* **Short abstract (central points, 2,000 characters)**
* **Graphical abstract**
* **Abstract (long version)**
* **UPDATE – new streamlined NEPA process means NSAA can hope to complete the EIS in spring / summer 2023 with no more review if the EIS is not challenged**
* **Public comment on NASA’s draft environmental impact statement in 2022**
* **Introduction**
* **NASA agrees we need to protect Earth’s biosphere from Mars samples,** though they believe the surface of Mars is too inhospitable for life today
* **However it is hard to find even one astrobiologist who would agree with NASA** in their confidence that the Martian surface is too inhospitable for microbial life, and some astrobiologists say there is a significant possibility of present day life even in Jezero crater
* **NASA’s attempts to protect Earth in 1969 for Apollo 11 were judged to be inadequate by representatives of the National Academy of Sciences and Public Health Servic**e – but NASA overruled these objections, saying that they didn’t have time to make the required changes
* **This time NASA won’t be able to overrule objections by other agencies**, because of the NEPA legislation introduced in 1970
* **With the technology not yet ready**, 9 years for the build, and 2 years to train technicians, NASA can’t guarantee when they will be ready to receive unsterilized samples
* **Objections could lead to new design requirements – such as new filter technology or quarantine requirements** – and this restarts the clock for the build
* **Reviews by other experts or objections by the public during the legal process could lead to a requirement to contain nanobes even smaller than the 0.05 microns limit – perhaps as small as 0.01 microns, based on novel biochemistry such as mirror life** – or to an impractical “no appreciable risk of harm” standard – so NASA has to be prepared in case of a final decision that the required technology doesn’t yet exist
* **If NASA start the build before the end of the legal process they risk building a facility for samples when the final decision is that they can never return to Earth or that require far higher containment standards than current filter technology can achiev**e – and ESA risk launching spacecraft that can’t return samples to Earth directly
* With this end to end requirement, 2028 is the earliest date for NASA to provide detailed cost and schedule with engineering details, which they are required to do before the build starts – so 2039 becomes the earliest date for a sample return with delays beyond 2039 likely **[SECTION OUT OF DATE DUE TO NEWER STREAMLNED NEPA PROCESS]**
* **First proposed solution: to sterilize samples** – the extra radiation added to the levels already received on Mars is not likely to impact on geological studies, and any sterilized extant life would remain recognizable
* **Second proposed solution: to return unsterilized samples of astrobiological interest to a safe orbit above GEO for telerobotic study** then return sterilized sub-samples immediately
* **Sketch for a third proposed solution - to aim for 100% containment of any conceivable exobiology** with a facility in a nuclear bunker protected by a high temperature oil sump stable at 300°C, with samples inside the facility studied remotely by telerobotics
* **Perseverance’s sample tubes weren’t sterilized 100% leading to risk of false positives that may prevent distribution of unsterilized samples from containment** – estimated 8.1 nanograms maximum organic contamination per sample tube are equivalent to 81,000 ultramicrobacteria or 160 million hypothetical RNA world mirror nanobes
* **Potential for major cost savings if samples handling decisions are made before ESA launches their spacecraft** – such as building a sterilization capability into the spacecraft to permit it to return the samples direct to Earth – or removing the heavy aeroshell for the Earth Entry Vehicle as unnecessary weight
* **Proposals to sterilize all the samples or return to above GEO could be done with no possibility of risk to Earth’s biosphere** and minimal legal process
* **Mars has a higher potential for habitability today than the Moon as understood in 1969**
* **Could Mars be habitable but lifeless, perhaps with life in the past?** Cockell’s example scenario which leads to possibility of uninhabitable habitats and may reduce the likelihood of returning extant life
* **Proposed solution of a self sustaining barely habitable Swansong Gaia which might explain current conditions on Mars**, and increase potential for past life to continue to the present and of viable life returned in the sample
* **A prebiotic Mars, lifeless for billions of years, could still develop protocells, naked genes, Ostwald crystals etc** – theorized forms of “almost life” and life precursors of great interest to us - value of sterile containers to sample potential uninhabited habitats
* **Proposals to modify the ESF lander and sample selections to increase potential for returning viable present day or identifiable past life** with samples of the dirt, dust from the air during dust storms, and compressed large samples of Martian air collected in 100% sterile containers by the fetch lander – and to use Marscopters to search for freshly excavated young craters for Perseverance to sample
* **Some Mars colonization enthusiasts argue that no planetary protection is needed, however their arguments aren’t accepted by NASA** and wouldn’t be persuasive for the general public, other agencies or justices
* **Scenario based approach to explore the consequences if Earth or Mars develops a mixed biosphere involving two forms of biochemistry or alien species from the other planet** – such as mirror life, RNA world nanobes, early life cells that cooperate rather than compete before modern evolution, fungi and molds that our immune systems don’t recognize, or a new domain of life that is largely beneficial to terrestrial ecosystems similarly to the archaea
* **How to complete astrobiological knowledge gaps rapidly with future telerobotic study from Mars orbit**
* **Perseverance’s mission within the wider context of an ambitious vigorous program of exploration and potentially settlement in our solar system**
* **Modern legal processes didn’t exist at the time of Apollo - no legal precedent for a modern restricted sample return**
* 1969 Apollo procedures didn’t protect Earth even according to the Interagency Committee on Back Contamination (ICBC) that advised NASA – can we learn from their mistakes?
