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Experimental Arrangement for Testing the Effectiveness of Lead Glass for Shielding Against Ionizing Radiation in Low Earth Orbit for Future Space Vehicles

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Abstract: The present times are exhilarating, full of possibilities, which humans, just a century ago, would deem impossible. One of them is space travel: an effort to step one foot in the vast cosmic ocean. Through this experimental arrangement, we want to make the journey a little bit affordable, easier, and most importantly, more enjoyable. The future of transportation is in space. The future space vehicle needs a material that is transparent, cheap, and safe by blocking ionizing radiation. Lead glass which is abundantly found on earth and is cheap is proved to be effective in shielding ionizing radiation. The problem is that it is tested in the earth's environment for less energy radiation. Our experiment arrangement is designed to test the effectiveness of lead glass and if effective, the thickness of lead glass required for effective shielding of skin cells and microdrive. The experiment is designed as such to accommodate the whole setup in a cube of 3cm*3cm*3cm, so that experiment will be portable enough and easy to transport in low earth orbit This paper, however, doesn't address the structural engineering solutions regarding implementation of lead glass as the material for space vehicles.
Keywords: Ionizing radiation, radiation shielding, lead glass, low earth orbit, future space vehicles

I. INTRODUCTION

An exciting field for the transportation industry is space. The design of space vehicles and materials to be used for space vehicles is still a field of active research. Entrepreneurs would want to provide space tourists a thrilling experience without compromising on safety and cost. Thrilling experience can be provided by giving a 180-degree view of space(i.e. a Glass castle ship). Safety can be managed by using material that can block ionizing radiation which is found in space. Cost can be managed by using materials that are cheap and can be easily manufactured, so a cheap, transparent, and radiation blocking material would be a near-perfect material for space vehicle construction. Lead glass is widely believed to be blocking ionizing radiation. [1] However, a concise and experimental study has not been done yet. This paper outlines a method to test the effectiveness of lead glass for cellular, physical and electronic protections, and the level of protection as a function of the dimension of lead glass.

II. LOW EARTH ORBIT SPACE ENVIRONMENT

Low Earth orbits are satellite orbits with an apogee lower than 1000–2000 km. The radiation environment in low-Earth orbit is a mixture of galactic cosmic radiation, particles of trapped belts, and secondary particles generated in both the spacecraft and Earth's atmosphere. Infrequently, solar energetic particles are injected into the Earth's magnetosphere and can penetrate into low-Earth orbiting spacecraft.

The following graph by Daly et al. shows how the radiation varies with altitude

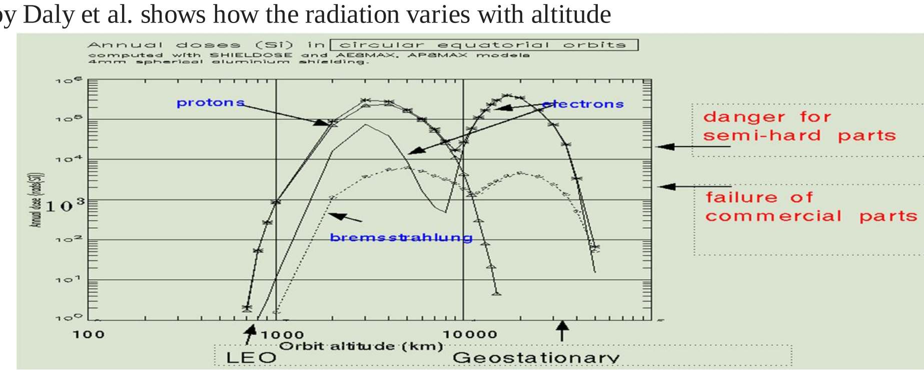

Fig. 1 Space Radiation Environment according to altitude. Source: E.J. Daly, A. Hilgers, G. Drolshagen, and H.D.R. Evans, "Space Environment Analysis: Experience and Trends," ESA 1996 Symposium on Environment Modelling for Space-based Applications, Sept. 18-20, 1996, ESTEC, Noordwijk, The Netherlands

Satellites and space probes typically encounter a total ionizing dose between 10 and 100 krad(Si). [2] As the total ionizing dose increases, materials degradation increases,. Long-term exposure can cause device damage, increased device leakage, and power consumption, timing changes, and decreased functionality. Total ionizing dose effects may be mitigated using radiation-hardened devices and shielding. Electrons and low-energy protons can be partially mitigated with shielding [3].

