Radiation in the Space Environment

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Radiation in the space environment is a major concern of spacecraft engineers. Photoemission by radiation is experimented with using a Cobalt 60 radiation source, potassium as the emitting material and a charged copper collection plate inside of a vacuum chamber. This experiment produced no significant results but suggestions are made for future attempts. Mitigating the amount of radiation that a spacecraft's payload is exposed to is another challenge. Different materials are tested for shielding effectiveness at varying thicknesses. Of the four materials tested, aluminum, lead, cardboard and Mylar, the lead and aluminum provided the best shielding.

Nomenclature

A	=	Richardson's Constant (in^2)
f_o	=	Minimum Threshold Frequency (Hz)
h	=	Planck's Constant (J-s)
k	=	Boltzmann's Constant (J/K)
T	=	Absolute Temperature (K)
ϕ	=	Work Function (J)

I. Introduction

The space environment introduces challenges to the spacecraft design process. A typical spacecraft will have to be designed to survive the effects of neutral particles, charged particles, µm-sized particulates and different types of radiation that are present in the vacuum environment. Understanding the possible effects of these hazards is an important step in mitigating the impact they have on the spacecraft. One of the most significant risks in space is the radiation environment. The radiation present can damage equipment and materials directly or indirectly. Experimenting with the effects of radiation is important in understanding the risks and possible ways to reduce the risk. One common result of radiation exposure is the photoelectric effect. The photoelectric effect releases free electrons and can possibly change the electric potential of different components in turn leading to possible arching or single event upsets. The ability to shield from the radiation in space is vital to mission success and is still a limiting factor to human spaceflight. Testing the effectiveness of different materials and material thicknesses can provide a deeper understanding of possible shielding techniques. This report will detail research findings, attempted experiments and a completed lab manual that can be used to repeat the experiments in future laboratory sections.

II. Background

The interaction of space particles with spacecraft materials and electronics is complex to describe and difficult to simulate with ground-based test facilities. It is also not possible to fully specify the space radiation environment for a given mission because of unknowns in mapping it and unknowns in the processes that generate it. The space radiation environment also changes with time, often in unpredictable ways, making it a challenge to completely assess the hazards in any orbit.

The space environment contains phenomena that are potentially hazardous to humans and technological systems. Many of these hazards involve plasmas and higher energy electrons and ions that are uncommon in Earth's atmosphere. The space environment is populated with electrons and ionized atoms that come from the sun, Van Allen radiation belts, galactic cosmic rays, and single particle events. At high energies, approximately millions of eV, these particles have sufficient energy to ionize atoms in materials of spacecraft. At lower energies, below thousands of eV, their effects range from charge accumulation on a spacecraft to material degradation.[1] Engineers have to consider the radiation environment when designing their spacecraft. For example, Small Astronomy

Satellite-1 was launched on an Italian San Marco platform off the coast of Kenya to avoid the Van Allen radiation belts that could damage the payload.[2]

Spacecraft charging is the process by which orbiting spacecraft accumulate electric charge from the surrounding natural space plasma. It is produced by interactions between satellite surfaces and space plasma, geomagnetic fields and solar radiation. These interactions are caused by unequal negative and positive currents to spacecraft surfaces and produce an accumulation of charge on exposed surfaces of a spacecraft.[3] The charging process continues until the spacecraft reaches an equilibrium charging level or floating potential. Sometimes high energy particles from the sun in the form of electromagnetic radiation (gamma, UV, or X-ray etc.), single particle events (SPE), or galactic cosmic rays (GCR), bombard a spacecraft and cause surface electrons to be emitted. When this happen this is called photoemission.[4] These ejected electrons will sometimes embed themselves on charged sections of the spacecraft like sensing equipment. This causes a larger electric potential that will increase the chances of arcing happening. Electrical arcs can cause damage to electrical equipment on the spacecraft. We demonstrate this subject in another Space Environments laboratory experiment.

Knowing the potential harms that space radiation can cause has led many scientists and engineers to study methods and materials to shield spacecraft and human payloads from the harms of radiation. Common shielding methods have been using the spacecraft's aluminum structure as a shield. There have been investigations into using magnetic fields and different combination of materials to use as shields.[1]

III. Past Experiments

Various past experiments done at other universities were researched for inspirations for an experiment. Going into the research, it was known that finding a suitable and affective radiation source that could cause photoemission would be key to the experiment's success. In the journal article, "Photoemission and Conduction Currents in Vacuum Ultraviolet Irradiated Aluminum Oxide", vacuum ultraviolet light (VUV) radiation was used to cause photoemission from an aluminum oxide wafer.[5] The VUV light came from a synchrotron light source. A synchrotron is a particular type of cyclic particle accelerator in which the magnetic field (to turn the particles so they circulate) and the electric field (to accelerate the particles) are carefully synchronized with the travelling particle beam.[6] This experiment showed that photoemission could happen from lower frequency radiation source like UV and a particle accelerator would be needed to get light particles to move fast enough to cause photoemission. Currently, Cal Poly does not have a particle accelerator that could have been used for the experiment. In the article, "Effect of Vacuum Ultraviolet and Ultraviolet Irradiation on Mobile Charges in the Bandgap of Low-k-Porous Organosilicate Dielectrics", a mercury pen lamp was used to cause photoemission from silicon chips.[7] A mercury pen lamp is quartz pencil lamp is a small, low-pressure, mercury-vapor discharge lamp that is made of double-bore material with both electrodes at one end. They are very stable lamps and maintain a high output of ultraviolet radiation.[8]

The research also led to different methods of measuring voltages and currents to see if photoemission was happening. In "Photoemission and Conduction Currents in Vacuum Ultraviolet Irradiated Aluminum Oxide," a kelvin probe was used to measure the surface potential of the charged aluminum oxide wafer.[5] The kelvin probe is a non-contact, non-destructive measurement device used to investigate properties of materials. It is based on a vibrating capacitor and measures the work function difference or, for non-metals, the surface potential, between a conducting specimen and a vibrating tip.[9] The work function is an extremely sensitive indicator of surface condition and is affected by surface charging and other factors. A kelvin probe would help in the experiment because of the importance of knowing if the item chosen to be our photon emitter was at the appropriate voltage to cause photoemission and also if the charged plate collecting the electrons was also at a the correct voltage. Another type of probe used was a picoammeter in the experiment called "Effects of Vacuum Ultraviolet Radiation on Deposited and Ultraviolet-Cured Low-k-Porous Organosilicate Glass."[10] It is a style of multimeter that can measure voltages and currents in the pico or 10^{-12} range. A picoammeter might be necessary to have if the voltages that will be produced will be very small. A kelvin probe and a picoammeter are too expensive and could not fit in the budget. A different method of measuring surface voltages indirectly needed to be devised.

