Planetary contamination: Why is it such an important issue? By Jinxin He

Abstract

Planetary protection is of significant importance when planning missions to space. However, recently it has been disregarded and said to be unnecessary for non-Earth return missions to the Moon. This would be due to the fact that there have only been negative results for life on the Moon and its hostile environments suggest that it is highly unlikely any organisms are living there and that any organisms could survive its environment. The Moon may be a hostile environment but there are many resilient bacterial spores that will not give up in even the toughest conditions. If we caused the contamination of the Moon, we could essentially compromise all missions exploring lunar life, future manned missions and we could even cause an ecological disaster. These bacterial spores could potentially be harmful and dangerous, if they stay viable for long enough they could harm humans when we send astronauts to set up colonies in the future. These Earth strain bacterial spores could also cause false positive reports for life on the Moon. The decontamination process may be costly but it is absolutely necessary if we want to conserve celestial environments to study in the future. Our observations on life forms on the Moon were all based on looking for signs of life forms with a DNA or RNA base, this could be why we have not been able to find anything. Our technology at this point is still holding us back and until we have such technology to explore other alien life forms, we need to conserve those environments and hopefully ecosystems.

Planetary contamination

Lunar Mission One is a recently founded mission to be sent up to space. Its goals are to leave archives documenting Earth life and to uncover the mysteries under the lunar surface. Of course any mission to the Moon has to well-planned with ever step carefully thought over. Planetary protection is an essential step that has been included in many missions before this one in particular, but why? Planetary contamination is a critically important issue to discuss when planning a mission to space. NASA defines planetary protection as 'the term given to the practice of protecting solar system bodies (i.e., planets, moons, comets, and asteroids) from contamination by Earth life, and protecting Earth from possible life forms that may be returned from other solar system bodies.'. NASA maintains its own policies for planetary protection that are in compliance with the COSPAR policy, the UN Outer Space Treaty and many other international agreements. [1] The UN Outer Space Treaty of 1967 provides the basic framework on international space law with its principles.[2] This suggests that, it along with other international agreements, form legally binding terms regarding space exploration that require organisations to implement procedures to ensure compliance to the requirements of these principles. NASA have made sure they have done so since the creation of such principles.[1]

The COSPAR policy is solely focused on the concerns regarding biological contamination but works in conjunction with the UN Outer Space Treaty. The policy and treaty states that parties signed to these are to pursue the exploration and studies of outer space while avoiding both the possibly harmful contamination of celestial bodies and the reverse contamination of Earth from foreign matter, providing obligatory international standards.[3] Planetary protection is so highly regarded by NASA such that they have a Planetary Protection Officer who specifically there to get involved in the development and planning phase of the missions to implement the necessary procedures for each mission, also taking into consideration the category of the mission. [1] All space exploration missions have to address the contamination risks, whether that are unmanned or manned.[4] The least we could expect from other organisations, including the Lunar Mission One, is to do the same but possibly on a smaller scale as the organisation is far from being as established as NASA.

''the official policy (from the International COSPAR Planetary Protection Panel) is that, unlike Mars and other bodies with the potential for life, the Earth's Moon is low priority with no real prospect of biological reactions. The convention is that Lunar Mission One requires "Simple documentation and reporting only"'.[5] This is an official statement from official Lunar Mission One website and as stated, planetary contamination of the Moon is not particularly worried about. But why is this the case? Mars, on the other hand, is regarded as more important in terms of protecting it from Earth contaminants. Mars is of such particular interest because the possible role scientists believe it could have played in the evolution of chemical processes.[6] Our Moon is considered as a 'remote' location and scientists believe that it would be impossible for organisms to survive in the harsh conditions. It is a common belief that due to the conditions of the Moon, it would be unable to sustain life and we have good reason to believe so. There is also no need for decontamination once the lander is already on the Moon as there is no return mission planned

