could aim for a 100% sterile rover. We could start with 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.

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, meaning that marscopters could access sensitive regions on Mars if they can be heated for a few hours at, say, 300 C first.

Or for a technology demo searching for past organics, it might be enough to sterilize a separate sample collector which is lifted by the Marscopter and used to acquire the rock sample.

We could search for a crater recently excavated to 2 meters and the marscopter could search for an exposed pebble from 2 meters depth with minimally degraded organics. This is not likely to return recognizable past life without in situ life 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)).

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)

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.

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. 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.

A picture containing transport, satellite

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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.

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[Dr David Williams](http://www.nhm.ac.uk/our-science/departments-and-staff/staff-directory/david-williams.html), a Researcher of Diatoms at the Museum, says 'Yes, technically tiny life forms such as diatoms and cyanobacteria could survive in these environments. But that is not the question we should be asking.

'A more interesting question is whether we would know what we're looking at, even if we did find something in the lake. Would we even be able to identify it as life, if it originated on Mars itself?'

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* [Comment posted December 13th](https://www.regulations.gov/comment/NASA-2022-0002-0237)

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*…*

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

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*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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