All of the past experiments showed plots that would be beneficial to recreate. Figure 1 from "Photoemission and Conduction Currents in Vacuum Ultraviolet Irradiated Aluminum Oxide" article, simply shows that as the energy of the impeding electron increases the photocurrent coming from the Aluminum Oxide wafer also increases until it reaches a maximum. In this case, the maximum photocurrent is 0.15 nano Amps.

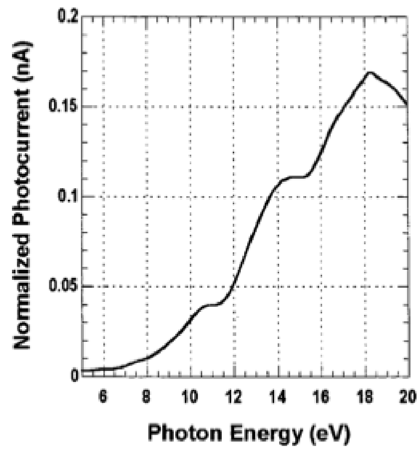

Figure 1. The Photocurrent from the Aluminum Oxide wafer increases as the impeding photon energy increases. [5]

IV. Experiment #1: Spacecraft Charging

A. Background

The initial idea was to demonstrate that radiation could cause photoemission from a material and in turn cause spacecraft charging. This experiment is beneficial because the outcome has a direct effect on a spacecraft. The different potentials on the spacecraft can induce arching and lead to significant damage.

A radiation source will cause photoemission from a surface finish or material. The escaping electrons from the finish or material would then be attracted to a positively charged component, changing the potential of the component. To demonstrate this theory, a material or finish is needed to emit electrons when in contact with a plausible radiation source. The work function of a material is the amount of energy that is required to release electrons from a material. Albert Einstein developed the equation

$$\phi = hf_o \tag{1}$$

where ϕ is the work function of a material in Joules, h is Plancks constant, 6.626 x 10^{-34} J-s, and f_o is the minimum threshold frequency of the impeding photon in Hz.[11] The current density emitted from the material can be determined by the equation

$$J = AT^2e^{-\frac{\phi}{kT}} \tag{2}$$

where A is Richardson's constant, T is the absolute temperature, and k is Boltzmann's constant. From this equation it can be seen that the current density will increase with added temperature. Based on these equations, it is evident that the two most vital materials to the success of this experiment would be the radiation source and the material that would be releasing electrons.

B. Material Choice

Initially two different types of radiation were looked at; Ultra Violet (UV) radiation, like that of the previous experiments and alpha, beta and gamma radiation. The UV radiation would be beneficial in that it has the ability to emit high energy level waves and is safer. Obtaining a UV source that could be used in the vacuum chamber at an affordable cost proved to be a challenge. The UV sources that are available require huge amounts of power and could not be integrated into the current lab set-up. This led to having to choose the other type of radiation.

Alpha, gamma and beta radiation sources are valid options that are prevalent in the spacecraft environment. Because of its higher energy and more occurrences in the space environment, a gamma ray source was the most plausible option. The next restriction on radiation source was safety and ease of obtaining. Because of the long term dangers of radiation exposure there are a lot of restrictions on ordering and storing radiation on campus. After some research a radiation supplier was found that had a list of sources that did not require licensing and has no special handling, storage or disposal restrictions. From the list of sources the source with the highest energy level, Cobalt 60 was chosen. The source comes as 1 micro curie in a sealed plastic disk of 1 inch in diameter and 1/8 inch in thickness. The Cobalt 60 source has a half-life of 5.27 years and emits gamma rays at an energy of 1332.5 KeV.[12]

The other important component to the experiment is the material that releases the electrons. As shown in the equations above, a material with a lower work function will be more beneficial for the experimental purposes. The material must also be something that is easy and safe to handle and put into the vacuum chamber. It was decided that potassium is the best choice because it is easy to obtain, relatively safe to handle and has a work function of only 2.3.[11] In using potassium use of a binder is avoided, and the chunks of potassium can be used as is.

As proof that the Cobalt 60 source should be significant enough to cause photoemission of the potassium, Eq. 1 is used to calculate the frequency required to cause photoemission from potassium. This calculated frequency is $5.56 \times 10^{14}\ s^{-1}$. The range of frequencies on the electromagnetic spectrum can be seen in Fig. 2.