The hostility of the Moon

It is commonly believed that the Moon has no atmosphere, while this is not true, it is very close to the truth when we compare the atmospheres of Earth and the Moon. The Earth has a thick layered atmosphere with a variety of different gases that form it. The Moon, however, has very little atmosphere and is extremely thin compared to Earth's.[7] The atmosphere on the Moon reaches the surface and does not extend far from it, due to the little gravitational force it exerts.[8] The atmosphere makes very little difference as being on the surface on the Moon is the same as being in open space.[9] These characteristics of this atmosphere would label it as a 'surface boundary exosphere'. Not only is the atmosphere extremely thin, it also has a very low density, its density could be compared to the density of Earth's very outer atmosphere, where the ISS would orbit.[7] Its low density means that there are very little molecules that make up the entire atmosphere, meaning they hardly ever collide. Per cubic centimetre there are only 1,000,000 molecules compared to 10,000,000,000,000,000,000 molecules per cm^3 on Earth. The lower density means that there would be much fewer collisions between the molecules on the Moon and our much denser Earth atmosphere.[7] Helium, argon, and possibly neon, ammonia, methane and carbon dioxide have been found to be present on the Moon's surface. These have been detected by Lunar Reconnaissance Orbiter, Lunar Prospector orbiter, detectors left by Apollo missions and Earth based spectrometers combined.[7,10] However, the atmosphere lacks breathable air that contains oxygen gas, this and the lack of an atmosphere are explained by the weak gravitational force. It is unable to keep the light oxygen gas on the surface and it escapes off into space.[8] The weak gravity is unable to retain the lighter gases in general, oxygen is not the only gas that is escaping out into space. Outgassing events take place, constantly releasing gas from underground. This is mainly caused by radioactive decay releasing a variety of gases from the lunar rocks but the lighter ones escape out into space immediately, they are present on the surface for such a short period of time that they would not be able to made use of.[10]

There are significant daily fluctuations in temperature due to the lack of an atmosphere, the average daytime temperature is 123°C and at night it can get to as low as -233°C. There is in fact water on the Moon, this has been confirmed by three different spacecrafts. Although it is in the form as separate molecule and as hydroxyl, it is there on the surface in low concentrations.[11] But due to the temperature fluctuations, the water found present on the Moon is either frozen or is present as a vapour. The ice is usually found as deposits on the parts that are constantly shaded. The ice in these deposits would have collected over time either from comets bringing water molecules on impact or from gases and vapours freely moving across the lunar surface and eventually reaching a cool enough area to form ice beds.[12, 19] Not only could the cold be a potential problem, ice is actually a 'killer' when it comes to microorganisms. The crystals formed by freezing water would be the main problem with the water being in ice form, this means that the microorganisms would not only not be able to use that store of water but they also have to avoid these ice beds.[9]

Atmospheres are not only a possible store of useful gases but they can also act as barriers to harmful cosmic rays. The thick, dense atmosphere of Earth is able to absorb and disperse the energy of these rays when they happen to be incident on the Earth's atmosphere. Anything on the Moon's surface would be completely exposed to cosmic radiation and solar flares because the atmosphere is so thin it is unable to act as a barrier like our Earth atmosphere does. UV rays are a form of cosmic radiation and is extremely damaging to cells. This cosmic ionising radiation is actual able to penetrate through the walls of spacecrafts so there's no doubt that these could easily affect unprotected microorganisms.[13] These rays are able to penetrate into cells and directly damage DNA strands. Simple experiments done in laboratories using 254nm wavelength UV light on bacteria species such as *E. coli* and *Serratia marcescens* show that even less than 2 minutes of exposure to the UV light results in 100% mortality. Even when the experiment was repeated with *Serratia marcescens* and only exposed for 15 seconds, the end result was a bacteria mortality of 40%-75% which is still significant for such a short time.[14] UV rays are able to initiate reactions between base pairs in the DNA sequence. These affected pair would then have to be replaced, replacing a few of these are no problem but they could occur when the damage is extensive. The risk of missing pairs increases as the exposure time increases, these changes in the base sequence then alter cellular processes. Cancerous cells could be created but cells can just die if the damage is widespread.[15]

These factors would make it incredibly difficult for any organism to survive there alone, even when we send astronauts on any mission to space we have to use our latest technology to protect them from the harshness of the vacuum of space. When we have been able to land and explore the Moon, the astronauts were only able to stay on the surface for up to 3 days at a time.[12] Non Earth return missions to the Moon are placed in 'Unrestricted Category V' because it is essentially of zero interest to scientists due to the strong belief that there would be no native life forms, the COSPAR lists no restrictions for this type of mission.[3] The first samples brought back from the first lunar landing confirmed that there was no native life on the Moon.[4]

Could there be life that could survive on the Moon?

