LUNAR MISSION ONE

Introduction

Lunar Mission One is a public-funded project, with more than 7,000 backers from more than 70 countries and over $1m raised to date. It has wide-ranging objectives including looking at the origins of the moon and planets of the solar-system and assessing the viability of the moon's South pole both for a future manned base and for deep-space radio astronomy. It is also intended to leave an archive buried in a borehole

Abstract

One of the aims of Lunar Mission One ("LM1") is to leave an archive with a lasting record of human life. A sample of DNA would give a legacy of mankind by providing a record of the human genetic code. However, exposure to space radiation could have a significant damaging effect on any DNA sample. It is therefore important to consider the potential effect of radiation on a variety of DNA sources in selecting a suitable DNA sample for inclusion in the LM1 archive.

Space Radiation

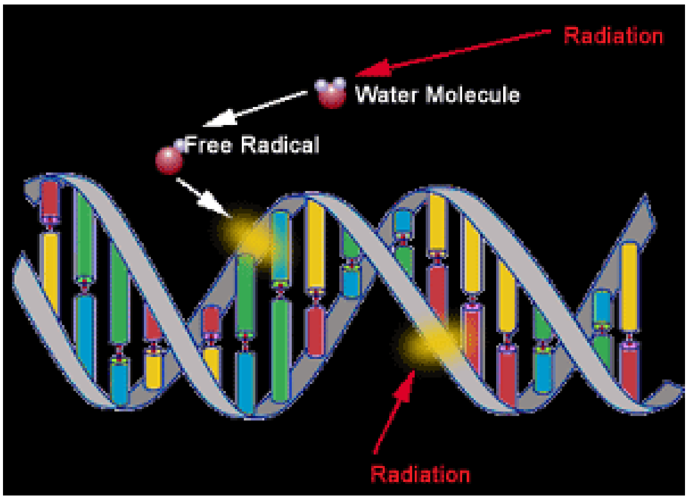
Radiation is the emission or transmission of energy in the form of waves or particles either through space or a material. This can take the form of electromagnetic radiation (which includes light, radio waves, x-rays and gamma rays) and particle radiation (such as alpha and beta radiation). Radiation is either non-ionizing or ionizing and this categorization depends on the energy of the particles being radiated. This is a significant distinction because ionizing radiation ionizes atoms and molecules and breaks chemical bonds, which causes harm to living organisms.

The radiation within the Earth's protective atmosphere is largely electromagnetic radiation. In contrast, the space radiation that would be experienced on the moon is ionizing radiation and is made up of both solar particles ejected into space during solar flares (large quantities of high-energy protons) and galactic cosmic rays, including heavy, high-energy ions. These are the remains of elements that have been stripped of electrons in their trip through space at close to the speed of light. Cosmic rays can ionize atoms as they pass, almost unimpeded, through many materials and they therefore pose a significant risk to a lunar mission.

Effect of Radiation on Cells

Exposure to radiation causes cellular DNA damage, with space radiation causing ionization of the molecules within cells. This can happen in two ways:

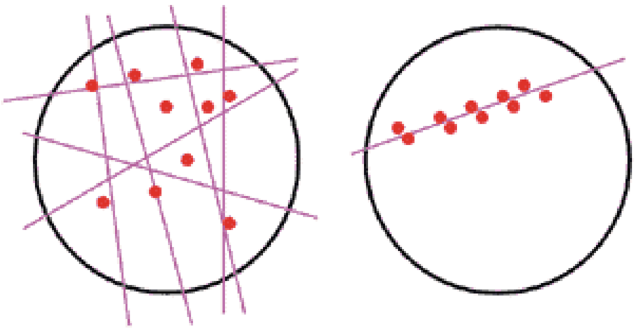
- Radiation can act directly on the cellular component molecules;
- Water molecules within an organism can absorb radiation and ionize which releases free radicals. These radicals in turn act on the molecules within cells.



Radiation interacting with a DNA molecule
Source SRAG

The major effect is that DNA breaks. Since DNA is made up of a pair of strands, breaks can occur to either a single strand or both strands. If the break is a single strand, the cell can usually repair itself (because the two strands are complementary, the intact strand is used as a template in repairing the damage). However, a double strand break is more important biologically because repair is more difficult and either cells may die or breaks may be repaired incorrectly resulting in mutations or chromosome aberrations. In cells that do survive damage caused by radiation, deletion of segments of DNA is common. This can occur either by a mis-repair of the two ends with the material between being lost or enzymes cleaning the DNA molecules at the break before repair resulting in loss of a segment of DNA.