* Comet and asteroid sample returns are legally straightforward - either sterilized during collection - or Earth has a similar natural influx
* Controversial 2019 report by Stern et al. recommended classifying parts of Mars similar to the Apollo 11 lunar requirements - no sterilization in the forward direction (Category II) – but Earth’s biosphere still protected in the backwards direction (restricted Category V)
* 2020 Review committee modified recommendations of 2019 report, saying our knowledge is not yet sufficient to classify parts of Mars as suitable for an unsterilized Category II mission in the forward direction – agrees on need to protect Earth in backwards direction
* Similar situation in 2014 / 2015: 2014 report said maps can identify areas of Mars of planetary protection concern in the forwards direction then 2015 review modified those recommendations, saying maps can’t yet be used – due to knowledge gaps on survival of terrestrial life in dust storms and potential for life to survive in microhabitats hard to detect from orbit
* All agree Mars sample returns need to be treated as restricted Earth return with potential for adverse changes to the environment of Earth
* **Could Stern et al’s classification be a possible future scenario once we understand Mars better – that we need to protect Earth from Mars but not Mars from Earth, indefinitely? We will find that in an alternative history the Moon could have been classified as for Apollo 11 indefinitely, and Mars potentially could be too**
* Carl Sagan’s hypothesis of a subsurface habitable layer on the Moon at a depth of tens of meters – which could risk backwards contamination of Earth – and originally there was thought to be a low risk of forwards contamination
* Decision to stop sterilizing missions to the Moon in 1963 because any forward contamination was expected to be localized – even if there were habitats below the surface
* Scenario of localized forward contamination on Mars depends on whether terrestrial life can be transported in dust storms
* Scenario of localized forward contamination by terrestrial life, but with Martian life still able to spread in Martian dust storms using spores adapted to Mars and more resilient than terrestrial spores
* Scenario of no possibility of forward contamination because Martian life occurs in extreme habitats inaccessible to terrestrial life
* All possibilities remain open: no need for sterilization to protect Mars, while Earth needs to be protected indefinitely – or no protection either way - or protection indefinitely both ways - or need to sterilize spacecraft to protect Mars indefinitely with no need to protect Earth or astronauts from returned materials
* Scenario of no present day life on Mars could give unique opportunity to study uninhabited habitats on another terrestrial planet, and microbes accidentally introduced to an uninhabited planet in the wrong sequence could make Mars less habitable for colonists – need to allow time for study first
* **How we understood the Moon in 1969 compared to Mars today - Mars with a thin atmosphere and liquid water, is more favorable for life than the Moon was thought to be back then**
* Views of astrobiologists on the possibility of present-day life on or near the surface of Mars
* Suggested sources for native life in equatorial regions such as Jezero crater include local microhabitats such as salty brines, and spores in windblown dust – while the dust and salts are not likely to be transferred to Earth via asteroid impacts
* **First restricted (potentially life bearing) sample return since Apollo, but needs much stricter planetary protection than was realized for Apollo – especially after discovery of starvation mode nanobacteria that pass through 0.1 micron nanopores**
* By European Space Foundation study (2012), particles larger than 0.05 microns in diameter are not to be released under any circumstances
* The three proposed methods of containing samples in a Mars sample receiving facility, BSL-4 in a clean room, clean room in a BSL-4 and triple wall - with examples for each design
* EURO-CARES sample return facility design filter requirements are out by an order of magnitude, due to unfortunate typo - ESF study’s probability of less than one in a million is for unsterilised particles of 0.01 microns (NOT 0.1 microns) – and ESF requires 100% containment for particles of 0.05 microns
* HEPA and ULPA filters are not tested for such small particles as 0.05 microns and not required to contain them
* Example of best available nanofilter technology from 2020, not yet commercially available, filters out 88% of ambient aerosol particles at 0.05 microns - far short of the ESF requirement to filter out 100% at this size – though this standard can be met with nanoparticles in water under high pressure
* Challenges for maintenance for future 0.05 micron compliant nanoscale filters – need to be designed for sterilization before any potential extraterrestrial biology is known, and may be easily damaged and hard to replace without risking release of nanoparticles