The one thing that seems to dismiss all theories of lunar life existing is the results from the samples from the first lunar landing, the Apollo 11 mission which reached the Moon in 1969. The problem with the results back then is that we were only looking for life forms that were DNA and RNA based[9] but in such a big solar system there is a possibility that not all life is based on DNA and RNA. We based our searches on what we already knew about life. This may well mean we've missed a lot when it comes to looking for life. There are many organisms just on Earth that have yet to be documented, there are so many yet to be discovered that we can't be sure that all life on our planet Earth is DNA or RNA based let alone organisms we could find in space.[9] If we don't know what else we are looking for then it would be impossible to find what we want.[9] Technology has advanced significantly since the first lunar landing, while we still might not be able to look for non DNA or RNA bases life forms, our testing techniques and knowledge of contamination have also improved. Another problem with those results is that they may not have been accurate due to the lack of advanced technology back then, also considering that the samples were only taken from one area of the Moon's surface, the negative result wouldn't be good general representative of life on the Moon. There also could be more essentials for life, not yet found, that we could discover through this mission. Up to date equipment that would be able to analyse samples directly from the surface and also from below the surface will give more accurate results than compared to the telescopes and probes we currently use for examining the conditions of the Moon. Given all the harsh conditions of our Moon, it still may not be a good idea to assume there is absolutely no chance there would life on the Moon. Just because we have yet to discover life on this hostile celestial body it doesn't mean we should assume it is lifeless. Earth life may be tougher than we think. The unreliability of past results can be seen even when lunar samples were brought back by Apollo and Luna programmes. At first these traces of water were found in rock samples brought back from past lunar missions, but these were assumed to have been caused by contamination to the samples as the container had leaked.[11]

The ability of resisting radiation would have been present in organisms back in prehistoric days where the Earth's atmosphere had not developed into what it is now, back then all organisms would have been exposed to harmful radiation. The early Earth's atmosphere lacked oxygen and ozone, which makes up the main protective layer in our atmosphere. It was thought that life had originated underwater as water is able to filter out a majority of the high energy radiation coming from space, water would have done a similar job as our current atmosphere does.[13] Photosynthesis was developed early on in Earth's history of life; this would mean that there should have been organisms that in habited the surface and was able to make use the energy from the sun. This would mean that those particular organisms would have also been exposed to the damaging UV wavelengths such as high energy UV-C rays and also X-rays and gamma rays.[13] it's been proven that UV is very damaging to cells even in short bursts[14] but the organisms would have had ways to protect themselves from this damage or all life on land would have died out. One method could have been to use physical barriers such as water, sand, rocks and salt could have acted as good barriers. Organisms such as lichens have enough biomass that it is able to act as a protective suit and protect itself. Cyanobacteria are photosynthetic microbes that were living on Earth around 2.8 billion years ago and have been able to make use of sunlight without sustaining levels of damage from radiation that would have killed them.[13] They have developed methods to protect themselves so they don't have to rely on those physical object for protection. These would have gained through random mutations but after several generations radiation resistant organisms would have made up most of the population as these characteristics would have increased survival rate, and would have reproduced passing on these useful characteristics.[13] Bacteria and lichens are the only organisms we currently know of that can survive the level of radiation exposure organisms would experience in space, this may seem like a very small group of organisms but there many different types of bacteria and lichens.[13] They may not be able to completely block out the radiation but the damage compared to complete exposure is minimal.[13] Although this characteristic was developed during the period when early Earth life was still developing, the resistance characteristic has not been lost over time. This can be explained by the fact that the resistance isn't specific to just UV radiation and that here on Earth there are places where radioactive substances such as uranium and radium can be found.[13] Not only are there microorganisms that are resistant to radiation, these microorganisms are able to reverse the damage done by radiation to some extent. They are able to repair their own DNA by piecing back together the broken DNA strands, this is done the proteins present in the microorganisms' cells.[13] These microorganisms are extraordinary as they can resist even the highest energy waves but a drawback of this is that they are not active during the period they are exposed to radiation. They are in a hibernation state where they do not grow, reproduce or carry out any normal chemical processes. No DNA repair would take place while they are in this state so they are only able to repair their chemical makeup when they return to their active state.[13]

The harsh conditions now seen like nothing to the microorganisms as we've found that they can survive through these. Radiation was a problem as the barely present lunar atmosphere couldn't offer any protection from this. However, the toughest microorganisms may not even need to depend on protection from a thick dense atmosphere, even when they are not in spore form. We know bacteria spores are inactive and are protected by their protective shell[16] but many active microorganisms, carrying out chemical processes, wouldn't have this shell.