III. ENTITIES

The entities used for the experimental arrangement are lead Glass, skin cells, photographic paper, and SD card.

A. Lead Glass

1) *Composition:* It is a glass variant that has had its calcium component replaced by lead and contains between 18 to 40% of lead (II) oxide by weight. [4]
2) *Chemical Properties:* Lead Oxide content (PbO)> 65%, Total heavy metal oxide content>; 70%.
3) *Physical Properties:* It is optically clear with a high atomic number and high density of 3.1 - 5.9 g/cm3. [1] Lead glass also has a higher refractive index and lower working temperature. It is well suited to scattering x-rays, gamma rays, and other radiations. Lead Glass is resistant to chemicals and does not darken due to UV light. The brilliance of lead crystal relies on the high refractive index caused by the lead content. Ordinary glass has a refractive index of $n = 1.5$, while the addition of lead produces a range up to 1.7 [5] whose electrons can absorb the energy of radiations and scatter them away due to its high atomic number and density providing a shield for humans. [6]

B. Skin Cells

Chemical Properties: It has mesodermal cells, pigmentation, such as melanin provided by melanocytes, which absorb some of the potentially dangerous ultraviolet radiation (UV) in sunlight. [7] It also contains DNA repair enzymes that help reverse UV damage, such that people lacking the genes for these enzymes suffer high rates of skin cancer. [8]

1) *Why Skin Cells:* Skin cells are used to detect whether the ionizing radiations can pass through the lead glass or not and affect them. We can check if cells are affected using PCR analysis to check for DNA damage, and microscopic analysis to check for DNA damages.

C. Photographic Paper

1) *Composition:* Photographic papers consist of a light-sensitive emulsion, consisting of silver halide salts suspended in a colloidal material – usually gelatin-coated onto a paper, resin-coated paper, or polyester support.[9]
2) *Chemical Properties:* Photographic film darkens on exposure to ionizing radiation
3) *Physical Properties:* It is very sensitive to light and has excellent ferrotype quality
4) *Why Photographic Paper:* The purpose of this photographic paper is to measure the degree of degradation caused by radiation. If this paper comes in contact with radiation, it will darken depending on the wavelength of light, and the amount of radiation falling on them. The emulsion is normally sensitized to lower wavelengths. It is sensitive to wavelengths shorter than 600 nm. [10] This way, we will be able to determine if any radiation has entered through our lead glass and affected our skin cells.

D. Microdrive (Secure Digital)

1) *Composition and Physical Properties:* SD cards are made up of flash NAND which makes use of transistor and diode. Silicon wafer and a solid gold line is also used in the card during its manufacture [11].
2) *Chemical Properties:* Its data get corrupted when exposed to radioactive materials like uranium, thorium, and other radiations as well but are capable of withstanding operating temperatures from -13ºF to 185ºF. They are affected in low earth orbit space environments as well. [12]
3) *Why SD Card:* Memory errors or data corruption can occur under influence of cosmic and other radiations emitted from space. These errors are often manifested as logic state disturbances of memory cells or disturbances in sense amplifiers. Microdrive is used to examine the effectiveness of lead glass for electronic device protection.

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IV. DEPENDENT, INDEPENDENT VARIABLES AND THEIR RELATION

The Independent Variable in this experiment is increased exposure to ionizing radiation. The Dependent variable in this experiment is the thickness of the glass layer to prevent cellular, drive damage, and coloration of paper.

1) *Relation:* When the experiment is exposed to ionizing radiation and if the lead glass is ineffective, the photographic paper will be discolored, cellular and Microdrive contents will be damaged. If the lead glass is effective then, the visual examination of photographic paper (i.e. if the photographic paper is colored or not), microscopic analysis of skin cells, and computer analysis of microdrive provide the thickness of the glass layer for radiation protection.

