Cosmic Ray Shielding

Natasha Honcharik
Mass Academy of Math and Science
Table of Contents

Abstract...........................................................................................................................................2
Introduction........................................................................................................................................2
Literature Review.............................................................................................................................3
   Radiation........................................................................................................................................3
      Radiation Sources......................................................................................................................4
      Radiation Monitor.....................................................................................................................4
   Cosmic Rays..................................................................................................................................5
      Cosmic Ray Sources....................................................................................................................6
      Cosmic Ray Energies...................................................................................................................7
      Primary vs. Secondary Rays.........................................................................................................8
      Cosmic Ray Types.......................................................................................................................9
      Cosmic Ray Shielding..................................................................................................................10
      Soft Errors................................................................................................................................11
   Celestial Coordinates....................................................................................................................11
Hypothesis.........................................................................................................................................13
   Justification.................................................................................................................................13
Research Proposal...........................................................................................................................13
Methodology......................................................................................................................................14
Results................................................................................................................................................20
   Discussion....................................................................................................................................22
Conclusions........................................................................................................................................23
   Error Analysis..............................................................................................................................24
   Further Research..........................................................................................................................24
Limitations and Assumptions............................................................................................................25
Acknowledgements..........................................................................................................................25
Literature Cited..................................................................................................................................26
I. Abstract

In the field of computing, one ongoing problem is soft errors, or data corruption, caused by cosmic rays. Rather than going back to search for the errors, a potential solution is to shield against cosmic rays. The purpose of this experiment was to test different materials for their effectiveness as cosmic ray shields and magnets for their effectiveness as cosmic ray deflectors. Different materials including aluminum foil, gold foil, and arrangements of small magnets were tested for their shielding ability against natural sources of cosmic radiation. (Most likely) aluminum foil will cause moderate decrease in detected radiation, and gold foil and magnets will cause a significant decrease in detected radiation. A useful shielding method for important equipment would be gold foil, which is currently used, as well as deflecting magnets which would be less expensive.

II. Introduction

Cosmic rays are all around us. Subatomic particles are constantly arriving from distant stars and galaxies and passing right through us. They are a background of radiation that we often do not notice. However, they can cause significant problems and dangers for humans in the right circumstances.

All computers run programs using a code of zeroes and ones. When a cosmic ray hits a computer chip, it can cause a reaction with the silicon, sending the wires over their critical voltage. This can flip one of the bits in the
code from zero to one or one to zero, and suddenly the code is incorrect. The program now has a “soft error” that may cause it to fail. Soft errors are an ongoing problem for computer engineers, and the issue is only getting worse as smaller transistors, which are more affected by cosmic rays, are developed.

Besides computers on the ground, cosmic rays pose a more pressing problem for spacecraft. Both computers and humans spending long periods of time in space are exposed to larger amounts of cosmic radiation. Computers in a spacecraft are responsible for navigation and life support, so it is essential for accuracy and precision to be maintained and for errors not to occur. Spacefaring humans require protection from cosmic rays to avoid the harmful disease-causing effects of radiation. Although computers currently have some software in place to search for and fix errors, shielding against cosmic rays in advance would eliminate the problem and help protect humans as well.

The purpose of this study was to test various materials including aluminum, steel, gold, and magnets for their cosmic ray shielding ability. In the future, this could lead to smaller, more effective, and less expensive cosmic ray shields for use in space stations and ground based systems in need of high accuracy.

III. Literature Review

Radiation:

Radioactivity is energy produced by the decay of atoms. Ionizing radiation is the dangerous kind because it is energetic enough to knock an
electron loose when it hits an atom, thus ionizing it. Therefore it can affect cellular processes when it passes through human tissue and computer programs when it hits a computer chip (Barksdale, n.d.).