Bacteria are much smaller than lichens so they don't have much biomass to protect themselves also while in space, such as on the outside of spacecraft, there may not be anything such as ice, sand, rocks or salt to protect them. Bacteria has its own way of surviving through tough circumstances, not all bacteria are able to do this but some strains have this ability. Many types of bacteria are able to form spores when its living conditions become too tough to handle. It's much smaller mass means that without thorough sterilisation, they could easily make it to space unnoticed. Lichens are much bigger so could be removed even with a simple cleaning process to remove organic matter. Therefore, bacteria most likely would be the type of microorganism travel up to space and survive the journey and space. There are many examples of when bacterial spores were able to survive for an exceptionally long time but were still viable. Bacteria was brought back from its spore form which was preserved by it being encased in salt crystals deep in the Earth. Scientists had discovered this in 2000 and were easily able to revive them in a lab.[16] The bacteria revived were found to be similar to modern day bacterial commonly found in soil, but they were estimated to have been around for as long as 250 million years.[16] Like all spore forming bacteria, they had formed bacterial spores when the environment took a change for the worst rand in this instance they were also encased but salt crystals giving them an extra layer of protection.[16] The spore is composed of a tough protective shell that protects the contents, the genes and the basic cell parts are in an inactive state and are safely contained within the protective shell. Spores are able to survive blasts or radiation and can even many years of no water and no nutrients.[16] When this sample was found many precautions were taken before the analysis of these to prevent the contamination of the samples so that the results would be reliable as possible.[16] There was some speculation that the sample had been contaminated as the supposedly 250-million-year-old bacteria was so similar to modern day bacteria but the more examples of centuries years old bacterial spores they find the more believable each discovery becomes.[16] This is not the only example of bacterial spores surviving for millions of years, this just one of the more recent discoveries. In 1995 a group of scientist discovered and revived 30-million-year-old bacteria that were found in the gut of an ancient bee. The bacteria were in spore form inside the bee, they both were preserved when they got trapped in a drop of tree sap which later then became amber.[16] The few examples we currently have are not dangerous as far as we know[16] but this doesn't mean dangerous and pathogenic bacteria are not able to form spores, it's just that they have yet to be found in the circumstances where they have been preserved for centuries. When the scientists revive these microbes, many precautions are taken in the secure labs to prevent any contact/exposure to the outside world, this currently done to protect the ancient microbes from the outside world but it could be that in the future we could discover a bacterial spore that would be harmful to current Earth life.[16]

In theory bacterial spores would be very good at surviving in space but where is the evidence to show that the theory is true? There have been studies conducted on the ISS showing that there are known and identified spore-forming types of bacteria that can survive in space. These studies took place in the European Technology Exposure Facility, EuTEF which was attached to the ISS. This testing facility allowed microorganisms to be tested against the hostility of space and its high energy radiation. Bacterial spores of *Bacillus pumilus* SAFR-032 and *Bacillus subtilis* 168 were studied in a range of experiments varying in conditions. Some spores of Bacillus pumilus SAFR-032 were found to have survived even after 18 months of exposure, this particular strain of bacteria has also exhibited especially high resistance to typical spacecraft sterilisation techniques. It is known to be resistant to cleaning methods using UV radiation and peroxide treatment. In this particular experiment these bacterial spores were exposed to the conditions experienced in space. Analysis after this experiment showed that some of the spores that survived had higher concentrations of proteins associated with UV resistance than normal spores.[17] Bacteria mutate more often than we thought suggesting that more genes mutate when bacteria are adapting to an environment. With E. coli specifically it was found that the bacteria cells had 1000 times more mutations that originally thought.[18] A greater number of mutations happening means a higher number of advantageous mutations[18], this could mean that there could be a mutation that increases the radiation resistance and exposing the bacterial spores to such radiation could lead to them developing a higher tolerance in the overall population as only the more resistant bacterial spores would survive. Bacteria, unlike humans, do not have a cell cycle so any abnormal cells with mutations would carry on living and reproducing and since bacteria reproduce so often and quickly new characteristics become apparent in the population very quickly, especially if it affects survival rate.[19] There are also estimated to be between 100 billion and one trillion different species of microbes on Earth, with most of them yet to be documented.[20] These microorganisms would also experience mutations, some of which may lead to radiation resistance so it is highly unlikely that the that group of microorganisms that can survive is as small as we think. Another experiment involving both Bacillus pumilus SAFR-032 and Bacillus subtilis 168 exposed the bacterial spores to space conditions but the UV rays were filtered out to simulate a likely situation where there would be layers of spores so some spores would be protected by the top layer, in this situation the spores were also able to survive 18 months of exposure.[17] These types of bacteria are labelled as extremophiles, a category of microorganism that are able to survive the harshest conditions. Extremophilic bacteria have different biochemistries to average bacteria which allow them to withstand extremely high or low temperatures and radiation, just to give a few examples.