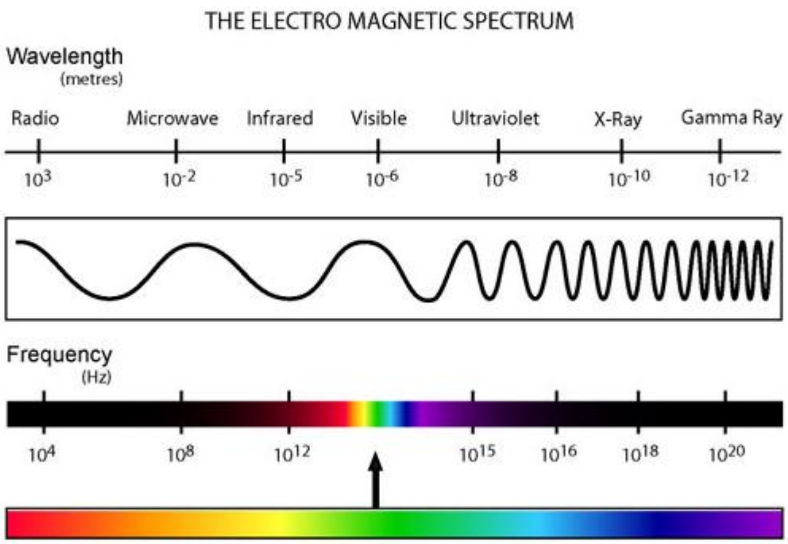

Figure 2. The electromagnetic spectrum shows that gamma rays are at a higher frequency than the minimum threshold frequency of Potassium.[13]

The calculated minimum threshold frequency is in the infrared range and Gamma frequencies are much higher suggesting that the Cobalt 60 radiation source will have a high enough frequency to cause the potassium to emit electrons.

C. Apparatus

With the materials chosen, the experimental setup could be designed and tested. The primary components include the radiation disk, the potassium and a positively charged plate. The whole apparatus would need to be set up inside of the vacuum chamber. Figure 3 shows the set up that was used.

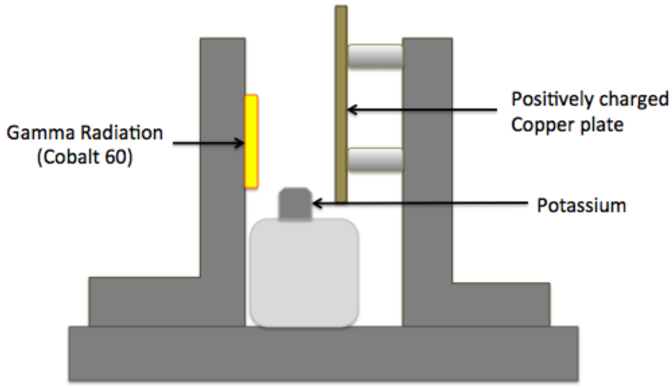

Figure 3. The apparatus used to hold the potassium, Cobalt 60 and copper plate is shown.

The base and L-brackets are made steel and connected using finger tightened bolts. The potassium is sitting on a raised piece of plastic for the purpose of getting it closer to the radiation and copper plate. The copper plate is attached with plastic stand-offs and plastic screws and the Cobalt 60 disk is attached to the L-bracket with Kapton tape. The electrical set-up of the apparatus is more complicated and can be described by the electrical diagram in Fig. 4.

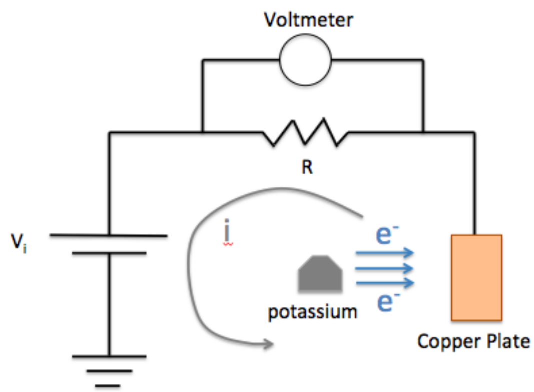

Figure 4. This circuit diagram shows the electrical set-up of the experiment.

The concept behind this design is that the potassium will emit electrons that will be attracted to the positively charged copper plate. When electrons flow to the plate, a current is created and can be seen on the voltmeter over the resistor. With this set-up two electrical attachments are needed to go through into the chamber, one for the voltage supply and one for the Voltmeter. Five separate tests were run, each time changing a variable. Table 1 is a summary of the different runs.

Table 1. An outline of the different factors of each experimental test that was run.

Run #	Dimensions (in)				K mass (g)	Average Vacuum Level (Torr)	Voltage Range (Volts)	Other
	X_{RC}	X_{RK}	Y_R	Y_C				
1	2	1.5	1	3	0.12	3.65×10^{-2}	5-60	
2	2	1.5	1	3	0.12	2.5×10^{-2}	10-60	
3	1	0.5	0	0	0.13	2.75×10^{-2}	10-60	Closer proximity
4	1	0.5	0	0	0.07	8.9×10^{-5}	10-200	Higher vacuum and voltage
5	0.9	0.4	0.7	0.1	0.37	3.5×10^{-5}	10-200	Added heat (T_k=51.3 °c)

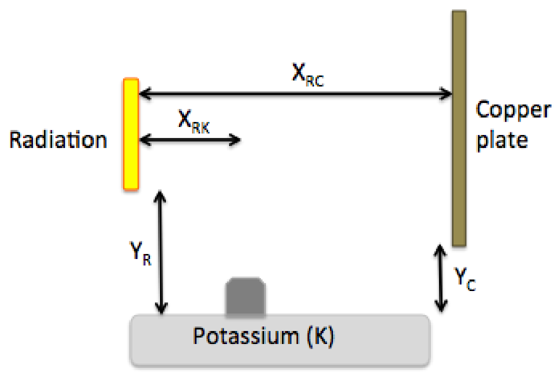

Figure 5. This image shows the dimensioning scheme for the apparatus set-up.