It is also significant that the nature of space radiation, being high-energy radiation causes dense ionization along its track known as high linear energy transfer (High LET) and this is more difficult for the cell to repair than the low linear energy transfer (Low LET) of a radiation such as x-rays and gamma rays, where ionizations are more widely distributed through the cell, even if the overall radiation dose (the number of ionizations per cell) is the same.



Both examples produce the same total number of ionizations and thus represent the same radiation dose.
Source: RERF

This means that the high LET radiation results in far more complex damage, with clusters of DNA damage including single and double strand breaks.

Failure of DNA double strand breaks to repair correctly from ionizing radiation can therefore be seen to cause genetic mutation and this has been closely associated with carcinogenesis.

There are also indications that radiation may cause genetic abnormalities in cells that do not suffer directly from radiation. Radiation may result in genomic instability, which can promote mutations in descendants of a cell that has suffered from radiation for many subsequent generations of cell division (J B Little – Carcinogenesis)

There is one further implication of radiation in cells which is known as bystander effect, which suggests that mutations and changes to genes can occur in cells that have not been irradiated but which are affected by signals from irradiated cells in tissue up to about 1mm away. (F A Cucionatta, M Durante Cancer risk from exposure to galactic cosmic rays).

The potential of ionizing radiation to cause cancer was found soon after its discovery, with the first radiation cancers being ulcerated skin carcinomas and leukemia in people working with radiation at the start of the 20th century. World War II resulted in rapid progress of research into radiation cancer and systems were subsequently developed to look at malignancy of individual cells *in vitro.* However, this research investigates the effects of the Low LET radiations experienced on earth. In order to research the effects of High LET space radiation requires highly specialized facilities to replicate the high speed particles and there are few of these facilities (NASA facility in Long Island). Risks of carcinogenesis as a result of High LET therefore rely on experimental models and biophysical calculations.

Potential DNA samples for the Lunar Mission archive

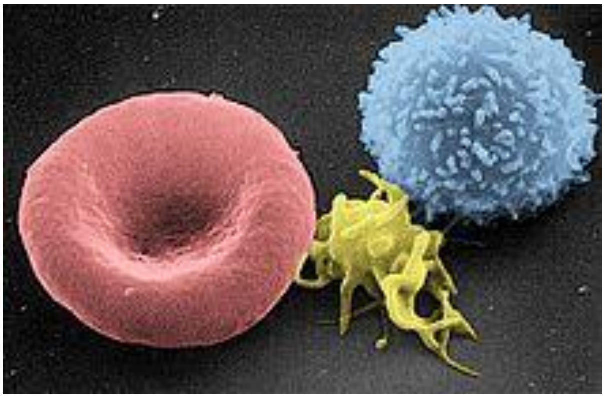
It can be concluded that the space radiation that would be experienced on the moon could significantly damage the DNA of any sample included in the Lunar Mission Archive, therefore adversely affecting the integrity of the genetic record. In looking at the suitability of a specific sample type for inclusion in the archive, consideration of the risk of associated radiation cancers could provide an indication of the susceptibility of a sample to DNA damage.

It would be useful to consider if there are any samples, which as a result of their structure or properties could result in more or less damage by radiation and what the benefits or limiting factors would be of their inclusion. The assumption must be made that if a carcinogenic risk exists from genetic mutation as a result of Low LET radiations on earth, then the risk of damage from High LET will also exist, albeit that the risk of damage to the DNA is higher.

Some of the most common DNA samples are blood, skin, semen and hair.

Blood

The major constituents of mammalian blood are erythrocytes (red blood cells), leukocytes (white blood cells) and thrombocytes (platelets).



Scanning elctron microscope image of (left to right)
Erythrocyte, thrombocyte and leukocyte.

Both erythrocytes and thrombocytes are anucleate and do not contain DNA and are therefore not suitable as a sample for the archive. Leukocytes are the best source of DNA in blood. However, significant correlations exist between exposure to radiation and leukemia.

Leukemia is a group of various cancers of blood cells. With damage to the DNA of immature leukocytes increased numbers are produced which suppresses production of normal blood cells. Types of leukemia can be chronic or acute and can be lymphocytic (affecting the marrow producing a type of white blood cell, lymphocytes) or myelogenous (affecting the marrow that produces other white blood cells, platelets and red blood cells).