The specifics of this mission

The Lunar Mission One is like no other that has ever been planned so the specific aims of this mission are unique. This mission would allow us to analyse lunar material better than ever before with new technology and allow us to leave a footprint of human history with the archives. But this mission in particular could also cause some problems if we are disregarding the decontamination step. We're still unsure as to what is below the surface past a couple of metres as the furthest we've ever been able to drill is around 3 metres when Apollo 17 was sent to collect samples. Out of the many bore hole the deepest one was only 3 metres deep into the Moon's surface, see figure 2.[21] Apollo missions 15 and 16 carried out prior to Apollo 17 were also able to recover rock samples but did not reach as far down as 3 metres, see figure 3.[22] We've proved that there definitely some bacterial spores that are able to survive in space. These strains in these experiments were shown to survive for only a small fraction of the time that those that were encased in salt or rock were able to survive for. However, if the bacterial spores were able to get deep enough underground they could survive for as long the spore found suspended animation. The plan for this mission is drill down to at least 20 metres and possibly even down to as far as 100 metres, even if the drill does not make it as far as 100 metres, 20 metres is already many times further than ever drilled before in previous missions.[23] The drilling tool could provide a way for bacterial spores to get to such depths if it is not sterilised. Being so far underground, there would be a very thick layer of rock to further protect the bacterial spores from not only the radiation but the rock layer would also protect them from elemental particles from the sun, micrometeorites and even larger meteorites that are constantly battering the lunar surface.[5] Even David Iron the founder and leader of Lunar Mission One[24] had left his own comment on this possibility.

"One of the big drivers in space exploration is the search for primitive forms of life, and the expectation is that it's more likely to be detected below the surface rather on or above it," - David Iron.[25]

Table 1: Frozen core samples A17.

sample	weight (g)	depth (cm)	unit (Vaniman)	unit (Taylor)	~ Is/FeO	
70001,5	3.431	290.3 - 292.0	A	H	~40	capped end
70002,5	3.005	251.8 - 252.3	B	H	~55	middle
70003,5	3.004	212.4 - 213.0	C	G	~55	middle
70004,5	2.97	173.2 - 173.7	C	F	~50	capped end
70005,5	3.026	132.7 - 132.3	C	E	~70	middle
70006,5	2.998	94.5 - 95	C	D	~45	capped end

Is/FeO from Morris et al. 1979

Figure 1 (reference 21)

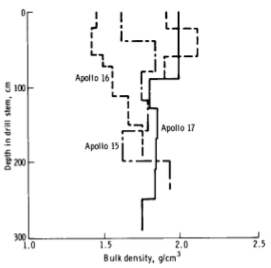

Figure 1: Density of drill core segments (Mitchell et al. 1974).

Figure 2 (reference 22)

Even if the spores are not able to make it that far underground they can still survive for long enough to cause problems and the specific placing of this landing site could also extend their unwanted stay. The lack of resources no longer effects the ability for the bacterial spores in particular to survive as the spores remain in a hibernation state so they do not need the resources they usually would when active.[13] But this is only for spore forming bacteria. There could be other microorganisms that have a high radiation resistance but are also able to be active in areas with high levels of radiation.[13] These types of organisms seemed to have existed in the past and they still might be around as advantageous mutations tend to stay present in organisms for very long periods of time.

As these organisms are active they need resources as they carry out their chemical processes, these may already be readily available on the lunar surface. The planned landing site is also a permanently shadowed area[25] making this area cooler than the areas of the surface where the sun is incident on it. We've pointed out that lunar water as ice is a problem for microorganisms and water in this form would be unusable anyway.[9] Water is present as ice in shadowed areas and is found as vapour in areas exposed to the sun, so there could be a small area on the boarded between these two areas where the water found is in liquid form at certain times when the surface temperature allows to become liquid. These areas could be very close to the landing site where several ice bed can be found so liquid water is available for microorganisms to use. Even at the landing site the surface temperature is relatively stable at around 273K which is 0 degrees Celsius.[12] This is the freezing point for pure water so it's likely that there are traces of liquid water in the lunar soil of the landing site. Water could also be found in the less shaded areas but then the water would have to underground for it to maintain its liquid form as further underground there would be layers of lunar rock to absorb the heat energy preventing the heat energy from breaking the bonds between water molecules and turning to into a vapour. For the extremophiles that are able to withstand tremendously low temperatures, the cold is not necessarily a problem for microorganisms as biological reactions have been found to still take place at 122 K.[9] oxygen may not be available as a gas but it is present in an abundance within certain lunar rocks. this was discovered by scientists who analyses lunar rock sample brought back from the Apollo 17 mission, the rock that hold the most oxygen was found to be titanium oxide. The oxygen from these rocks is easily release by a blast of heat or chemical processes which is more achievable by microorganisms.[8] Amino acids have been found in lunar soil samples[9] which can be absorbed and used by the microorganisms. These simple molecules could be vital as they are essential for the formation of proteins required for regular cell function.
Whether the organisms are active or not they can still cause problems in the exploration of the Moon.