The dimensions can be seen referenced in Fig. 5 where X_{RC} is the distance between the radiation and the copper plate, X_{RK} is the distance between the radiation and the Potassium, Y_R is the height of the bottom of the radiation disk and Y_C is the height of the bottom of the copper plate. K mass is the mass of the radiation prior to the experiment. The mass was also recorded after the experiment, but did not change. The average vacuum level in Torr is the average of the vacuum levels recorded at each voltage level. The voltage range is the input voltage that was used in the circuit and corresponded to the charge of the copper plate. The final column takes note of the variable that was changed from the previous run. The first run was done at a low vacuum (3.65×10^{-2}), with low voltages (5-60 volts) and the apparatus was set up such that all the components were spread apart. Leaving the set-up alone, we continued to pull a vacuum and ran through the voltage levels again for run 2. For run 3, all of the components were pushed together so that everything was in closer proximity. Each of these tests produced no results and it was decided decided that a higher vacuum and higher input voltages might help produce results. In theory, a higher vacuum would allow photoemission to occur easier and a higher input voltage would make the copper more attractive to electrons and hopefully create a higher current. Even at the higher voltage and higher vacuum no results were seen in run 4. As a final attempt, heat was added to the system in run 5. In theory, an increase in temperature could increase the emitted current density as seen in Eq. 2. A heater circuit was added underneath the potassium and caused the temperature of the potassium to be 51.3°c during the run. The set-up with the resistor heater can be seen in Fig. 6 and Fig. 7. Sadly, run 5 also produced no results.

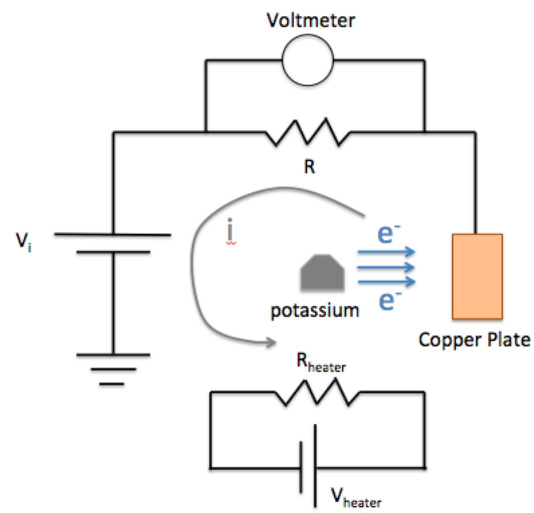

Figure 6. The circuit diagram with the heater added to the system is shown.

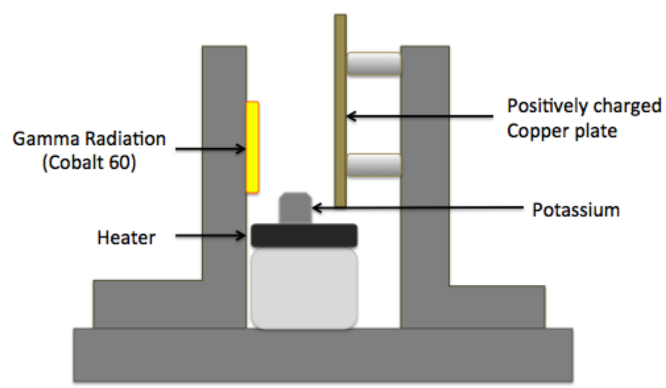

Figure 7. The heater was added directly beneath the potassium to increase the emitted current density.

D. Discussion

Looking back on the experiment, there are a few factors that may have prevented the needed results. The first possibility is that the radiation source is not strong enough. It was proved mathematically that the radiation frequency was high enough, but the strength and magnitude of the radiation were not enough. To obtain a stronger dosage of radiation would require permitting and safety equipment that is not easily available. Another possibility is that the potassium was actually emitting electrons, but the current was so small that the measuring equipment could not detect it. If a picoammeter could be obtained and used, it would be interesting to see if smaller currents are detectable. With the proper equipment and radiation source, proper results from this experiment would be exciting and educational.

V. Experiment #2: Radiation Shielding

A. Introduction

Many of the effects of radiation are known and can be experimented with in developed laboratories and on flight. The ability to protect a spacecraft from the radiation to help reduce the risk of these events taking place is

critical. A major part of a spacecraft's design is shielding material choice and design. The focus of the proceeding experiment demonstrates the effectiveness of different shielding materials and thicknesses from the gamma radiation source.

B. Apparatus

The general idea behind this experiment is find the effectiveness of blocking the radiation using different materials and thicknesses. The same radiation source as used in the other experiment, Cobalt 60, will be used in this experiment. A Geiger counter is used to measure the dosage of radiation. The Geiger counter that is used is called the Vernier Digital Radiation Monitor. This handheld device, shown in Fig. 8 will output counts per minute and milliRoentgens per hour onto the screen.

Figure 8. A Vernier Digital Radiation Monitor uses a Geiger tube to display the counts per minute coming from the radiation source.[14]

The count light will flash with each count. For the purposes of this experiment, the Calibration Input port and the Data Output port will not be used. The LCD screen will display the counts per minute (CPM) and the mode switch will be set to CPM. The set buttons will be used to designate an amount of time over which to create a count. The Alpha window is the input to the Geiger tube and where the radiation will be placed.

Four different materials are used to experiment with shielding ability. Multiple sheets of each material are needed so that the shielding thickness can gradually be increased. The materials being used include aluminum,2 ½ # lead, Mylar thermal blanket and cardboard. There are twelve sheets of aluminum measuring 4 in. by 4 in. each with a thickness of 0.096 ± 0.001 in. The twelve lead sheets also measure 4 in. by 4 in. and are each 0.045 ± 0.005 in. thick. The Mylar is bundled together with Kapton tape to create ten separate shields that are each .062 ± 0.001 in. thick. The ten cardboard pieces also measures 4 in. by 4 in. and each sheet is 0.11 ± 0.01 in. thick.

C. Procedure

Before demonstrating the effectiveness of shielding it is important to also understand the effect distance has with the strength of radiation. To show this, multiple recordings were taken at different distances from the Geiger counter. The set-up for this experiment is shown in Fig. 9.