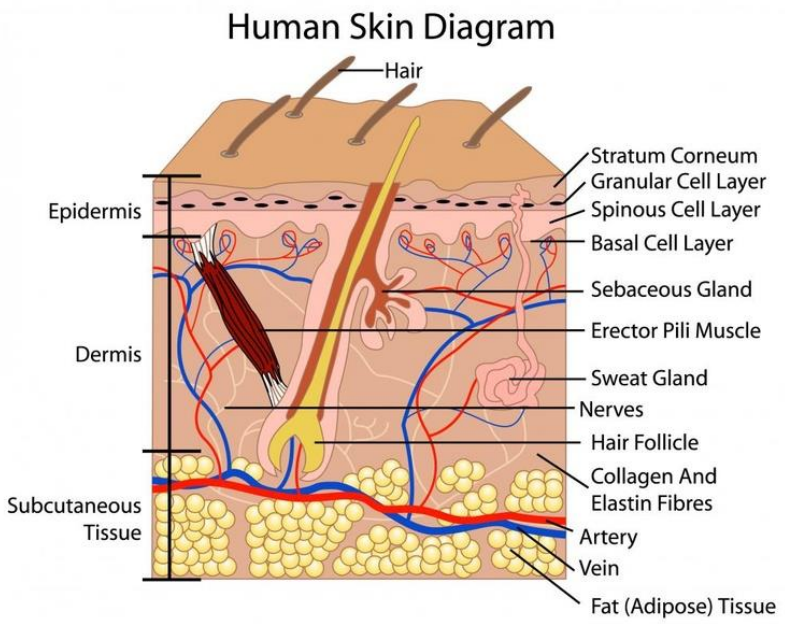
Epidemiological and radiobiological studies have brought evidence that exposure to ionizing radiation can cause cancer and leukemia (Dr K Leraud – Radiobiology and Epidemiology Dept, Fontenay-aux-Roses, Cedex, France). Leukemia is known to be caused by high doses of radiation like that released by the atomic bombs dropped on Japan in 1945 and in the years following these bombings, leukemia cases increased amongst survivors.

Strong evidence has been recorded of a connection between forms of leukemia and exposure to ionizing radiation amongst nuclear energy workers, with the cumulative dose of radiation exposure increasing the risk of dying increasing

Conclusions are that radiation causes acute leukemia and chronic myeloid leukemia and that human blood lymphocytes are one of the most radiosensitive mammalian cells (IAEA Publications).

Skin

Skin is composed of three layers: the outermost layer is he epidermis, composed largely of keratinocytes but also melanocytes; the layer of connective tissue beneath, called the dermis which contains sweat glands, hair roots, nerve cells and blood vessels and the subcutis, a layer of fat and connective tissue. Skin is an organ that is constantly changing as shedding of the outer layers causes cells on the inner layers to move up to the surface.

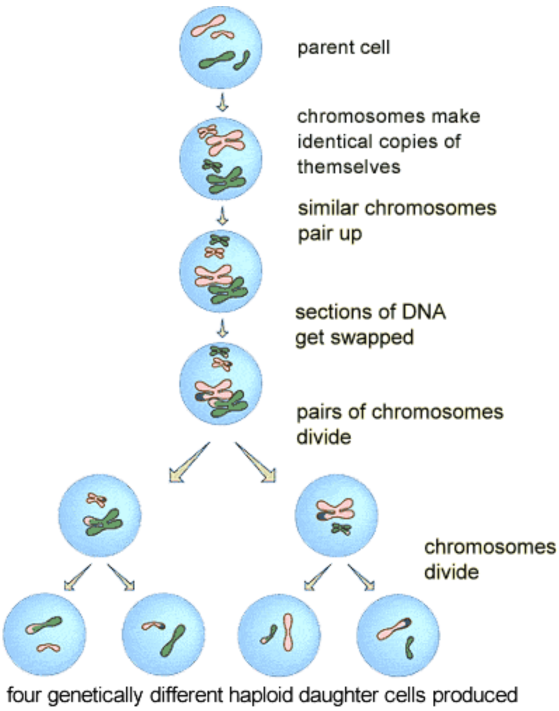


It is well known that melanomas and other skin cancers can be caused by excess exposure to UV radiation, a non-ionizing radiation. However ionizing radiation can also affect skin. It can cause chronic radiation keratosis (a pre-cancerous skin lesion) and other cancers such as basal-cell carcinoma cancers arising in the skin's basal cells which line the deepest layer of the epidermis, and squamous cell carcinoma (a cancer of the keratinocyte cells in the epidermis, at the site where skin is exposed to radiation. There have also been suggestions that ionizing radiation can be linked to melanoma. Evidence suggests that the increase in risk of developing cancer from ionizing radiation is approximately in proportion to the dose of radiation received.