Radiation Sources:

There are many different sources of radiation. Some are used in medicine including X-rays, scans, and radiation therapy. Wireless technology like cell phones does emit radiation in the form of radio waves. However, radio waves are non-ionizing radiation, meaning they do not have enough energy to ionize atoms when hitting them. Some types of television screens and cathode ray tube monitors emit X-rays, and certain types of smoke detectors also contain alpha particle radiation. Ionization smoke detectors detect smoke when it interrupts a flow of alpha particles from a radionuclide inside them, americium-241. In addition to alpha particles, they also release some gamma rays. When uranium in rock or soil decays, it produces a gas called radon. This can then be found in many buildings (the EPA estimates one in 15). Radon accounts for half of the radiation we receive. Other small sources that account for only 5% of our radiation intake include cell phones, glow in the dark watches, microwave ovens, and antique glass. Natural sources account for about 80% of the radiation we receive (Barksdale, n.d.).

Radiation Monitor:

The Vernier Radiation Monitor is a directional probe for measuring counts of radiation (number of particles). The probe detects ionizing radiation
using a Geiger-Mueller tube, a tube filled with a noble gas with electrodes on either side. The radiation monitor detects alpha, beta, gamma, and X-ray types of radiation. Low energy gamma rays (10-40 KeV) can enter through the opening at the end of the tube but cannot penetrate the sides (Vernier, 2013). Once radiation enters the tube, it ionizes the gas inside. The ions are attracted to the electrodes, and this produces an electric current. Every time an electric current caused by a particle of radiation is measured, one count of radiation is recorded (Siegel, n.d.).

**Cosmic Rays:**

Cosmic rays are high energy particles of radiation from a variety of cosmic sources in space. It is clear that cosmic rays come from space because their frequency of appearance increases with altitude. As altitude increases, more cosmic radiation is observed because there are less layers of atmosphere to protect from it. However, even a cross country airplane flight at high altitude gives only half the radiation of a chest X-ray (Barksdale, n.d.) At very high altitudes the measured frequency of cosmic rays detected suddenly drops off drastically. This is probably because the detection method used only measured secondary particles produced by primary cosmic rays through interactions in the atmosphere. Additionally, cosmic rays are charged particles, and this is known because their frequency also changes with latitude, showing that they are affected by the earth’s magnetic field. (Cosmic Rays, n.d.).
Cosmic Ray Sources:

Cosmic ray radiation comes from the sun, our galaxy, other galaxies, and within the Earth’s magnetic field where they become trapped. A lot of cosmic rays from the sun include proton radiation. One study looked at solar cosmic rays from 1956-2012; researchers used several different early methods to measure these cosmic rays. There were ground based methods as well as rocket based and balloon based methods. They also used some near-earth orbit crafts and, later, another spacecraft orbiting the sun (Getselev, 2013). The sun releases cosmic rays with solar flares and coronal mass ejections. However, these events are less common than the constant flow of galactic cosmic rays. Therefore, during periods of high activity for the sun, there are actually less cosmic rays measured because the sun’s magnetic field acts as a shield against galactic cosmic rays (Space Radiation Shielding, 2014).

Supernovae are another source, usually of high energy cosmic rays (Gunn, 1969). Another source, pulsars are stars with a beam of radiation coming from each pole. They spin quickly on a different axis from the poles, causing it to act like a lighthouse and shine the two beams in circles. Each time a beam passes over the Earth, a pulse of radiation is measured. It is also theorized that particles can be accelerated by colliding with clouds of plasma, becoming high energy cosmic rays (Shapiro, 1962). Cygnus X is thought to be an example of this. It is a star cluster that accelerates cosmic rays and is also a gamma ray source (Reddy, 2011).
Cosmic Ray Energies:

