# The Radiation Shielding of an Archive underneath the Moon’s Surface

*By Rose Tanner*

**Abstract**

The purpose of this paper is to look into what radiation can be expected within the Moon’s crust and how to shield an archive buried 100m below its surface from the effects over a billion years. It will discuss the information found from several sources, looking into the different radiation that the archive will be exposed to, how that radiation affects the archive and the different materials needed to protect it.

## Introduction

Lunar Mission One is a project that plans to send a probe to the moon by around 2024. The plan is to drill a 100m hole into the Shackleton Crater at the south pole , to take and analyse samples and to see if it is a possible area for a manned base. There is a possibility that there may be a lot of water ice at the bottom of the Shackleton Crater which would mean that if humans were to inhabit the moon they would be able to use the water as both drinking water and fuel without having to use up the Earth's resources.

Another part of the plan is to leave behind an archive as a time capsule, made to last about a billion years. Inside this archive will be both a digital archive and a collection of DNA samples from around the world. Lunar Mission One’s goal is for this to be a global project with contributions from as many different communities as possible, whether is is donated hair samples or a short video from some school children. This archive is to be a snapshot of life as it is now so that one day someone can look over who we once were.

One of the major problems that will effect the archive over this time scale is ionising radiation. Though the moon's surface should be more than enough to shield the archive from cosmic radiation, radioactive isotopes within the moon’s surface give off their own radiation. Although the amount the archive is likely to be exposed to over it’s life cycle is relatively small, the cumulative effects over such a long period of time could be damaging, especially to the DNA samples. It is therefore important to look into ways to shield or harden the archive against the different radiation.

## Method

At first google was used to search broad terms in order to find topics which could be studied in more detail. Websites such as Google Scholar and Web of Knowledge were then used to find articles and papers. Finally, by looking over all the information found, links between them could be found and put together in this report.

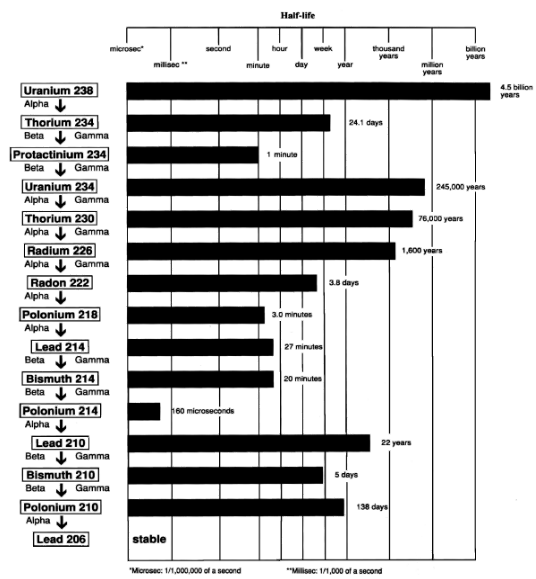
## Results and Discussion

Universe Today believes the crust of the moon is made up of mainly oxygen, silicon, magnesium, iron, calcium, and aluminum with only traces of radioactive elements such as uranium and thorium.[1] As stated in the article, the composition of the moon isn't that well documented and although the crust is the most well documented there hasn't been enough samples taken of anything further down than a few meters. The regolith (the first couple of meters of the moon) will be different to the crust due to the effect of asteroids and meteors than bombard the surface. However that is a major part of the Lunar Mission One project; looking into the composition of the crust.

The results from the japanese probe SELENE, also known as Kaguya, were published at the 40th Lunar and Planetary Science Conference. Amongst the results, Gasnault O. *et al* showed proof in the preliminary analysis of SELENE GRS data, of radioactive isotopes, including potassium, thorium, and a small amount of Uranium[2] which were found using a gamma ray spectrometer which they trained on the regolith[3]. They were detecting the different frequencies of gamma rays coming from the moon's surface which tell us there are absolutely radioactive isotopes on the moon. However, it could be argued that these findings only show what is on the surface and may not be found deeper down where the archive is being kept. Though the preliminary results mention thorium and potassium in the short paper, it does not mention uranium in the way 'The

Telegraph' tells it, however the article could be talking about a more indepth article that may have come later. Therefore the true amount of uranium on the planet is questionable. That being said any radioactive isotope will emmit radiation, the effects of which build up over time.