This increased risk of skin cancer associated with exposure to ionizing radiation has been reported in various exposed populations, including the atomic bomb survivors, uranium miners, radiologists and individuals treated with radiation for malignant tumours (Skin Cancer Incidence among Atomic Bomb Survivors. Sugiyama H, Misumi M et al 2014).

<u>Semen</u>

Spermatozoa are motile sperm cells contained within semen. These gametes are haploid cells, which are able to move. The diploid offspring are comprised of approximately half of the nuclear genetic information from the sperm cells and half from the ovum. Therefore, the cells within semen do not provide a record of the full genetic code.



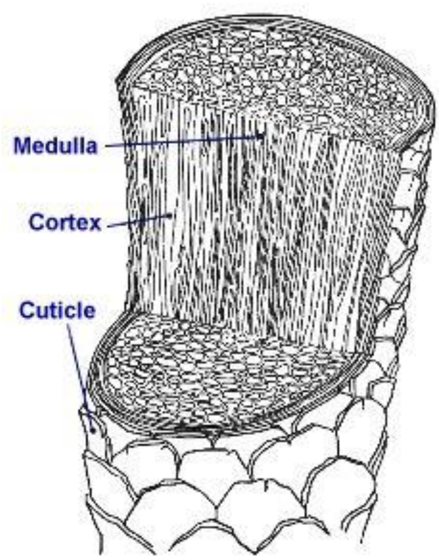
Gametes replicate via meiosis. Meiosis is a different kind of cell division to mitosis. It produces female and male gametes. Nearly all human cells contain 46 chromosomes arranged in 23 pairs. The gametes only contain half the number of chromosomes (23). This is why meiosis is sometimes called reduction division.
Meiosis therefore explains why the gametes do not contain the full set of genetic information.

A gamete therefore represents half of the human genetic code

There is evidence that exposure to radiation has an effect on the reproductive function. Direct irradiation of the testis in low doses affects germinal epithelium (the innermost layer of the testes) and high doses causes aspermia (absence of sperm from semen). (P Ash BJR Vol 53 Issue 628)

<u>Hair</u>
This is a potential sample whose structure is substantially different and could provide an interesting choice as a sample for inclusion in the archive.

Hair consists of a fibrous protein called keratin (which also makes up skin, nails and animal hooves). It is composed of three layers; the innermost soft medulla, the middle layer called the cortex (with pigments giving hair its colour) and the outer cuticle, which is the hard, scaly surface layer.



THE HAIR SHAFT

The hair shafts are formed from keratinocytes, cells that die and are converted into hair in the process of cornification. This results in the destruction of the cell nucleus, which means that the hair shaft itself is anucleate and cannot provide a reliable source of DNA. In a small number of samples of cut or shed hair, it is possible to extract DNA from nuclear DNA of corneocytes, which have survived cornification. Why these nucleated cells survive the normal cell nucleus destruction of the cornification process is not known and it is likely that this only occurs in some individuals.

It is known, however, that UV radiation can damage the hair shaft itself with UVB affecting the cuticle and UVA penetrating to the cortex, with damage to the hair proteins, including keratin and pigments, suggesting that the hair shaft is also sensitive to damage from radiation.

The only reliable source of DNA within the hair shaft is that of mitochondrial DNA. Mitochondrial DNA is a circular molecule of DNA found in the cell mitochondria , and is formed from 16,569 base pairs rather than the full human genome which consists of over 3 billion base pairs organized into 23 chromosomes.

The hair root is sited below the skin surface and is surrounded by a hair follicle which is connected to the blood stream by dermal papilla. The hair root, in contrast to the shaft, contains live keratinocytes which provide an excellent source of DNA. However, the cells within the hair root and follicle would be subject to the effects of radiation as other nucleate cells in the body. The hair follicle is known to be very sensitive to radiation with most individuals undergoing radiation therapy suffering hair loss.

Conclusion

Studies on Earth have shown that exposure to moderate to high doses of ionizing radiation increases the risk of cancer in most organs and hence damage to DNA. However, this should be considered in the context of the risk uncertainty of the effects of space radiation because of the different quality of radiation in space to that on earth. Furthermore, studies of cancer risks as a result of exposure to radiation look at living organisms rather than a preserved sample.

There is no obvious candidate for a cell sample for inclusion in the Lunar One Archive as all cells will be susceptible to DNA damage by radiation. However, if hair is chosen, the follicle that provides nucleic DNA will be subject to the same limitations as other samples and the shaft would provide a reliable record of only mitochondrial DNA and not the full genetic code from nucleic DNA.

The ultimate decision may rest with factors other than effect of radiation, such as ease of collection, preservation and storage, which are issues being considered separately within the Lunar Mission One project.

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