V. ARRANGEMENT AND EXPLANATION OF EXPERIMENT

The measurements for this explanation are based on a cube of 3cm*3cm*3cm. As shown in figure 1, we will have a right-angle prism with a perpendicular height of 3 cm and a base of 2.5 cm, and a prism height of 2.5 cm inside a foam enclosure for protection. As shown in figure 2, at the bottom we will have 3 layers: skin layer, photographic paper, and microdrive. The perpendicular dotted rays falling show radiation falling on the prism surface. Let's take the photographic paper which darkens on radiation exposure. The paper at point B faces the radiation traveling a distance of L1, so the thickness of the shield for point B will be L1. Similarly, for paper at point D, the thickness of shielding material will be L2. In this way, there will be paper for every thickness from zero to 3 cm. The paper at point E faces no protection because it has a very small layer of lead glass above it. When we examine cells from point E to point F, the effect of radiation goes on decreasing because the thickness of the glass layer above it goes on increasing. The point at which there will be no radiation effect at all will be the required thickness for effective physical protection against radiation in space. Similarly, we do this process for photographic paper and microdrive and we will get the required thickness for biological and electronic protection respectively.

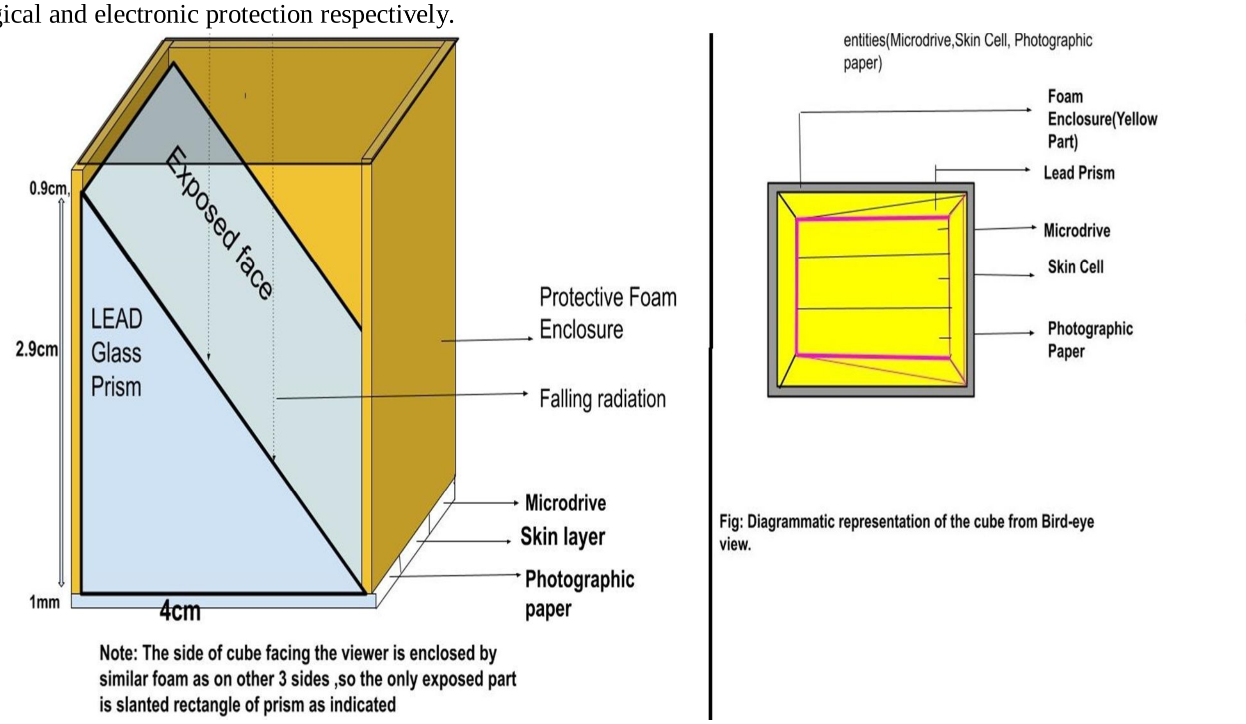

Fig. 1 Side view, and top view of the experimental arrangement

VI. DATA COLLECTION AND ANALYSIS

After we obtain the experimented cube, All three entities can be examined. For this, Each layer is first to cut into 5 patches, and the corresponding heights of lead glass over them are marked. For the photographic layer, we can observe the area of the darkened part as a function of the thickness of lead glass over the patch. For this, a microscopic high image resolution image of each patch can be taken, and using computer analysis, we can study the comparative damage of each layer and plot it into a graph to obtain the equation of shielding depending on the thickness of lead glass. For the cellular layer, we can perform microscopic observation to look for possible damages in cell organelles and PCR analysis for possible DNA damage. For the microdrive, it can be observed in the computer if the contents of the microdrive are affected or not.

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VII. THE MARGIN OF ERROR WHILE EXPERIMENTING IN SPACE ENVIRONMENT

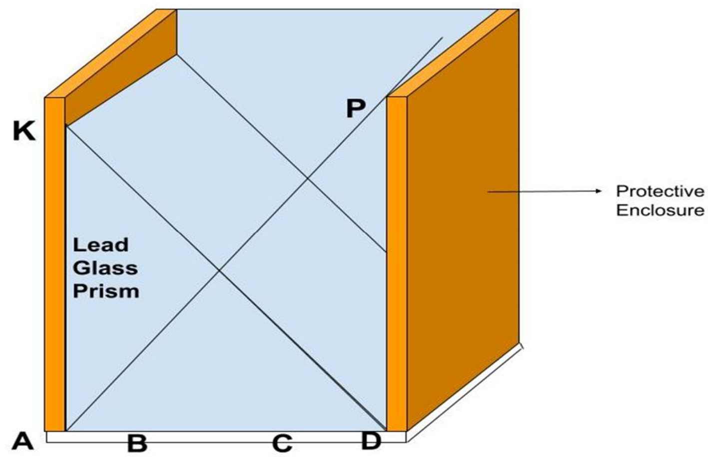

Fig. Calculation for margin of error in the experiment results in real space environment