Why is this step so vital?
There is more than sufficient evidence that microorganisms can survive in space but why do we need to prevent them from getting up there? Finding out that the Moon may be able to support life would be a break through as this help us make advancements in our technology to be used for colonising, but if life from Earth can be transferred to the Moon and is able to survive there, then what is there to say that there isn't already life present on the Moon? Potentially introducing new life to that environment could have absolutely not effect but there is also a chance that introducing these new microorganisms to the environment could be biologically disastrous.[9] There have been many cases where organisms were introduced to a new land, they made a home for themselves there but that didn't come without consequences. One of the most well-known cases is when cane toads, originally from south and central America, were introduced to Australia to rid the sugarcane crops of destructive beetles. These poisonous toads turned out to be more destructive that the beetle population they were brought in to control and are still to this day spreading across the country. The cane toads are now seen as pests and are continually disrupting other sensitive ecosystems as they become more widespread.[26] The need to prevent any possible harm to both current and future inhabitants of the Moon further emphasises the necessity of decontamination processes. When referring to life on the Moon, it is not only limited to microorganisms or whatever meteorites may bring. There is a chance that humans may be the first organisms that inhabit the Moon, with plans already in place for future manned missions to the Moon. Russia is planning to send a manned mission up in 2029 and China by 2036.[25] Bacterial spores stay viable for a very long time, we do not know what microorganisms survive that journey and how long they stay viable but if they are disease causing the could compromise manned missions. Space actually makes bacteria more dangerous. In studies using Salmonella typhimurium the conditions of space triggered a change in the bacterium's gene expression which caused it to be three times as aggressive.[27] The increased aggressive nature of bacteria in space and the fact that the future colonies would be in very restricted spaces within the living quarters would increase the impact the bacteria would have on humans if they ever meet. If anyone were to become critically ill, the infection could spread incredible fast due to the restrictive quarters. The colonies may also not be prepared for such instances but the journey back to Earth may take too long to help the patient. Its situations like this that we need to avoid, where people's lives are at risk due to one overlooked step.

Sterilisation and cleaning
The spacecraft and the equipment to be carried on board needs to go through a sterilisation process. Sterilisation is considered one part of the overall decontamination process. Sterilisation is where all living microbes, bacteria, viruses, fungi and all parasites, including bacterial spores are removed or destroyed. Whereas decontamination is the overall processes combined including cleaning to remove organic material and sterilisation where a very high of a level of decontamination is required. Disinfecting could be done in place of sterilisation but it essentially a less effective process as it does not remove bacterial spores.[28] To find such suitable processes we could look at the medical field as hospitals are known to be exceptionally clean while still housing patients infected with possibly deadly diseases. Reusable surgical instruments would have the most intensive cleaning process so it would be best to look at these methods to find one suitable for the spacecraft and lander. There is even a detailed life cycle that needs to be followed

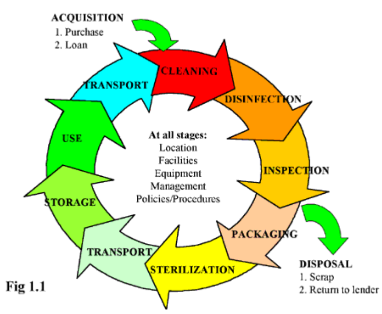

Figure 3 (reference 29)

step by step to ensure the instruments are safe to use also stating the precautions needed to be made at each stage, see figure 3. Not all of the steps would apply to the spacecraft and lander such as the packaging step. A good management system is also required to oversee that all steps in the cycle are being completed to an acceptable standard.[29] There are no official documents readily available showing the processes followed by NASA act as a guideline. So this cycle that surgical instruments follow could be built upon to create a more intensive process that could eventually be used in the decontamination of the spacecraft.

Microorganisms such as bacteria, viruses and fungi are present where ever human are present. This being an unmanned mission, the pathways of which the microorganisms would be carried is greatly decreased as there would be no humans to act as vectors for the organisms. Still any exiting microbes on both the equipment and the spacecraft will have to be removed to minimise the impact of the microorganisms. If they could survive in the vacuum of space, they could be transferred to the Moon when the spacecraft or the equipment such as the drill comes into contact with the Moon's surface. Any equipment that will have contact with the lunar surface must be decontaminated. The only piece of equipment that does not require sterilisation is the lander. The outside of the lander will be exposed to UV-C rays and extremely high temperatures on the way up through the atmosphere, leaving no microorganisms on the exterior. We've established that the bacterial spores are very resistant to harsh conditions this means we would need the processes used for removing microbes would have to be both effective and efficient.