* ESF study’s recommendation for regular review of the size limits
* **Scientific developments since 2012 that may be considered in a new review of the ESF study’s size limits – life with a simpler biochemistry such as minimum size RNA world cells without DNA or proteins could potentially lead to a requirement that release of even a particle of 0.014 microns is not acceptable under any circumstances**
* Could the postulated RNA world nanobacteria 0.014 microns in diameter spread through Earth’s environment (or other simpler forms of life)? Answer seems yes, possibly, with similar advantages to the postulated nanobes of the shadow biosphere hypothesis
* Priority to decide on minimum size of released particle for filter requirements early in legal process and to outline future technology to achieve this standard
* Discussion of potential large scale effects from mirror life could lead to a call for near certainty of containment, as for some experiments in synthetic biology
* The 2012 ESF study in their discussion of precautionary principle said we need to minimize risk using best available technology because if we require no appreciable risk of harm the mission has to be cancelled – considerations of large scale effects could lead to a need to re-evaluate this conclusion
* Clarifying this question of which version of the precautionary principle to use with Sagan’s criterion that “we cannot take even a small risk with a billion lives”
* Uhran et al recommend an advanced planning and oversight agency set up two years before the start of the legal process - Rummel et al recommend it should include experts in legal, ethical and social issues – while the ESF recommends an international framework should be set up, open to representatives from all countries
* **NASA procedural requirements for mission planners to develop a clear vision of problems, show it’s feasible and cost-effective, develop technology with engineering details and show it will meet requirements before build starts – because of significant costs involved in modifying designs at later stages in the build**
* Examples of how sample return facility requirements might change during the legal process – more stringent filter requirements than for BSL-4 – quarantine to be replaced by telerobotics – and required safety levels far higher than the one in a million “gold standard” for a BSL-4 facility
* Minimum timeline: 2 years to develop consensus legal position, less than one year to complete EIS, 9 years to build sample return facility and 2 years to train scientists and technicians in its use
* Need for legal clarity before build starts - NASA has reached keypoint A for the budget for entire program, but not for the facility – they can’t know what they will be legally required to build for the facility – perhaps they can pass keypoint A without legal clarity – but keypoint B requires detailed engineering knowledge of what to build
* Need for legal clarity before launch of ESA’s Earth Return Orbiter, Earth Entry Vehicle, and NASA’s Mars Ascent Vehicle
* Legal process likely to extend well beyond 6 years with involvement of CDC, DOA , NOAA, OSHA etc., legislation of EU and members of ESA, international treaties, and international organizations like the World Health Organization – NASA don’t seem to be prepared for this or even mention potential international ramifications [unless their EIS gets used to bypass this stage altogether]
* **The legal process and public debate for NASA’s mission as precedent for China’s mission to return a sample too – perhaps as soon as 2030 – with sterilization a likely solution for a country that wants to be first to return a sample**
* NASA can’t accelerate the legal process to return an unsterilized sample before 2039 – but it could “win” this race with a sterilized return or a return to a safe orbit with sterilized subsamples – leading to China and other nations doing the same
* **Public health challenges responding to release of an extraterrestrial pathogen of unfamiliar biology**
* Failure modes for sample containment
* **Complexities of quarantine for technicians accidentally exposed to sample materials**
* Vexing issue of authorizations to remove technicians from quarantine to treat life threatening medical incidents in hospital
* Example of a technician in quarantine with acute respiratory distress and symptoms similar to Legionnaires’ disease – a disease of biofilms and amoebae that adventitiously infects humans – and sometimes mentioned in planetary protection discussions
* Arbitrariness of technician’s quarantine period for an unknown pathogen – Carl Sagan gives the example of leprosy which can take 20 years or more to show symptoms
* How do you quarantine a technician who could be a life-long symptomless super-spreader of an unknown Martian pathogen?