Cosmic ray energies are between 1 Mega electron Volt (MeV) and 1000 Tera electron Volts (TeV). An electron Volt is the energy given to an electron by accelerating it through one Volt of electric potential. The thermal energy of a molecule at room temperature is approximately 0.04 eV (Energies in Electron Volts, n.d.). The extremely high energy cosmic rays from 100 to 1000 TeV only come from a few specific sources like Cygnus X-3, a neutron star which also emits a lot of X-ray radiation (Cosmic Rays, n.d.). There are observatories in Japan and Utah that currently measure cosmic rays. Using these, four cosmic rays of extremely high energy were observed coming from one place. It is very unlikely that the coincidence of the rays was random. There are many possible reasons for these cosmic rays to have such high energies. Possible sources include gamma ray bursts, quasars (active galactic nuclei), and black holes being formed by collapsing stars. The Sloan Digital Sky Survey (a sky mapping and imaging project at the Apache Point Observatory in New Mexico) was then used to determine the source. In the area of the high energy cosmic rays, there were two merging galaxy clusters which might contain obscured quasars. It also remained possible that the source could be from gamma rays or X-rays (Burnham, 2005).

Some very high energy cosmic rays, on the order of $10^8$ Tev, have uncertain sources. The high energy rays are unlikely to be protons or other nucleic particles because they lose energy when they interact with a photon, meaning their energy would be decreased by the time they reached Earth. The
high energy particles are also not photons because the cascades of secondary particles produced through interactions with the atmosphere do not match that of photon interactions. Neutrinos are also ruled out because at that energy level they should interact with only the Earth and not the atmosphere. So explaining what these particles are and where they come from would require new particle physics or new astrophysics. They are most likely explained by a new source in astrophysics rather than new particle physics because a manmade particle accelerator would likely have already revealed this new particle physics (Burdman, 1997).

Primary vs. Secondary Rays:

Primary cosmic rays are the particles coming directly from space. When they hit the atmosphere, or anything else, they interact with the molecules in the air and form showers of secondary cosmic rays (See figure 1). When primary cosmic rays interact with the atmosphere they produce pions and kaons which then become muons (an elementary particle) by decaying. At sea level about half of cosmic rays are muons (Cosmic Rays, n.d.).

Researchers from the University of Mighigan used a cloud chamber to study cosmic rays underground in a salt mine in Detroit to see what kind of cosmic rays can penetrate the Earth to that depth and what kind of secondary particles they produce from interacting with the salty Earth. Secondary particles were produced when cosmic rays pass through the earth interacting with the ground. Showers of electrons were sometimes caused by a penetrating cosmic ray (Tiffany 1950).
Cosmic Ray Types:

Most cosmic ray particles, about 90%, are protons. Approximately 9% are alpha particles, or helium nuclei, and 1% is electrons, or beta particles. Very small amounts are lighter elements like lithium and beryllium. Even the small amount of light element cosmic rays that exists greatly outnumbers the
proportion of these elements to others in the universe. This shows the light
element cosmic rays might be secondary particles that were hit and energized
by collisions with primary cosmic rays. Heavier elements are proportionally
more abundant in cosmic rays than in matter in the universe. This suggests that
the origin places of cosmic rays are rich in heavy elements. There are very few
antimatter cosmic rays. (Antimatter is particles with opposite electrical
charges as normal matter. For example, antielectrons have a positive charge.)
All of them that are observed can be attributed to collisions forming matter-
antimatter pairs (Cosmic Rays, n.d.).

Alpha radiation is emitted by atoms of radioactive elements and consists
of positively charged particles. Each is a helium nucleus. They are large and
slow, and they do not make it through the atmosphere. Beta radiation consists
of electrons. Protons and neutrons are also common cosmic rays. Muons, pion,
and kaons are all secondary cosmic rays produced by interactions of primary
cosmic rays with the atmosphere (Barksdale, n.d.).

Cosmic Ray Shielding:

Alpha particles can be easily stopped by things like skin or paper. Beta
particles can pass through water; however, thin aluminum is easily capable of
stopping it. Lead or concrete are needed to stop X-rays, gamma rays, and radio
waves. Neutrons can only be stopped by heavy barriers. Other than neutrons,
cosmic rays are charged particles. They can be affected by magnetic fields.
The magnetic field of the Earth acts as a shield against some cosmic rays, and
it also traps some. The magnetic field of the sun also affects cosmic rays. When
its magnetic field is stronger at periods of high activity, it blocks out more galactic cosmic rays (Space Radiation Shielding, 2014).