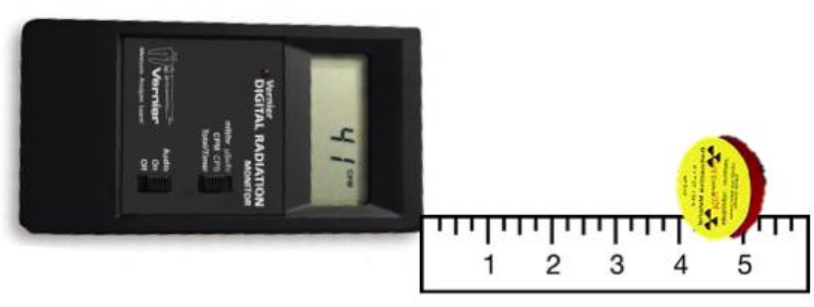

Figure 9. The distance test is set up such that the radiation is moved in small increments away from the Alpha window of the monitor.

The results from this are shown in Fig 10.

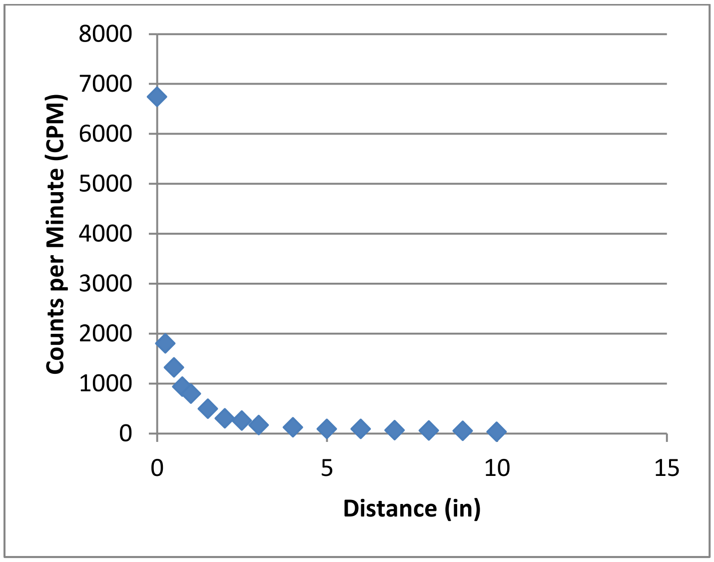

Figure 10. The results of the distance test are shown with distance on inches on the x-axis and counts per minute on the y-axis

As expected, the CPM is proportional to the inverse of the distance. With this understanding the experiment can be run with the different materials as shields, gradually increasing the thickness of the material. The setup for this experiment can be seen in Fig. 11. Throughout this test, the radiation will stay at the same distance from the Alpha window. This distance is chosen to be three inches, allowing all the layers of shielding to fit and still providing high counts per minute. With each addition of a shielding layer, a new data point is created.

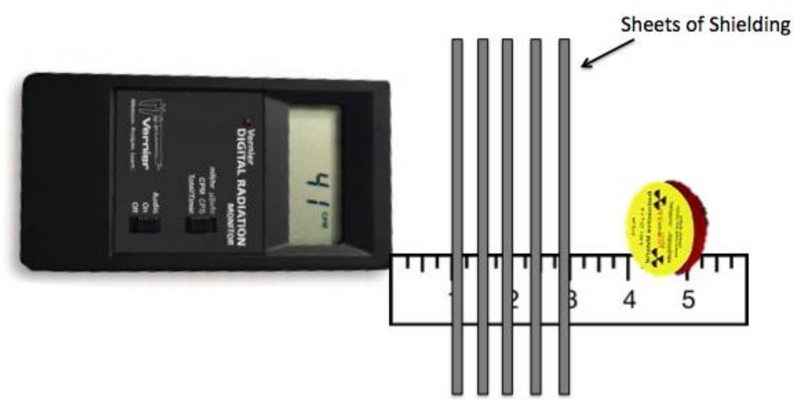

Figure 11. When testing shielding materials at different thicknesses the shielding is places in layers between the radiation and the monitor. During this test the distance between the radiation and monitor does not change. Note: The experiment was done with the radiation at a distance of 3 inches.

D. Results

After obtaining data points for each material at each thickness a plot can be created to compare the effectiveness of each material. The results of this experiment can be seen in Fig. 12.