* Martian microbes could participate harmlessly or even beneficially in the human microbiome but harm other terrestrial organisms when the technician exits quarantine - example of wilting Zinnia on the ISS
* What if mirror life becomes part of the technician’s microbiome?
* Potential for mirror life on Mars and survival advantages of mirror life competing with terrestrial life that can’t metabolize mirror organics
* Similar considerations apply to astronauts returning from Mars - in some scenarios such as mirror Martian life, astronaut quarantine would be insufficient to protect Earth’s biosphere
* A laboratory with the samples handled telerobotically as a solution to all these human quarantine issues – however the other problems remain and the safest way to do telerobotics is in an orbital facility with the robotics controlled remotely from Earth
* **Zubrin's arguments in: "Contamination from Mars: No Threat" - not likely to be decisive in legal process - response of planetary protection experts in "No Threat? No Way"**
* **These complexities arise due to need to contain almost any conceivable exobiology – simplest solution to sterilize the samples**
* **Sterilized sample return as aspirational technology demonstration for a future astrobiology mission – with the six months return journey used to sterilize the sample**
* Level of sterilization needed to protect Earth’s biosphere is similar to ~10 million years of Martian surface ionizing radiation - and would leave present day life and past life still recognizable - if recognizable without sterilization
* Suggestion to use low power nanoscale X-ray emitters for sterilization during the six months return journey from Mars
* Experimental data on effects of sterilizing doses of gamma radiation – preserves the geological interest of rock samples - need to test effects of X-rays
* **Why it’s a major challenge to find samples from Jezero crater to help decide central questions in astrobiology until we can send in situ life detection instruments - most past biosignatures will be degraded beyond recognition – nearly all organics on Mars are expected to be abiotic - past and present day life is expected to be low in concentration and patchy in distribution – and all this is especially challenging if Martian life never developed photosynthesis or nitrogen fixation**
* Most Martian organics are expected to be from non living processes even if Mars has present day life and had abundant past life – and most organics found so far by Curiosity and Perseverance resemble meteorite organics
* Curiosity’s detection of organics depleted in Carbon 13 could be from biologically produced methane which then interacted with UV in the atmosphere - but samples of those organics would give no other biosignatures to distinguish between the hypotheses
* If Perseverance returns samples similar to the Curiosity carbon 13 depleted organics, or the Tissint meteorite or ALH84001, this won’t resolve the question of whether they were produced by life – a more unambiguous sample is needed
* The processes on Mars expected to destroy most surface organics from past life
* Possibility that past life in Jezero crater life, or even modern Martian life, never developed photosynthesis
* Alternative to photosynthesis - chemosynthesis – perhaps using hydrogen sulfide or hydrogen including hydrogen from radiolysis in rocks – with much lower levels of biomass than a photosynthesis based ecology
* Possibility that past life in Jezero crater or even modern life never developed nitrogen fixation – or if it did, that nitrogen fixation was never taken up by microbes in oxygen rich surface layers
* **Present day and past life may be patchy or inhabit millimeter scale features**
* If Mars has present day life - it’s likely to be in low concentrations as for hyper-arid terrestrial deserts, and may colonize temporary habitats slowly over thousands of years
* We don’t know which geological contexts on Mars best preserve past life (if it’s there) - many Martian processes can destroy organics, or wash them out, and even a thriving past ecosystem might leave no biomass, for instance in acidic conditions
* Need many example samples as we study factors that lead to lifeless samples
* **Mars sample tubes weren’t sterilized 100% out of concern by engineers that a sterile container might not be able to open on Mars - higher levels of sterilization needed to detect life unless Perseverance returns life with recognizably different biology or abundant exceptionally well preserved life**
* Achieved levels of sterilization yield a 0.02% probability of a viable cell in at least one sample tube, so if a single viable microbe is found in one of the tubes, proof of detection of Martian life can only achieve 3.09 sigma
* Estimated achieved level of maximum 0.7 nanograms for each tested biosignature and 8.1 nanograms total organic contamination in every gram of returned rock sample – with no tests for chlorophyll or carotenoids, amongst the most robust biomarkers for ancient life on Mars, which could also get into the tubes, for instance through the cyanobacteria found in clean room samples