**Soft Errors:**

Soft errors occur when an ionizing particle of radiation hits the RAM chip of a computer and interacts with the silicon in it (See figure 2). This interaction produces a charge, and if the charge exceeds the critical charge of the chip, then a bit will flip from one to zero or vice versa (Certichip, 2014).

![Diagram of Soft Error Causes](Certichip, 2014)

Figure 2: (Certichip, 2014) Diagram of Soft Error Causes

The changed bit means the data that was stored is now incorrect. This is called data corruption and can cause programs to fail or return incorrect results. There is software in place in most computers to search for these errors and fix them; however, this method of handling soft errors is not 100% effective. Furthermore, the problem continues to worsen as smaller transistors which are easier to effect with cosmic rays are developed (Ziegler, 1994).
Celestial Coordinates:

Altitude and azimuth are coordinates for the stars based on the location of the observer. Altitude is the angle above the horizon and azimuth is the angle from north. Celestial or equatorial coordinates on the other hand are fixed with the positions of stars, and the Earth rotates under them. The declination coordinate is comparable to latitude, and the right ascension coordinate is comparable to longitude.

Figure 3: (University of Michigan, 2011) Diagram of Celestial Coordinates

The advantages of celestial coordinates are that the coordinates of an object never change and the object can be tracked across the sky over time (University of Michigan, 2011).
IV. **Hypothesis**

If aluminum foil, gold leaf, steel, or magnet shields are placed in front of a radiation monitor, then fewer cosmic rays will be detected.

**Justification:**

The research indicates that beta particles can be stopped by a few millimeters of aluminum, so aluminum foil is likely to decrease the amount of cosmic rays. The steel plate sample is thicker and denser than the aluminum, so it is likely to block out more cosmic rays. Gold is used as a shielding method in spacecraft. Although the gold sample used in this study was much thinner than the ones used in spacecraft, it may still have a significant effect on the number of cosmic rays detected due to its high density.

Cosmic rays are charged particles and can be influenced by the magnetic fields of the Earth and sun. If it is possible to significantly alter the path of a cosmic ray with the magnetic field of the Earth, then it may also be possible to slightly alter its path away from the opening of a detector using small metal magnets.

V. **Research Proposal**

**a. Researchable question being addressed:**

Cosmic rays cause data corruption problems in computer processors. How do environmental conditions and possible shielding methods affect the amount and type of cosmic rays present and their impact on a computer?
b. **Hypothesis:**

If a thick shield or a magnetic shielding method is used, then it will lessen the amount of cosmic rays present in the shielded area.

C. **Description of methods or procedures:**

A radiation detector was aimed at a natural source of cosmic ray radiation using a telescope as an aiming system. The number of cosmic rays was measured over ten minutes, and the angle of the detector was adjusted every five minutes. The ten minute trial was repeated ten times for the control. For each variable group, a material was placed in front of the detector to shield against the cosmic rays. The materials tested were aluminum foil, gold leaf, steel, and two magnet configurations (circle and line).

VI. **Methodology**

For this experiment, the Vernier Radiation Monitor was chosen for data collection. It was chosen over the other available probes because it was directional. It could be aimed at a specific point in the sky, allowing a constant cosmic ray source to be used. The alternative options were to use a probe that collected background radiation from all directions such as an older model from Vernier, the Digital Radiation Monitor, or to construct a cloud chamber to measure cosmic rays. With the changing cosmic ray sources in the sky and differing nearby objects, it was more consistent to choose to restrict the collected radiation to one isolated source and use the directional detector. The other advantage to the
directional probe is that it could be connected to data collection software. Specifically, it was attached to a lab cradle for the Texas Instruments Nspire calculator. This allowed data to be immediately viewed in table and graph form on the calculator.