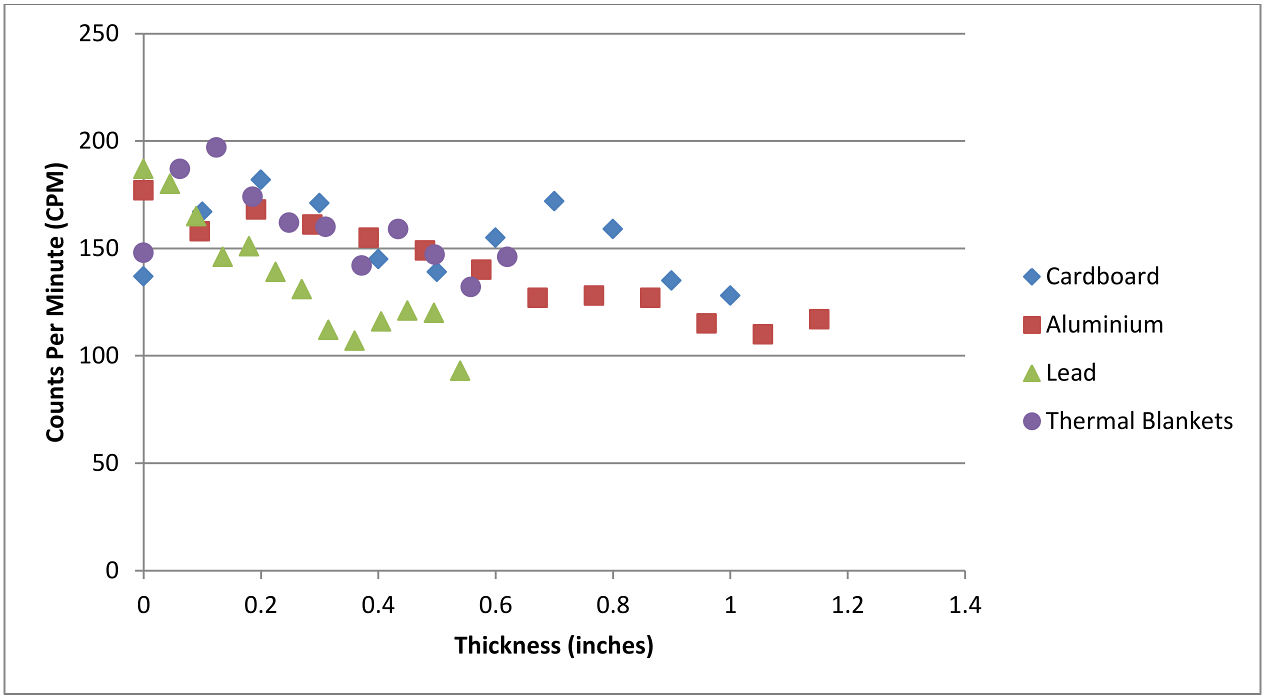

Figure 12. This plot shows the difference between the different shielding materials used.

As expected the lead provided the best protection from the radiation source. Cardboard had little affect shielding the radiation source. It fluctuated around 154 CPM and never decreased significantly. Ignoring the first point, Mylar thermal blankets initially decrease but level off later. The decrease is not as steep as lead. Aluminum follows a decreasing trend but is not as effective as lead. These measurements were taken over a one minute period. To get a better CPM average, data should be collected over a longer period of time to allow for error. In an error test that was run after the experiment, collecting data over a one minute interval gave a standard deviation of 17.6 CPM. This error is high and leaves skepticism about the points that were obtained. As a quick test, the standard deviation was found when the test period was switched to 3 minutes for each point. With the longer test period, the standard deviation decreased to 7.5, a much more reasonable uncertainty. In future experiments, longer test times should be used to reduce the amount of error in the data points. In designing a spacecraft engineers cannot simply use the material that creates the best shield. Although the lead shields the best it is also the heaviest. In design, a trade study would have to be done to weigh the different variables and determine the best shield.

VI. Conclusion

Radiation is a major cause for concern in designing a spacecraft. It has the ability to damage electronics and it is very hazardous to human space travel. Understanding the effects of radiation and possible mitigation techniques is vital to a spacecraft's success.

Radiations ability to cause photoemission is a concern for many vital parts of the spacecraft. Creating an experiment that demonstrates this hazard proved to be quite challenging. In theory, the experiment design will show a change in electric potential of the collecting plate. Although no results were obtained from this experiment, the concept still holds. In future attempts a stronger radiation source and better measuring devices could work. A stronger radiation source would have the ability to cause a greater photoemission current from the emissive material. The emitted current is very small and the voltmeter was unable to recognize such small changes. Use of a picoammeter would be required to see the entire effect of the radiation. Demonstrating this concept could be done with the proper lab equipment.

It is essential that a spacecraft is designed with the radiation environment in mind. The most simple and common way of protecting a spacecraft from radiation is by use of different shielding materials. The completed

experiment compares the effectiveness of different shielding materials at different thicknesses. As expected the lead is the best shield, but also impractical for flight because of its weight. Aluminum also proved to be a reasonable shield and is often used in space. The data collected for these comparisons didn't turn out as clean as expected. This is due to the large error in CPM from taking measurements over a single minute. Collecting the data points over a longer period of time would reduce the error in the average CPM and produce cleaner plots with more obvious trend lines. This particular experiment will be done by students in the upcoming Space Environments lab. A lab manual was created that details the background, the processes and possible discussion topics. This lab manual can be seen in the attached appendix.

Appendix

A. Raw Data

B. Error Analysis

C. Lab Manual

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Raw Data

Distance (in)	CPM
0	6741
0.25	1801
0.5	1322
0.75	940
1	794
1.5	491
2	301
2.5	259
3	166
4	120
5	89
6	88
7	63
8	55
9	51
10	32

	aluminum	
#	thickness	cpm
0	0	177
1	0.096	158
2	0.192	168
3	0.288	161
4	0.384	155
5	0.48	149
6	0.576	140
7	0.672	127
8	0.768	128
9	0.864	127
10	0.96	115
11	1.056	110
12	1.152	117

Cardboard		
#	thickness	cpm
0	0	137
1	0.1	167
2	0.2	182
3	0.3	171
4	0.4	145
5	0.5	139
6	0.6	155
7	0.7	172
8	0.8	159
9	0.9	135
10	1	128

Lead		
#	thickness	cpm
0	0	187
1	0.045	180
2	0.09	165
3	0.135	146
4	0.18	151
5	0.225	139
6	0.27	131
7	0.315	112
8	0.36	107
9	0.405	116
10	0.45	121
11	0.495	120
12	0.54	93

Thermal Blanket		
#	**thickness**	**cpm**
0	0	148
1	0.062	187
2	0.124	197
3	0.186	174
4	0.248	162
5	0.31	160
6	0.372	142
7	0.434	159
8	0.496	147
9	0.558	132
10	0.62	146

Error Analysis

Data collected at 3 inches in 1 minute intervals:

198
173
131
165
152
153
151
168
150
181
157
179
142
168
141
131
163
150
176

Average: 159.4 CPM
Standard Deviation: **17.6**

Data collected at 3 inches in 3 minute intervals:

496
500
536
540
535
513
520
497
543
502
473

Average: 171.4 CPM
Standard Deviation: **7.5**

Lab #7: Radiation Part 2: Ionizing Radiation & Radiation Shielding.

Objective

The objective of this laboratory experiment is to demonstrate the effects of radiation in space and how shielding can mitigate those effects.

Background

The space environment contains phenomena that are potentially hazardous to humans and technological systems. Many of these hazards involve plasmas and higher energy electrons and ions that are uncommon in Earth's atmosphere. The space environment is populated with electrons and ionized atoms that come from the sun, Van Allen radiation belts, galactic cosmic rays, and single particle events. At high energies, approximately millions of eV, these particles have sufficient energy to ionize atoms in materials of spacecraft. At lower energies, below thousands of eV, their effects range from charge accumulation on a spacecraft to material degradation. Engineers have to consider the radiation environment when designing their spacecraft.