* Perseverance’s estimated achieved levels of 8.1 nanograms of organic contamination per gram of returned rock sample is more than the amount of organics in 81,000 ultramicrobacteria, or 160 million hypothetical minimal volume RNA world nanobes and is equivalent to the organics found in trillions of terrestrial amino acids – life detection instruments that astrobiologists hope to send to Mars can detect a single amino acid in a gram of sample
* We can expect to find novel species and genera from terrestrial contamination in the sample tubes – in a ribosomal survey of samples taken from the clean room used to assemble Perseverance, 4 species were found that didn’t closely resemble any previously detected terrestrial ribosome – and 41 species only detected through their small ribosomal subunit and example of the genus Tersicoccus first found in clean room samples
* The permitted contamination will make it challenging to prove Perseverance’s samples do NOT have Martian life in them and make it harder to spot genuine Martian microbes that closely resemble terrestrial biology – they will need to contain exceptionally well preserved past or present day life - or we need to collect additional samples in more sterile containers with the sample fetch lander
* **Could Perseverance’s samples from Jezero crater in the equatorial regions of Mars contain viable or well preserved present day life?**
* Puzzles from the Viking landers – why some think Viking detected life already in the 1970s – evolved gases in the labelled release experiment offset from temperature fluctuations by as much as two hours, more typical of a circadian rhythm than a chemical reaction
* Could spores from nearby habitats explain the Viking results?
* Detection by Curiosity rover of liquid water with enough water activity for life though too cold for terrestrial life - as ephemeral perchlorate brines in the Gale crater sand dunes - similar conditions are predicted in Jezero crater dunes
* How Martian life could make perchlorate brines habitable when they only have enough water activity for life at -70 °C – biofilms retaining water at higher temperatures - chaotropic agents permitting normal life processes at lower temperatures – and novel biochemistry for ultra low temperatures
* Some Martian brines could be oxygen-rich, permitting aerobes or even primitive sponges or other forms of multicellularity - Stamenković‘s oxygen-rich briny seeps model
* Life could also exploit enhanced humidity in micropores in salt deposits - but these may be rare in Jezero crater
* Melting frosts - and potential for a temperature inversion to trap a near surface cool humid layer at dawn as the air warms, perhaps permitting thin films of water to form briefly
* Experiments with black yeasts, fungi and lichens in Mars simulation conditions suggest life could use the night time humidity directly without liquid water
* Surface conditions of ionizing radiation, UV radiation, cold and chemical conditions don’t rule out the presence of life
* Sources of nitrogen on Mars as a potential limiting factor – potential for Martian life to fix nitrogen at 0.2 mbar – and “follow the nitrogen”
* **Could Martian life be transported in dust storms or dust devils, and if so, could any of it still be viable when it reaches Perseverance?**
* Native Martian propagules of up to half a millimeter in diameter (including spore aggregates and hyphal fragments) could travel long distances with repeated bounces (saltation) - if they can withstand the impacts of the bounces
* Martian propagules could evolve extra protection such as a shell of agglutinated iron oxide particles to protect themselves from UV
* Martian life could also use iron oxides from the dust for protection from the impact stresses of the saltation bounces - or it might use chitin - a biomaterial which is extremely hard and also elastic and is found in terrestrial fungi and lichens
* Potential for spores and other propagules transferred from distant regions of Mars similarly to transfer of spores from the Gobi desert to Japan – if little dust from a nearby habitat with of order 1000 viable spores per gram is blown to Perseverance’s site during a dust storm, this could still return several cells per gram
* Proposed surface microhabitats on Mars outside Jezero crater – droplets on the legs of the Phoenix lander, brines that form rapidly when salt overlays ice at high latitudes, caves that vent to the surface, fumaroles, and fresh water melting around heated grains of dust trapped in polar ice layers through the solid state greenhouse effect – these could achieve higher densities of life and be a source for propagules in the dust 197
* Searching for distant inhabited habitats on Mars through presence or absence of one originally living cell per gram – a rough first estimate assuming uniform mixing throughout Mars for a first estimate requires life to cover between 114,000 and 1,140 square kilometers with densities of life in the dust similar to an Antarctic RSL analogue in cell count, but less than a tenth of a square kilometer if any reach a billion cells per gram – these figures can be higher if any source habitats with high densities of cells are closer to the rover with uneven mixing 200
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