The baton-shaped detector was attached parallel to the main tube of a Meade telescope with an equatorial mount. It was lined up with the telescope as precisely as possible by lining up the two orange circles on the detector with the
surface of the telescope and by lining up the tube of the detector with a straight and parallel piece of plastic on the side of the telescope. See Figure 4 for the complete apparatus.

The telescope was oriented to face north using a compass and calibrated using the location of the sun. The sun’s equatorial coordinates at that specific day and time were calculated using the Geocentric Positions tool on the United States Naval Observatory website. The telescope was aimed at the sun by setting it to the given declination coordinate and then turning it on its right ascension axis until the mirror in the back of the telescope reflected a sun beam. This avoided the danger of looking through the telescope at the sun. Once the telescope was aimed at the sun, its right ascension dial was calibrated to the known right ascension of the sun at that time.

Celestial coordinates in the J2000.0 system for the star cluster Cygnus X were found using the Sky View Virtual Observatory. Cygnus X was chosen because it is a gamma ray source, and it also collects and accelerates other cosmic rays. Additionally, Cygnus is in the sky during the day and evening in the northern hemisphere where testing was done.

The radiation monitor was connected to a TI Nspire in a lab cradle. For the control group, nothing was placed in front of the detector. For each variable group, a shielding material was placed in front of the detector. Materials included aluminum foil, gold leaf (25 sheets with tissue paper separators), Buckyballs magnets arranged in a circle, Buckyballs magnets arranged in a straight line, and a 2mm thick steel plate (See Figures 5-10). Buckyballs were chosen because they are strong magnets for their size and can be arranged in different configurations.
Aluminum was chosen because previous research indicates that thin aluminum is capable of stopping beta particles. Gold leaf was chosen because gold foil is sometimes used as a radiation shield for space missions.

Figure 5 (above): Control Radiation Monitor Photo

Figure 6: Detector with Aluminum Foil Shield Photo
Figure 7 (above): Detector with Gold Leaf Shield Photo

Figure 8: Detector with Steel Plate Shield Photo
Radiation counts were collected at one sample per second for ten minutes and the total radiation count for each ten minute trial was summed. The angle of
the detector was adjusted to account for the rotation of the Earth at the beginning of each trial and at the five minute mark of each trial. Ten trials were performed for each variable group. On the first day control tests were done, it was overcast. The control group was redone and the original was compared to the control as a “clouds” group.

VII. Results

Table 1: Sum of Radiation Counts per Trial

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>average</th>
<th>STDEV</th>
<th>%RSD</th>
<th>Anova P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>control</td>
<td>205</td>
<td>204</td>
<td>204</td>
<td>182</td>
<td>205</td>
<td>160</td>
<td>152</td>
<td>167</td>
<td>143</td>
<td>151</td>
<td>177.3</td>
<td>25.60</td>
<td>14.44</td>
<td>0.181</td>
</tr>
<tr>
<td>clouds</td>
<td>172</td>
<td>154</td>
<td>156</td>
<td>162</td>
<td>182</td>
<td>170</td>
<td>147</td>
<td>191</td>
<td>173</td>
<td>171</td>
<td>167.8</td>
<td>13.31</td>
<td>7.94</td>
<td></td>
</tr>
<tr>
<td>aluminum</td>
<td>192</td>
<td>199</td>
<td>187</td>
<td>213</td>
<td>175</td>
<td>168</td>
<td>167</td>
<td>165</td>
<td>160</td>
<td>157</td>
<td>178.3</td>
<td>18.58</td>
<td>10.42</td>
<td></td>
</tr>
<tr>
<td>gold</td>
<td>155</td>
<td>165</td>
<td>144</td>
<td>164</td>
<td>173</td>
<td>206</td>
<td>201</td>
<td>208</td>
<td>205</td>
<td>174</td>
<td>179.5</td>
<td>23.59</td>
<td>13.14</td>
<td></td>
</tr>
<tr>
<td>line magnets</td>
<td>167</td>
<td>169</td>
<td>206</td>
<td>192</td>
<td>161</td>
<td>152</td>
<td>160</td>
<td>180</td>
<td>161</td>
<td>149</td>
<td>169.7</td>
<td>18.00</td>
<td>10.61</td>
<td></td>
</tr>
<tr>
<td>circle magnets</td>
<td>180</td>
<td>196</td>
<td>182</td>
<td>170</td>
<td>182</td>
<td>166</td>
<td>149</td>
<td>176</td>
<td>153</td>
<td>177</td>
<td>173.1</td>
<td>14.14</td>
<td>8.17</td>
<td></td>
</tr>
<tr>
<td>steel</td>
<td>159</td>
<td>158</td>
<td>154</td>
<td>147</td>
<td>173</td>
<td>178</td>
<td>157</td>
<td>156</td>
<td>161</td>
<td>150</td>
<td>159.3</td>
<td>9.57</td>
<td>6.01</td>
<td></td>
</tr>
</tbody>
</table>

