Protection of a Lunar Mission Archive against Ionising Radiation

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Abstract:

This project sets out to investigate radiative sources on the moon and their potential effects on any archive derived from Earth, and ultimately find a method of shielding the archive from radiation. This paper suggests the use of a FeRAM to hold the digital information to be stored in the archive, this decision was made by analysing and evaluating research from the internet and other scientific journals.

1. Introduction:

Lunar Mission One is a planned robotic mission to the moon, it is publicly funded and led by Lunar Mission Limited. The mission plans to send a lander to the moon in 2024, the lander will drill into the moon to a depth of up to 100m, to access lunar rock 4.5 billion years old, in order to gain a better understanding of the origins of the moon and the solar system. The lander will also place a time capsule in the borehole containing an archive holding information about the history of human civilisation, the biosphere of the Earth, and a private archive - which will consist of digital memory boxes which will be available for purchase, to be filled with information such as photos and videos from the consumer. As well as this consumers will also be able to store a strand of hair, as a record of their DNA. [10]

This paper explores radioactive decay, and the effect this would have on the proposed archive, outlines the radioactive materials that the archive will encounter by exploring the geology of the moon. The paper then goes on to detail potential methods of protecting the archive.

2. Problems

2.1 Radioactive Decay:

Alpha decay consists of an alpha particle (helium nucleus) being emitted form the atomic nucleus. Highly charged and heavy, alpha particles lose their several MeV of energy within a small volume of material, such as a few cm of air or a piece of paper.

e.g $^{238}_{92}U \rightarrow \, ^{234}_{90}Th + \alpha$

$$^{238}_{92}U \rightarrow \, ^{234}_{90}Th + \, ^{4}_{2}He$$

ß$^{-}$ radiation consists of an energetic electron. It is more penetrating compared to alpha radiation, and can be stopped by a few centimetres of plastic or a few millimetres of metal. ß+ radiation is the emission of positrons and will annihilate an electron releasing 2 gamma photons of 511 KeV. [12]

Gamma rays penetrate much further than the other two types of radiation previously mentioned (alpha and beta), they can be stopped by a sufficiently thick or dense layer material, such 1.3 feet of lead. [11]

Out of the three types of radiation that will be present, the main problem is gamma radiation as alpha and beta radiation will be blocked by the thin metal canisters that the data base is kept inside of.

2.2 Effects of Radiation on the Archive:

The digital archive consists of millions of semiconductor memory boxes, which are often a limiting factor in applying a device in a radiation environment since they are easily damaged when exposed to radiation. Thorium and uranium isotopes' radiation (which are present in moon rock) can lead to soft errors occurring in the memories (a soft error is where a signal is wrong). Radiation can cause problems in other parts of the memory chip, such as inducing the sudden occurrence of charge carriers (electrons and holes), these go on to cause the generation of false currents which can disturb data written into the chip or influence data processing. Gamma radiation causes generation of electron-hole pairs in SiO2 insulator of the gate, influencing the logical state of a memory cell. Based on analysis of data gathered from performed experiments, the exposure of semiconductor memories to gamma radiation causes three effects: holes being captured in trapping sites of an oxide, injection of holes from oxide into FG, and emission of electrons through FG-oxide interference [2]. It can be concluded that gamma radiation from the surrounding moon rocks will majorly damage any digital information stored in the archive, if the database isn't properly shielded. Gamma radiation would also damage or destroy and DNA samples or hair samples in the archive.