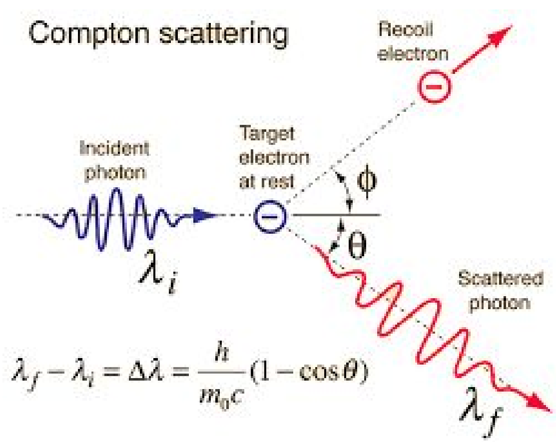
Depending on how close to pockets of these elements the archive will be, the main radiation that will effect the archive will likely be gamma radiation. As seen in figure 1[4] almost all of these elements release some form of gamma, and those that don't will become elements that do. Another reason gamma will be the most exposed is due to the penetrating power of each type. Alpha has the least energy due to being the heaviest and can be shielded by just a few cm of air and will very rarely reach the archive and even then will easily be blocked by whatever shielding is used. Beta is a little more likely to hit the archive and will need more specific shielding due to reasons that shall be discussed later on. Finally gamma is the most penetrating of the three, although it is a lot less ionising than the other two[5].




As stated in an article by the Radiation Effects Research Foundation[6], ionisation occurs when radiation has enough energy to remove an electron from an atom. This is not to be confused with ion formation which occurs during chemical reactions. Using beta radiation as an example, the high speed electron with pass through many atoms, releasing energy along its path by interacting with electrons. The energy is then absorbed by the atoms which results in excitation (the raising of an electron to a higher energy level) or ionisation (the release of an electron from an atom). The difference between the ionisation that occurs during chemical reactions and that due to radiation is that chemical reactions only affect the outer shell where as ionising radiation can affect any level of electron which causes the atom to become very unstable. These atoms are now known as radicals and are very chemically reactive, some so reactive that they will only exist for a microsecond. X-Rays and Gamma rays do have a slightly different effect as they will first release a high speed electron and neutron radiation has a different effect altogether due to its lack of charge, however neutrons are highly unlikely to reach the archive due to the fact they are only really produced during fission reactions.

According to Nuclear-power.net[7] there are three things that will limit the damage done by radiation exposure. The first is limiting the time which the object is exposed. Unfortunately this doesn't really apply to this situation as the whole point of this project is leaving the object in the rock. The second is distance, the further away from the source something is the less energy the radiation will have when it reaches the subject. This means it will have less ionisation energy and will damage less atoms. Again this is not something we can really control once on the moon. We will not know how close to radioactive sources the archive will be buried, however we do know that any non-radioactive rock will shield the archive a fair bit. This is based on the principle that any material will work as shielding as long as it's thick enough. The final option is shielding; certain materials work better than others and often the type of shielding needed is different depending on the type of radiation.

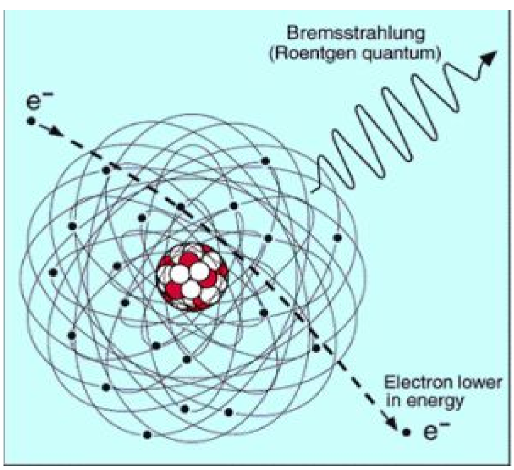
Nuclear-power.net[7] and an article by the Health Physics Society[8] state that the main interaction mechanisms of gamma radiation are:




- The Photoelectric Effect - *The emission of photoelectrons from matter when exposed to high energy electrons.*
- Compton Scattering - Figure 2[9] - *The inelastic scattering of photons by charged particles (in this case electrons) which decreases the energy of the wave (known as the Compton shift).*

- Pair Production - *In which energy becomes matter, in this case high energy gamma rays will pass through matter and produce a positron.*

It is the first two that will be taken advantage of for shielding as the gamma rays are unlikely to meet the energy threshold for Pair Production to occur. What this means is that the material which is used to shield gamma must have two characteristics. The first is a high atomic number which means the material will have a high electron density. This is because the gamma radiation will be interacting with the electrons which is how the photons lose energy. This causes a problem though as this is what turns the atoms into ions, by removing electrons through the Photoelectric Effect. In order to counteract this problem the material must have a high density. This ensures that the amount of energy needed for an electron to be emitted from the atom is relatively high and so the gamma does not affect the structure of the lead to much. Also Compton Scattering decreases with an increase in atomic number.