Avg: 10.10

Table 1 summarizes the data collected for each variable group. Each data point is the sum of all of the counts of radiation collected over 10 minutes. Each group of trials was averaged and the standard deviation was calculated. The precision of the data was low with a percent relative standard deviation of 10.10%. An analysis of variance (Anova) test was performed, and the p value was 0.181, so there was no significant difference between the variable groups.
Table 2: Summary Data

<table>
<thead>
<tr>
<th></th>
<th>min</th>
<th>Q1</th>
<th>med</th>
<th>Q3</th>
<th>max</th>
</tr>
</thead>
<tbody>
<tr>
<td>control</td>
<td>143.0</td>
<td>154.0</td>
<td>174.5</td>
<td>204.0</td>
<td>205.0</td>
</tr>
<tr>
<td>clouds</td>
<td>147.0</td>
<td>157.5</td>
<td>170.5</td>
<td>172.8</td>
<td>191.0</td>
</tr>
<tr>
<td>aluminum</td>
<td>157.0</td>
<td>165.5</td>
<td>171.5</td>
<td>190.8</td>
<td>213.0</td>
</tr>
<tr>
<td>gold</td>
<td>144.0</td>
<td>164.3</td>
<td>173.5</td>
<td>204.0</td>
<td>208.0</td>
</tr>
<tr>
<td>line magnets</td>
<td>149.0</td>
<td>160.3</td>
<td>164.0</td>
<td>177.3</td>
<td>206.0</td>
</tr>
<tr>
<td>circle magnets</td>
<td>149.0</td>
<td>167.0</td>
<td>176.5</td>
<td>181.5</td>
<td>196.0</td>
</tr>
<tr>
<td>steel</td>
<td>147.0</td>
<td>154.5</td>
<td>157.5</td>
<td>160.5</td>
<td>178.0</td>
</tr>
</tbody>
</table>

Table 2 comprises the summary data for each variable group. The minimums, first quartiles, medians, third quartiles, and maximums are listed to show the distribution of the data. This table was used to make a box-and-whisker chart to compare each group and show their relative distributions.

![Counts of Radiation Detected per Ten Minutes](image)

**Figure 11: Box-and-Whisker Plot of Counts of Radiation**

Figure 11 shows the amount of cosmic rays detected in each variable group as well as the distribution of the trials in each group. It is clear that the
data were not precise enough to determine a difference between the shielding methods and the control. The Anova test agrees with this, showing no statistically significant difference. Instead, any difference between the groups was likely due to chance and variation in the data.