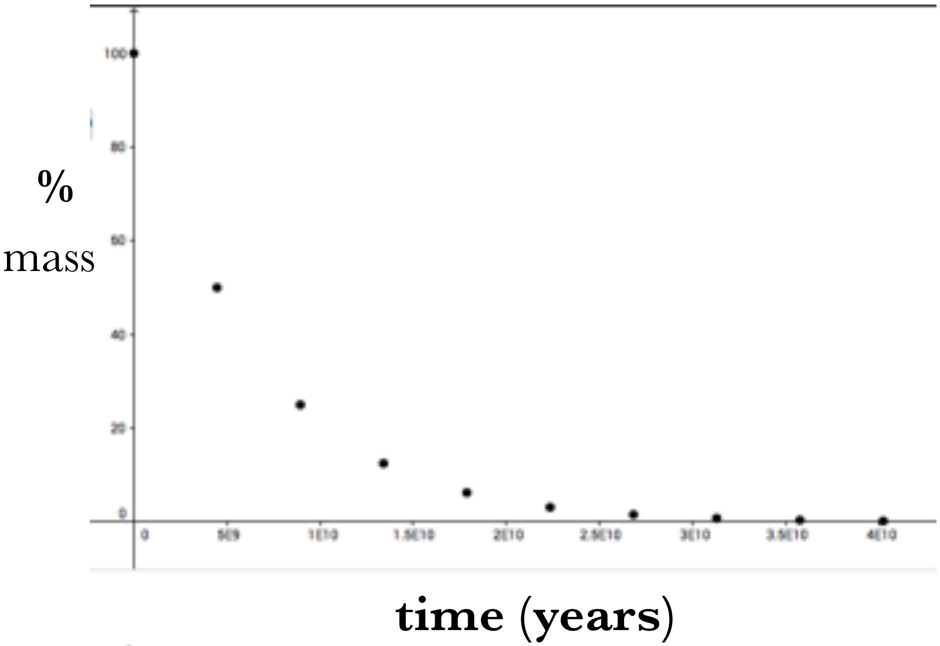
2.3 Radioactive Elements:

This section looks at the radioactivity of Uranium, Thorium and Potassium identified in section

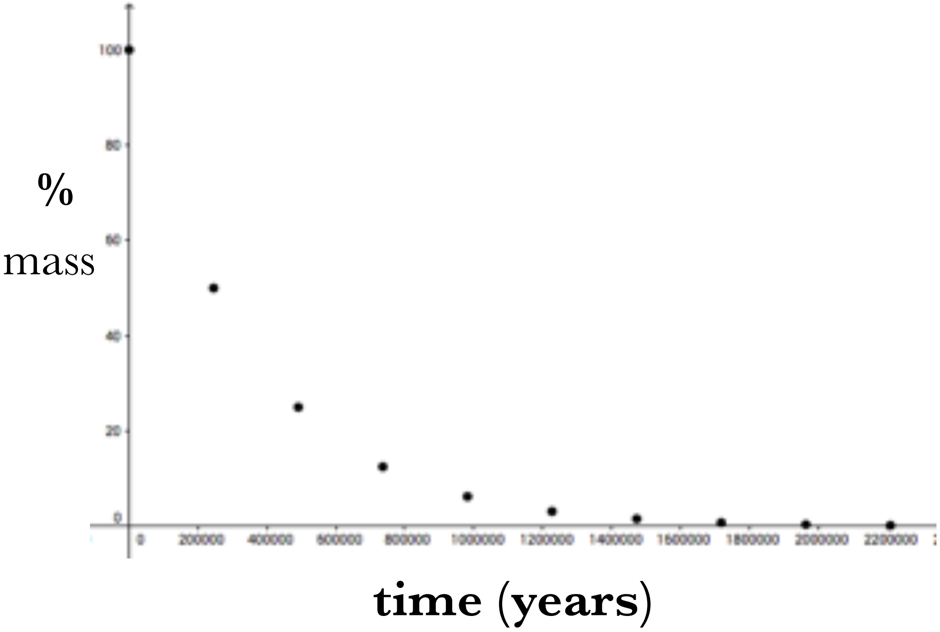
Uranium-238 (the most abundant isotope of uranium) radiates alpha-particles and decays (by way of thorium-234 and protactinium-234) into Uranium-234. Alpha-decay of uranium releases low energy gamma-radiation (49.5keV). Uranium occasionally decays by double beta decay or spontaneous fission with probabilities of 2x10^-12 and 5x10^-7 per alpha particle respectively. The half-lives of Uranium isotopes are as follows: Uranium-238 - 4.47 billion years; Uranium-235 - 245,500 years; Uranium-235 - 704 million years. [13] [14]