Hospitals are reservoirs for many pathogenic microbes so environmental cleaning processes play an important role in patient safety, this then leads to hospitals having very good decontamination processes to ensure patient safety.[30]
However good the decontamination processes the may be, the standard may not be the same as the spacecraft may need a more vigorous decontamination procedure.[30] Past space exploration missions had actually used decontamination methods that were also being used in hospitals, such as UV light and hydrogen peroxide vapour. Heat treatment methods involving exceptionally high temperatures are without a doubt the most efficient and effective[31], but these methods would not be suitable for use on the equipment as the equipment's components are very sensitive and could be damaged but the process. Methods using UV light and hydrogen peroxide vapour have been proven to work according to statistics showing decreased rates of infections through health care assistance.[30] These methods help overcome the difficulties of decontaminating complex environments with multiple surfaces[30] helping the decontamination of different components with many crevices that make up the spacecraft and the parts of the equipment on board. This would destroy a huge majority of microorganisms, but the bacterial spores that we are so desperate to rid the equipment of are able to survive these two specific processes. So to rid the equipment of these troublesome spores we would need to add an extra method to the overall process. A pulsed xenon (PX)-UV light system, that has been newly introduces as the final step in cleaning patient rooms[30], could be added as the final step to this decontamination process. Whether this is effective on these spores specifically would have to be tested before this is put to use. If this system is not effective, research would have to be done to find a method of sterilisation that is able to strip the equipment of these spores, luckily there are already researchers working on this exact problem.
Any simple manual cleaning method could be used in the cleaning step as this is just to remove larger particles of organic matter.

In addition to the decontamination methods being carried out, clean rooms should be implemented to house these processes. Clean rooms would be necessary to maintain sterile conditions and any manual work needs to be done with operators wearing full sterile gowns, masks and gloves are also necessary. Full suits may have to be wore to ensure the sterile conditions stay that way. A management scheme is also required to manage and maintain all the processes to ensure consistent achieving of sterile conditions.[31] This may involve testing after certain time periods.

Considering all downsides, why should we still add this step?
It may seem all good that we are protecting the future of life exploration in space but there are costs to this. Up to $23.4 million in fact. NASA had spent $23.4 million on 'Mars Program Management' in 2012.[32] Admittedly this is not all spent on just planetary protection but even if a very small fraction of this amount of money had been spent on this, it still is a significant amount. The decontamination is both costly and time consuming, additional time and money needs to be invested to make the processes possible. What if we've already brought microbes to space through previous missions to the Moon? Would all our efforts now be to waste? We've been sending probes to both the Moon and mars for decades, there have been many cases made apparent to the public that microorganisms have been able made their way to space in the past. This provides evidence showing that we've essentially contaminated space with Earth microbes as we've found them living on the outside of our spacecrafts that orbit us. As we've landed on the Moon before, it is almost certain that we've brought some microbes to the Moon either dead or alive. It's not just us that's providing transport for microorganisms across the solar system, it is believed by some scientists that microorganisms have been travelling freely though space for as long as life have been present on Earth.[33] This is not just a theory; planetary contamination may be entirely unavoidable as we've been close to being contaminated by 'alien microbes'. These 'alien microbes' were found to not be native to Earth and were found in our stratosphere[34]. So there is a chance that there are foreign microorganisms orbiting us even if there are so few for us to have encountered them. So decontamination

essentially a big waste of time and money as we cannot control the movement at all objects in such an unimaginably huge open space that is space itself.

There is an agreed 1 in 10,000 risk limit, stating that any mission planned must have a less than 1 in 10,000 risk of contaminating the celestial body.[4] This just shows that it is widely known in the space exploration community that it is impossible to completely decontaminate and sterilize the spacecrafts going up into space and landing on celestial bodies. This shows that space exploration programmes are still trying to avoid planetary contamination as the possible effects outweigh the costs by a great amount. Planetary contamination could lead to false reports[20] setting back advancements in discovering life in space by years if we mistake Earth strains for native species. Introducing a foreign species to a species native to celestial bodies could cause ecological disasters. the biggest fear of this is contaminating the planetary bodies so much that all exploration to look for life is compromised.[4] Preventing contamination by sterilising the spacecraft is much easier and is actually possible to do, compared to the impossible task of dealing with the after math of contaminating an entire planet. By allowing a path for dangerous bacterial spores to travel up to space by, we could risk the lives the astronauts who are sent to set up colonies.