The issue with gamma radiation being shielded by high density materials is that high level beta radiation is shielded by low density materials. This is due to a radioactive process known as *bremsstrahlung*. As shown in figure 2[10], this is where a high speed particle (electron) passes through a magnetic field or interacts with another charged particle and decelerates very quickly. When this happens, electromagnetic radiation is emitted such as X-Rays and low level gamma radiation[11]. This would be a problem with the archive due to the thickness which the shielding may end up being (a problem I will discuss later) and so it may expose the archive to more ionising radiation.

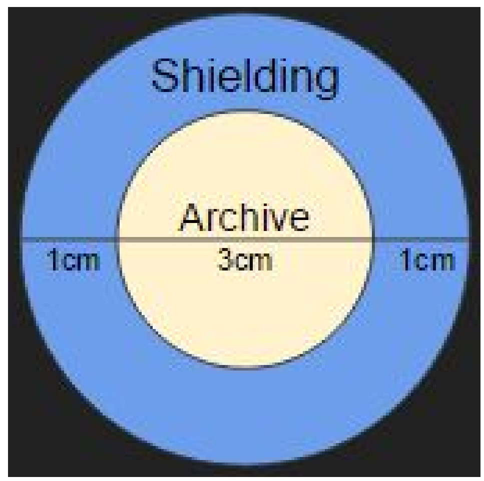
The archive is planned to be made up of two different sections, the digital archive and a collection of DNA samples. One of the main reasons radiation is so harmful to humans is because of the effect it has on our cells. It can damage them, mutate them and just kill them. It's why radiation can both give us cancer and kill the cancer for us. Though there will be issues with sustaining the DNA for so long anyway due to the breakdown of DNA overtime, any radiation exposure will speed up that process as parts of the structure breaks down[12]. This is a major issue because it is unknown if we can store DNA for so long even without radiation damage.

The digital archive will also be affected although by how much depends greatly on what materials are used and the design of the storage system. Semiconductors are the most damaged by ionising radiation as it disrupts the crystalline structure. It creates electron holes which causes charge buildups in the component which causes them to stop functioning. The damage can be limited by a process called radiation hardening which is done to all electronics that go up into space. The process isn't any specific thing but a plan must be made from the beginning, from design to assembly to increase how much radiation the digital archive can withstand.[13]

It is generally agreed that lead is the prefered shielding material for gamma radiation. It has a high atomic number, it is dense, it is stable and (most importantly) it is relatively cheap to make. In nuclear power stations other materials are sometimes used, such as concrete but this wouldn't work in the context of this project. 1cm of lead can shield an equal amount of radiation in comparison to 6cm of concrete and the archive will only have room for relatively thin layers of shielding. This is another reason why lead could be used; a relatively thin layer can block a lot of radiation[14]. Another option is tungsten, however according to Daniel Burbank, answering a question on an engineering forum, this is more expensive and gives similar results anyway, so it most likely wouldn't be worth the money unless there were a reason why lead absolutely couldn't be used[15]. Comparatively Wolfmet[16], a materials company, argues that tungsten alloys work well as an alternative to lead due to the fact that lead is poisonous and that tungsten alloys can be made into thinner layers and still have the same level of protection. However, since this is coming from a company that is trying to sell its products, this must be taken with a grain of salt.

For beta radiation plastic is commonly used or other materials with low atomic numbers such as glass. When explaining radiation shielding to secondary students the example often used is an aluminium sheet. This is because, according to NASA[17], most space crafts are made of aluminium, partly because of its strength but also because of its shielding abilities. That being said they are currently researching materials which could be lighter and are able to shield more radiation.

One of the biggest issues overall however is the size of the borehole where in the archive will be placed. Leaving the archive in the borehole means that the shape of the capsule with be a long tube and it is the diameter of that tube which is the issue. According to Paul Bennett, our Lunar Mission One contact, the borehole is planned to be 50mm in diameter. This means that the thickness of the shielding may only be 10mm thick which is not much at all by any standard. The general agreement is that the thicker the material is, no matter what the material is, the better the shielding. As seen in figure 3[18], it would be advisable to have shielding that is, at the very least 10mm all the way round which would give a 30mm diameter to the archive itself. The DNA samples, which are likely to be much smaller than the digital archive, should also have their own shielding built into their capsules.




**Conclusion**

Over the archives life span of a billion years, the main exposure to radiation will come from isotopes in the rock itself. These levels are predicted to be quite low and so the main threat will be the total dose which will accumulate over time. The rock itself will act as shielding so the main type of radiation likely to reach the archive is gamma radiation which is the hardest to shield against due to the amount of energy it contains. However it is practical to also be prepared for any beta radiation that the archive may be exposed to.

Two layers are likely to be needed. The first being a material with a low atomic number such as polyethelene or aluminium, in order to stop the beta radiation. This should also be the outer layer because whilst gamma will pass through this layer, beta passing through a material with a high atomic number would just create more electromagnetic radiation.