Potassium-40 undergoes all three types of beta decay: it decays to calcium-40 emitting a beta particle (ß$^{-}$, an electron) with a maximum energy of 1.33MeV and an anti-neutrino; it can decay to Argon-40 by electron capture, with a 1.46MeV gamma ray and a neutrino; rarely it can decay to Argon-40 by emitting a positron and a neutrino. The half-life of Potassium-40 is 1.251 billion years. [15]

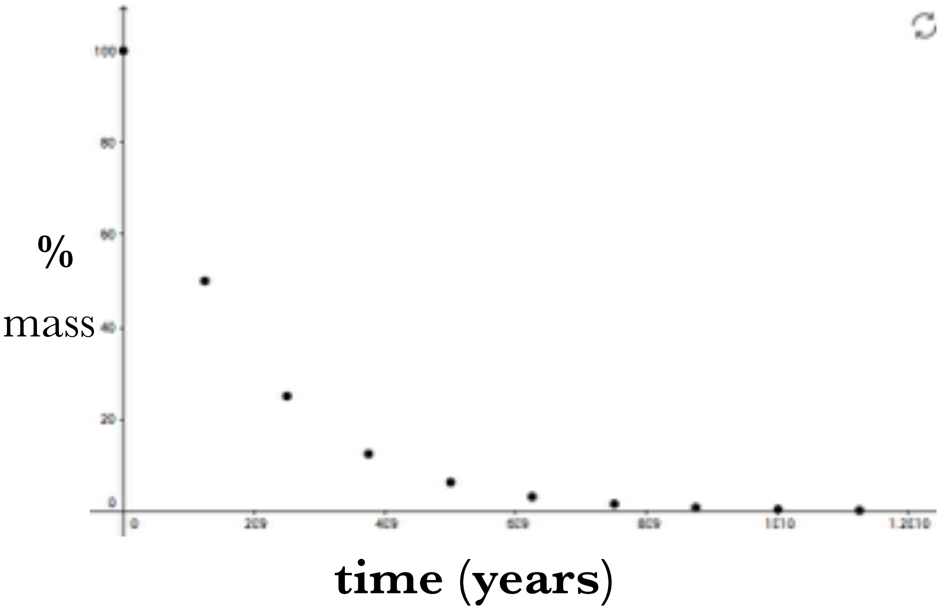
All known isotopes of Thorium are unstable, and decay slowly through alpha-decay. Thorium has the longest half-life of all significant radioactive elements. [16]



Half-life of Uranium-238



Half-life of Uranium-235



Half-life of Potassium-40

2.4 Geology of the Moon:

The geology of the moon differs to that of Earth due to a number of factors, including: the lack of a significant atmosphere (no erosion due to weather) ; it had no plate tectonics ; the moons small size (cooled quicker than Earth during formation). The moon had a similar internal structure as the Earth, consisting of a crust, mantle and a core.

Our knowledge of the geology of the moon comes from multiple sources, such as: earth-based telescopes; measurements from orbiting spacecraft; lunar samples; geophysical data. However, a number of geological questions still remain unanswered. The main elements that the moon consists of are: Oxygen, Silicon, Iron, Magnesium, Calcium, Aluminium, Manganese and Titanium, none of which are radioactive. However, the Lunar Prospector space probe detected the radionuclides Uranium, Thorium and Potassium (which generate gamma rays spontaneously) using its Gamma Ray Spectrometer (GRS), these radioactive elements could cause damage to the proposed lunar archive by damaging the information contained. [17]

3. Solution

3.1 Methods for Protecting the Archive:

Gamma radiation is best absorbed by atoms with heavy nuclei, the heavier the nuclei, the more absorption. Most commonly lead is used but, in special cases depleted uranium or thorium can be used. The most important factor in the level of absorption is not the weight of the nucleus, it is instead the total mass per unit area of the material used - the higher the mass per unit area, the higher the absorption will be.