Conclusion

Not only is the decontamination step necessary for only this mission but it will be necessary for all missions to any celestial body until we have hard evidence that there is absolutely no possibility that Earth life could survive and that the celestial bodies themselves do not have their own native life. In order for this to be ensured and to be agreed upon internationally, it needs to be brought up that as we are searching for other life forms, in our solar system and beyond, the native life forms on other planets may not be DNA or RNA based and we have to recognise that every mission we send up now will affect the next. The COSPAR policy needs to be re-evaluated more regular and frequent basis as our curiosity and want to explore space increases. Even the smallest sliver of a chance that we could disrupt an ecosystem needs to be brought up and discussed. It may also be a good idea to have an international group of planetary protection officers to work with independent space organisations to bring about the high standards of planetary protection no matter how big or small the missions are.

Since the policy was created in 2002 there have only been five amendments to it with the latest being on the 24th of march 2011.[3] This is alarming for a policy that is so depended upon. The re-evaluation needs to be thorough, paying attention to all current interests and also regarding all new findings and advancements in relevant technology. The fact that non Earth return mission have been categorised in same 'Unrestricted' category for as long as the policy has existed, proves that in the past amendments these category placements had not been questioned enough and it's unlikely any of the findings referenced in this report were brought up.

As concluded by a NASA conference on July 29th 1964, ''Negative data will not prove that extra-terrestrial life does not exist; they will merely mean that it has not been found''[35] Suggesting that we should not give up on the Moon just yet, we just need to be more patient and positive results may come our way.

Appendix

Figure 1

Table 1: Frozen core samples A17.

sample	weight (g)	depth (cm)	unit (Vaniman)	unit (Taylor)	~ Is/FeO	
70001,5	3.431	290.3 - 292.0	A	H	~40	capped end
70002,5	3.005	251.8 - 252.3	B	H	~55	middle
70003,5	3.004	212.4 - 213.0	C	G	~55	middle
70004,5	2.97	173.2 - 173.7	C	F	~50	capped end
70005,5	3.026	132.7 - 132.3	C	E	~70	middle
70006,5	2.998	94.5 - 95	C	D	~45	capped end

Is/FeO from Morris et al. 1979

Figure 2

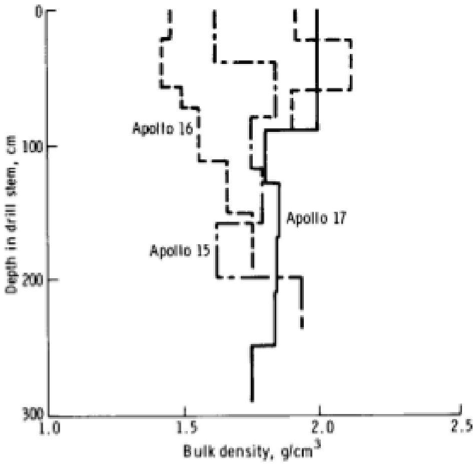

Figure 1: Density of drill core segments (Mitchell et al. 1974).

Figure 3

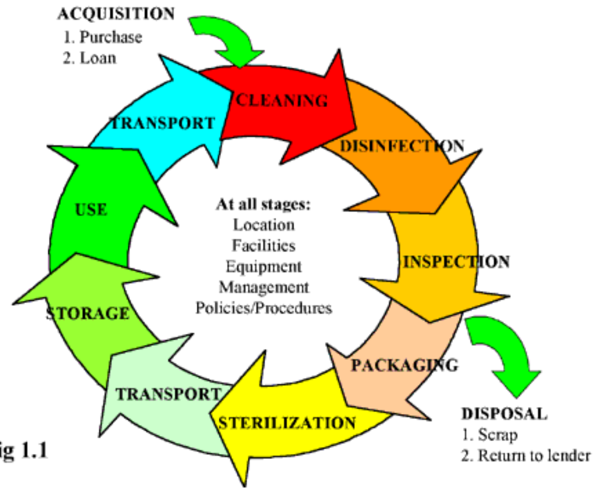

Fig 1.1

Planetary contamination: Why is it such an important issue? By Jinxin He

Summary
By first basic plan lead to a rough conclusion that planetary protection was absolutely necessary. As my researching sources widened I was able to access more reliable journal and articles. Some of my ideas developed as I read through these but I managed to find evidence through these sources to support my original conclusion. I used the articles and the people around me to build up ideas for discussion points to lead up to my conclusion. I made sure all of my references were recent and were reliable, were possible I checked the references that they had used to double check information. I did all of this to make sure I would end up with a strong argument with undeniable evidence to support my ideas.

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