The second, inner layer will be a material with a high atomic number which will be used to block gamma radiation. This material will need to be very dense as gamma radiation is stopped by electrons. Lead is the most common choice as it can probably still work effectively even when relatively thin. Tungsten is another possibility as they have similar shielding properties. Lead, however, is much cheaper  and does the same job but tungsten isn't toxic which may be a problem for whoever finds the archive.

There are things that should be looked into if the shielding is to be optimised. The first is thickness, the shielding must be as thick as possible which either means making the borehole bigger or making the archive as small as possible. The second is alloys, the main space agencies will be looking into alloys and composites for their own missions, so it would be worth looking into what sort of thing they use in satellites to protect the electronics.

To conclude, in order to protect the archive for a billion years, the capsule must be protected from radiation damage, accounting for the differences between gamma and beta radiation. This should be done with tried and tested materials that will not break in the freezing temperatures of space.

---

**References**

1. Fraser Cain (2015) What is the Moon made of? Available at:http://www.universetoday.com/20583/what-is-the-moon-made-of/ Access Date: 22/08/16
2. Jullian Ryall (2009) Available at: http://www.telegraph.co.uk/news/science/space/5711129/Uranium-could-be-mined-on-the-Moon.html Access Date: 19/08/2016
3. O. Gasnault, O. Forni, B.Diez1, C. d'Uston, S. Maurice, N. Hasebe, O. Okudaira, N. Yamashita, S. Kobayashi, Y. Karouji, M.Hareyama, E. Shibamura, M.N. Kobayashi, R.C. Reedy, and the Selene GRS team (2009) 40th Lunar and Planetary Science Conference 2253
4. Figure 1 - What are the Radioactive Byproducts of Depleted Uranium (Uranium-238)? (2016) Available at: http://www.ccnr.org/decay_U238.html Accessed: 10/08/16
5. NRC: Radiation Basics (2014) Available at: http://www.nrc.gov/about-nrc/radiation/health-effects/radiation-basics.html Accessed: 22/08/16
6. How radiation affects cells - Radiation Effects Research Foundation (2007) Available at: http://www.rerf.jp/radefx/basickno_e/radcell.htm Accessed: 06/09/16
7. Shielding of Gamma Radiation (2012) Available at: http://www.nuclear-power.net/nuclear-power/reactor-physics/atomic-nuclear-physics/radiation/shielding-of-ionizing-radiation/shielding-gamma-radiation/ Accessed: 31/08/16
8. George E. Chabot, Jr., PhD, CHP Shielding of Gamma Radiation Found: hps.org
9. Figure 2 - Available at: http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/compton.html
10. Figure 3 - Bremsstrahlung Available at: http://www.nuclear-power.net/nuclear-power/reactor-physics/atomic-nuclear-physics/fundamental-particles/beta-particle/bremsstrahlung-2/ Accessed:22/08/16
11. Shielding of Beta Radiation - Electrons (2012) Available at: http://www.nuclear-power.net/nuclear-power/reactor-physics/atomic-nuclear-physics/fundamental-particles/beta-particle/bremsstrahlung-2/ Accessed: 20/08/16
12. Effects of Ionizing Radiation on DNA (2016) Available at: http://teachnuclear.ca/all-things-nuclear/radiation/biological-effects-of-radiation/effects-of-ionizing-radiation-on-dna/ Accessed: 06/09/16
13. Rachel Courtland (2011) Radiation Hardening 101 Available at: http://spectrum.ieee.org/tech-talk/semiconductors/design/radiationhardening-101 Accessed: 10/08/16

14. Daniel R. McAlister, Ph.D. (2013) Gamma Ray Attenuation Properties of Common
Shielding Materials, PG Research Foundation, Inc.
15. Burbank (1998) Available at: http://www.madsci.org/posts/archives/1998-08/900729174.Eg.r.html Accessed: 09/09/16
16. Lead Replacement, Available at: http://www.wolfmet.com/about-us/resources/lead-replacement Accessed:09/09/16
17. Fire Away, Sun and Stars! Shields to Protect Future Space Crews (2004) Available at: http://www.nasa.gov/vision/space/travelinginspace/radiation_shielding.html Accessed: 09/09/16
18. Figure 4 - Created in Powerpoint

---

**Acknowledgements**

I would like to thank Sue Dimond for organising this for us and Gillian O'Carroll for sorting out all the administration. Thank you to Paul Bennett for introducing us to Lunar Mission One and the information you put together. Thank you to Andrew Ross for helping us with our reports, presentations and posters. Thank you to Nuffield for giving me this opportunity to further my scientific curiosity and finally thank you Bath University for hosting this placement and giving access to such a broad range of reports and papers.