A layer of lead surrounding the archive could be used to block out the majority of gamma radiation from the surrounding rocks, however the lead would have to be about 1.3 feet [8] thick in all places to sufficiently shield the archive. The density of lead is 11.34 g/cm^3 [9], assuming the dimensions of the archive are 15cm in diameter and 30cm deep (based on dimensions and images from [7]) then an estimate of the mass of lead required to protecting the archive is:

15cm + 39.624cm = 53.624cm
cross sectional area of lead = $(\pi \times 53.624^2)-(\pi \times 15^2) = 8326.9\text{cm}^2$
volume of lead = 8326.9 x 30 = 249807 cm^3
mass of lead = (249807 x 11.34)/1000 = 2855.29kg

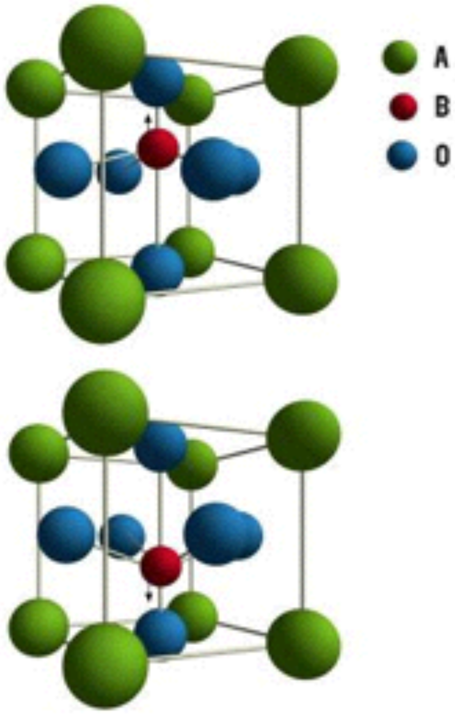
This amount of lead would be too heavy to transport and their is no practical way to implement it, therefore lead shielding cannot be used to protect the archive.

Apart from the impractical lead shielding there is currently no other method to protect the DNA samples in the proposed archive from the effects of radiation.

Another possible option for protecting the digital archive, is using a radiation hardened database. Radiation hardening is the process of making electronic components resistant to ionising radiation, such as the gamma radiation the archive will encounter. There are four main examples of radiation resistant RAM that could be used to store the digital information that will be placed in the archive, they are: Ferroelectric Based Memory (FeRAM); Chalcogenide Based Memory (C-RAM); Carbon Nanotube Based Memory (NRAM); Magnetoresistive Random Access Memory (MRAM). FeRAM is a better option compared to the other three as it is the only one to be widely produced, so will be easier and cheaper to obtain, as well as being more advanced (for example being able to hold more data, and be of smaller size), MRAMs are still in development.

3.2 FeRAM:

FeRAM is a non-volatile form of Random Access Memory that uses a ferroelectric material to store charge by moving a positively charged atom within the crystal lattice, and is highly resistant to magnetic fields and radiation. Ferroelectric material have a spontaneous electric polarisation that can be reversed using an external electric field. FeRAM stores data by using the polarisation of a ferroelectric film material placed between two electrodes. Volatile memories are susceptible to upset from radiation (alpha particles gamma rays, heavy ions etc), as they store charge using a capacitor or simple latch, which are flipped to an opposite state by the radiation. This changing of state is called a soft error, and the rate at which they occur is called the Soft Error Rate (SER). Since the cells of the FRAM stores the state ad a PZT film polarisation, an alpha particle hit is very unlikely to cause the polarisation to change a cell's state and the SER of the FRAM is unmeasurable. [3][4][5][6]



4. Conclusion:

In conclusion, a potential method for protecting the archive is using a FeRAM. However, more research is necessary to find a way to protect the DNA samples (hair) stored in the archive.

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