**Discussion:**

The results found in this study did not support the hypothesis. The shielding methods used in this investigation did not have as much effect on cosmic rays as expected. Thicker and denser shields as well as stronger magnets may be needed to achieve the desired shielding effect. It is possible that the cosmic rays measured in this study were of higher energies in the spectrum. This would prevent the thinner shields used from having a significant effect. The energy of the cosmic rays was not measured in this experiment, but it would be useful to determine what type of radiation is being blocked, if any. It is also uncertain which types of cosmic rays were detected because the radiation detector did not have the capability to measure this. Although previous research indicates that beta particles can be blocked with thin aluminum, the aluminum foil had no measurable effect. Therefore, it is possible that the detected radiation comprised mainly gamma rays instead of beta particles.

Another possible explanation for the lack of a decrease in radiation with the use of shields could have been particle showers. In the same way that cosmic rays interact with the atmosphere to produce a shower of secondary rays, they may have interacted with the shielding materials. The original
particle may have been stopped by the shield, but only after releasing a cascade of even more particles of which perhaps only a percentage were blocked. This production of more particles and the shielding of some might have canceled out and left the shielded groups with approximately the same amount of particles finally reaching the detector (B. Flaugher, personal communication, February 14, 2014).

VIII. Conclusions

The results of this investigation were inconclusive. None of the shielding methods performed as expected, and none could be determined to be more effective than the control or any other shield. Larger samples of shielding material and stronger magnets would have to be tested to begin to see an effect on the cosmic rays in this study.

It would be helpful to know what energies and types of cosmic rays were being detected because it would give insight into why the shields did not block significant amounts of radiation. The shields may simply need to be more thick and dense, and the magnets may need to be stronger in order to block cosmic rays with energies within the spectrum measured. Conversely, the cosmic rays may be interacting with the shields and producing showers of more particles that cancel out any shielding effect.

Further investigation in the area of cosmic ray shielding is worth looking into in the future. It will be useful in the field of computing to prevent soft errors, especially as smaller transistors are developed. Additionally, as space
travel becomes more common and more long-term, better shields against cosmic rays will be needed to protect astronauts from the harmful effects of exposure to radiation. Computers that operate in space and require great accuracy and precision as well as humans taking space walks will require protection from the bombardment of radiation from space. Currently, gold foil is used to shield spacecraft, and thick concrete, bedrock layers, and thick lead are used to shield radiation experiments from cosmic ray interference. These options are not very practical because they are either extremely expensive or much too large. Testing more types of magnetic deflectors could lead to a more feasible solution that would be smaller and less expensive.

**Error Analysis:**

Error in this study could have been caused by the lack of precision in the aiming system of the telescope. It was aimed north and calibrated as accurately as possible with the tools available. Fluctuations in the weather may have also caused error in the experiment. Significant weather trends were recorded, but it was not possible to track small changes throughout the course of a trial.

**Further Research:**

In the future, thicker samples of steel, aluminum, and gold will be used. Stronger magnets will be tested to determine if magnetism is an effective deflection method in larger amounts. More investigation could also be
performed on other materials such as polyethylene because its high hydrogen content suggests it would be an effective shield.

IX. Limitations and Assumptions

The experimentation in this study was limited by the position of the cosmic ray source in the sky. Testing could only take place at times when the source, Cygnus X, was far enough above the horizon that interference from ground sources would not occur. The study was also limited by the precision of the telescope aiming system. The northern orientation of the telescope had to be measured/estimated using a compass. The thickness of the gold material that could be tested was limited by the cost.

It was assumed that the radiation detector was attached parallel to the telescope; however, it may not have been perfectly parallel. Because the radiation detector was directional, and it was never pointed at the sun during testing, it was assumed that the sun did not affect the cosmic ray data. Thus it was assumed there was no difference between testing in the afternoon and evening. Finally, the assumption was accepted that changing weather patterns did not significantly affect the data.

X. Acknowledgments

Thank you to my STEM advisor Ms. Karen Lang and to Dr. Brenna Flaugher from Fermilab for answering questions for me.
XI. Literature Cited