It is true that the rays falling on the cube need not be perpendicular to the exposed face of the cube and also it may not be unidirectional. The result of that will be a certain margin of error in minimum thickness for protection.

The main variable to quantify in this experiment is the value of the path traveled in the lead glass. Let's take a point just beneath the base of the perpendicular right-angle triangle in the prism. For calculating the value of distance traveled by the farthest ray to reach that point, we construct a right angle triangle containing diagonal as hypotenuse and perpendicular of the prism as the perpendicular, on using simple trigonometry, we get the value of diagonal. Now, the distance traveled by that ray in lead glass will be half of the diagonal. The distance traveled by perpendicular ray can be found out. The difference in those values is the margin of error. Let us imagine a cube with a setup volume dimension to be $l * b * h$, where l, b are the height of prism and base length respectively. Then the maximum margin of error, d, will be, as shown in the figure :

d= AK-AP/2

d= $l - \frac{\sqrt{l^2+b^2}}{2}$

For a cube with setup, volume dimensions is 3cm*3cm*3cm, the difference in values is 0.82cm which is the margin of error due to the non-uniform direction of the radiation. The second realization that is useful is that only perpendicularly falling rays has maximum energy transfer or effect on entities, so the rays coming at a wide-angle will not be having much of an impact on the outcome of entities.

VIII. MEANINGS OF RESULT

With data collection, a graph of the area of darkened parts in the photographic paper can be plotted as a function of the thickness of lead glass over the paper which will indicate the relative strength of radiation for different thicknesses of lead glass. While observing the cells, we will find what thickness is the starting point for unaffected cells. Similarly, we will find what thickness is the starting point of unaffected drive content. In this way, we will obtain the minimum thickness of lead glass required for cellular and microdrive protection from radiation in space.

IX. CONCLUSION

The experimental arrangement outlined in the paper has the potential to answer multiple questions regarding the utility of lead glass as a future material for space vehicles and as a radiation shielding material, especially in low earth orbits. This experiment will also determine if the level of shielding varies for physical, biological, and electronic components. Similarly, it not only has the potential to find the minimum dimension for protection, but also the level of protection for different dimensions. This is very useful to drive down the costs, maintain safety, and having a transparent view of shielded materials.