Apparatus

Geiger Counter

Geiger counters are used to detect ionizing radiation and use a Geiger–Müller tube. A Geiger–Müller tube consists of a tube filled with a low-pressure inert gas. The tube contains electrodes, between which there is a potential difference of several volts, but no current flowing. The walls of the tube are either entirely metal or have their inside surface coated with a conductor to form the cathode while the anode is a wire passing up the center of the tube. When ionizing radiation passes through the tube, some of the gas molecules are ionized, creating positively charged ions, and electrons. The strong electric field created by the tube's electrodes accelerates the ions towards the cathode and the electrons towards the anode. The ion pairs gain sufficient energy to ionize further gas molecules through collisions on the way, creating an avalanche of charged particles. This results in a short, intense pulse of current which passes from the negative electrode to the positive electrode and is measured or counted.[1]

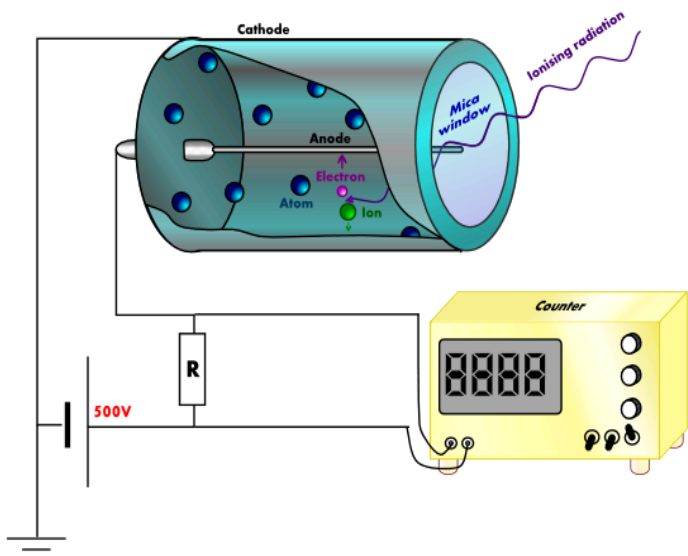

Figure 1. Geiger counter schematic.[1]

Figure 2. Geiger counter schematic with switches, buttons, and screen labeled.

Using the Geiger Counter

1. Turn the On/Off/Audio switch to "On"
2. Move the Mode switch to "Total/Timer"
    - If the switch is already there, switch it away and back to "Total/Timer"
    - The "Total/Timer" mode will record a total count for a set time period
    - The screen should display "Set 0:01" or whatever time span was last used.
3. Use "+" and "-" on top of the device to change the sampling time span
4. Press "Set" to start the count
    - The device will beep 3 times to indicate the start
5. **The device will beep 3 times at the end of the time span and the total count will remain displayed.**
    - A single beep is insignificant to the count.
6. To start the count again, move the switch back and forth to "Total/Timer" and press "Set"

Radioactive Isotope

This experiment utilizes the radioactive isotope Cobalt-60 to produce gamma radiation. This amount of Cobalt-60 is safe to be around with no Nuclear Regulatory Commission licensing. The isotope is in a plastic to prevent leakage and contamination.

Shielding Materials

- Corrugated Cardboard
- 2 ½# lead sheeting
    - Please wear gloves while handling lead.
    - Lead is poisonous if ingested.
- Aluminum Sheeting
- Mylar thermal blanket

Procedure

Distance Experiment

Find the radiation counts at each of the distances shown in table 1.

1. Place the radiation disk flat on the table at the appropriate distance from the Alpha Window of the Geiger counter
   - The actual radiation is located in the center of the plastic disk
   - For the 0 in measurement, hold the radiation disk vertically up against the Alpha Window.
2. Place the Geiger counter flat on the table pointing towards the radiation disk.
   - You may want to tape the counter in place to make sure that it doesn't move during the test.
3. At each distance step, find the total count over a span of 3 minutes. (See "Using the Geiger Counter") Divide this number by 3 to get the average counts per minute at each distance step.

Table 1. Distance experiment table.

Distance (in)	Total Count for 3 minutes	Counts Per Minute (CPM)
~ 0		
0.25		
0.5		
0.75		
1		
1.5		
2		
2.5		
3		
4		
5		
6		
7		
8		
9		
10		

Shielding Experiment

Experiment with different shielding materials and thicknesses

1. Secure the radiation disk onto the table 3 inches from the Alpha Window of the Geiger counter.

- Make sure both of these are secured in place so that they will not move throughout the rest of the experiment
2. Take a reading over a 3 minute time span with no shield between the counter and the radiation disk. (See "Using the Geiger Counter")
3. Add a layer of shielding material between the disk and the window as shown in Fig. 3.

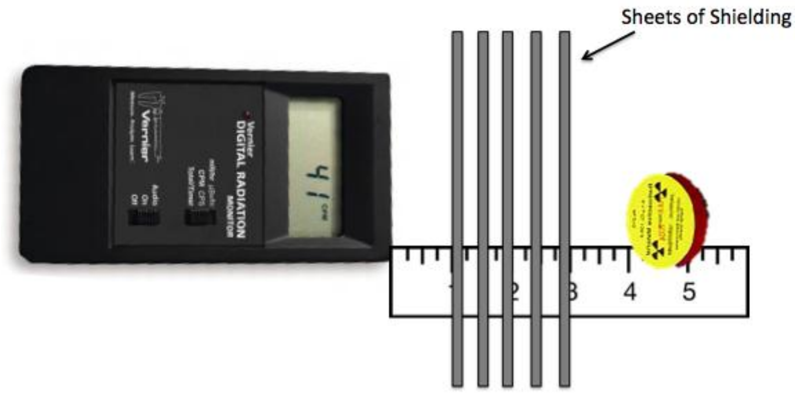

Figure 3. Shielding Experiment Schematic.