X. ACKNOWLEDGEMENTS

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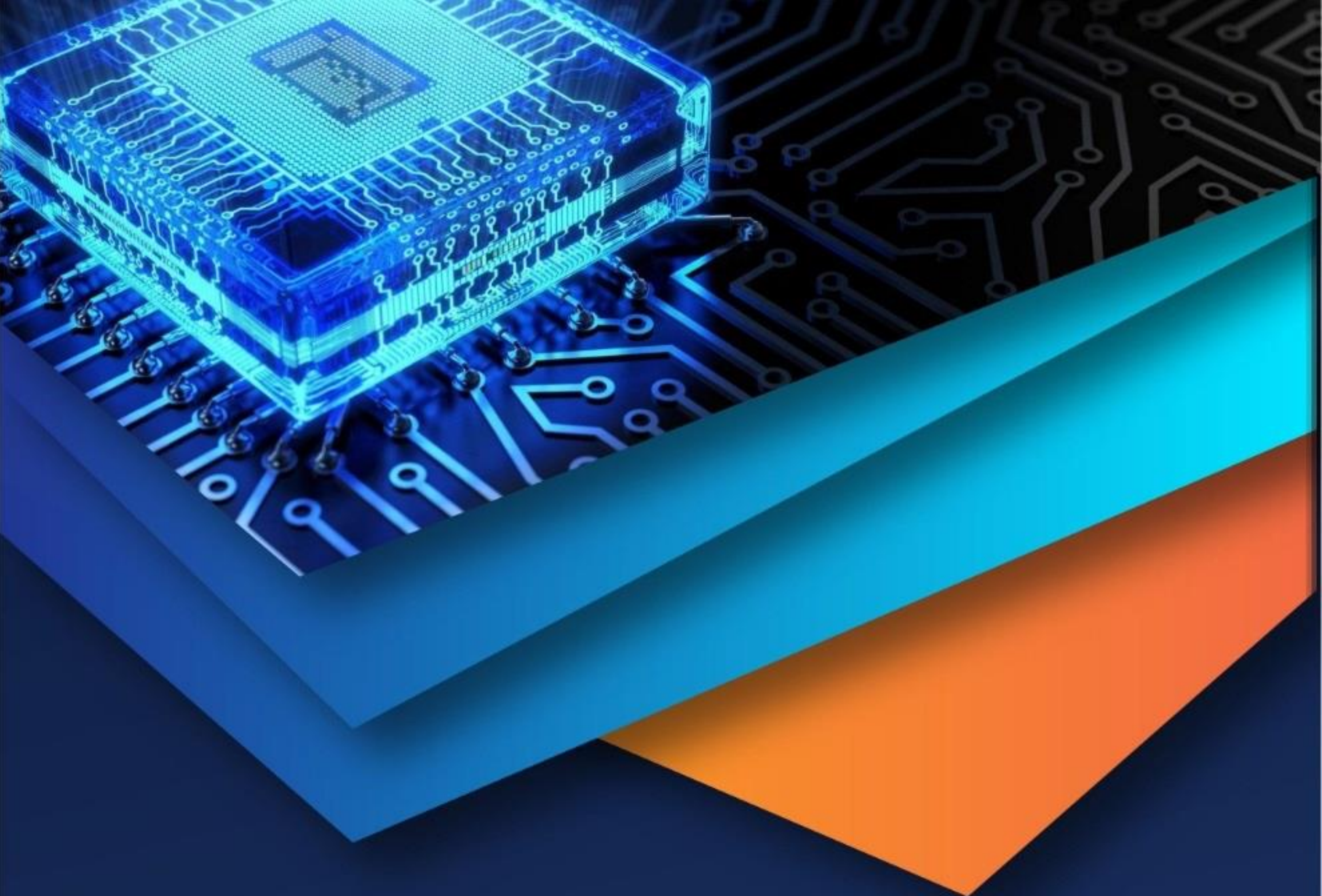

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