4. Record the thickness of the material shield and the new count.
5. Continue to add layers of similar material, recording the new count and thickness with each addition. See Table 2.
6. Repeat this process (Steps 2-5) for each of the different materials
   - Aluminum sheets
   - Lead sheets
   - Cardboard
   - Mylar bundles

Table 2. Shielding Experiment Table

# of layers	Total thickness (in)	Total Count for 3 minutes	Counts Per Minute
1			
2			
3			
...			

Analysis

1. Plot distance versus Counts Per Minute (CPM).
2. Plot Shield Thickness versus CPM for each shielding material used. Please put all of them on 1 set of axes
3. Calculate dose in Rad of the radiation disk at a 3 inch distance
   a. 1 CPM = 0.001 mR/hr
   b. 1 R/hr = 0.877 Radioactive

Discussion Questions

1. Add a trend line to the distance vs. CPM plot. What is the trend? Does it follow the Inverse Square Law?
2. What do you think was the best shielding material that you tested for on earth? In space?
3. Why are certain materials better as radiation shields?
4. What are different radiation shielding methods that are not physical material shields?
5. Are there any risks associated with the amount of radiation you calculated in the Analysis #3?
6. Using Fig. 5.19 from Tribble, compare your experimental Aluminum thickness range to the expected dose in GEO. At this dose level, which damage thresholds are a concern?

Table 3. Radiation Damage Thresholds.

Material	Damage Threshold (Rad)
Biological Matter	10^1-10^2
Electronics	10^2-10^6
Lubricants, hydraulic fluid	10^5-10^7
Ceramics, glasses	10^6-10^8
Polymeric material	10^7-10^9
Structural metals	10^9-10^{11}

7. How would Figure 5.19 change if the different materials you experimented with were plotted on the X-axis. (ie: how would the plot change if lead was plotted instead of aluminum? Steeper/shallower slope?)
8. Using Figure 5.20, determine how much Aluminum thickness would be needed to stay within the recommended dose limits in LEO for an astronauts eyes, skin and bone marrow (Table 5.4)?

Figures from Tribble

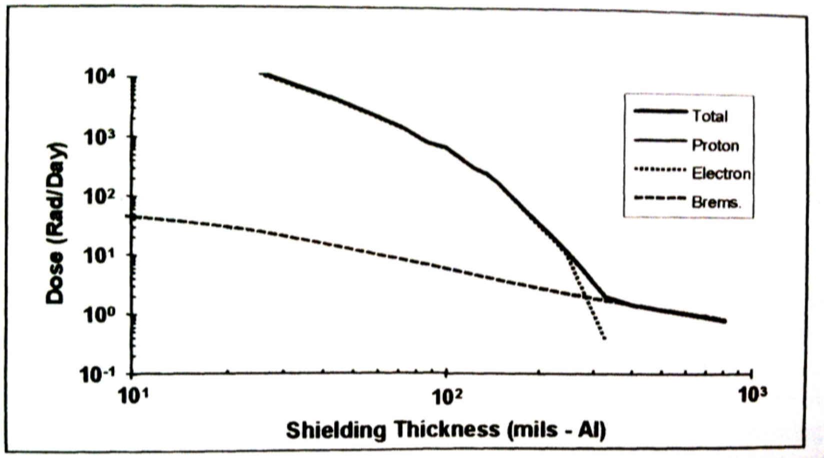

Figure 5.19. The radiation dose in the geosynchronous orbit – 35,800 km, 0º

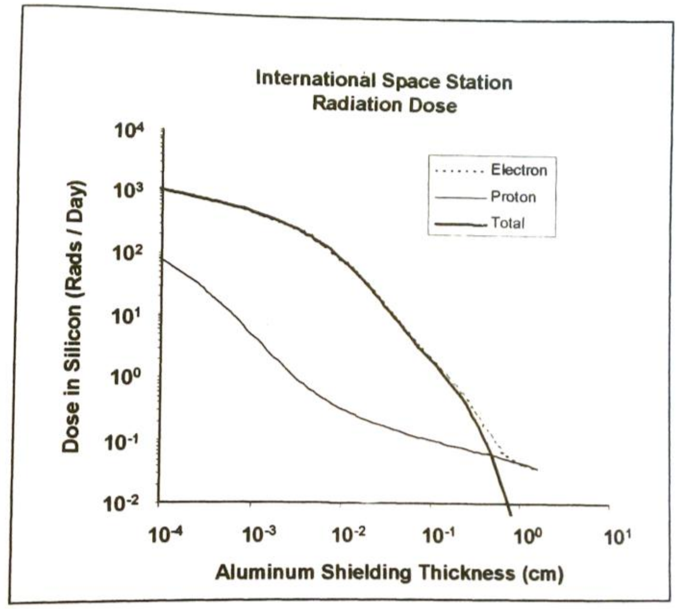

Figure 5.20. The low Earth Orbit radiation dose for the International Space Station – 400 km, 51.6º

Table 5.4. Recommended Radiation Dose Limits for astronauts

Mission Duration	Dose Limits – Rads (Tissue)		
	Skin (0.1 mm)	Eyes (3 mm)	Bone Marrow (5 cm)
30 days	75	37	25
90 days	105	52	35
180 days	210	104	70
1 year	225	112	75
Career total	*1200*	*600*	*400*

References

[1] "Instruments for Radiation detection." *Chem Prime.*Web. <http://wiki.chemprime.chemeddl.org/index.php/CoreChem:Instruments_for_Radiation_Detection>

[2] "Digital Radiation Monitor." *Vernier Software & Technology*. Web. <http://www.vernier.com/products/sensors/drm-btd/>.

[3]Tribble, Alan. C *The Space Environment: Implications for Spacecraft Design*, Princeton University Press, Princeton, NJ, 2003