Colorado Space Grant Consortium

Measuring Changes in Gamma Radiation Levels with Respect to Altitude

Team Anubis

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Introduction

Upon starting our project, Team Anubis had the goal of measuring the change in levels of gamma radiation with respect to altitude. Our hypothesis assumed the Geiger counter would likely pick up low levels of background radiation from the granite-rich Colorado bedrock during the early portions of the flight. After those readings decreased, we expected to see a linear increase in detections and levels as we approached the Regener-Pfotzer Maximum. There, we expected radiation levels to plateau between 60,000-80,000 ft as our payload passed through the Regener-Pfotzer maximum. This region of concentrated primary and secondary decay particles occurs between 60,000 and 80,000 ft due to atmospheric density, as high-energy cosmic radiation particles collide with molecules in the atmosphere. Once above 80,000 ft, we expected to see a slight decrease approaching maximum altitude. Initially, our project was focused on measuring radiation with respect to altitude. However, we discovered none of our predecessors had used the same Geiger sensor, so we were asked to do an in-depth review of its efficacy. Our group then added a new goal to our project; to review the quality and function of this sensor in the field of high-altitude balloon experiments. The purpose of this paper is to discuss our research data, the methods we used to obtain that data, speculation regarding errors, an in-depth review of the SparkFun Pocket Geiger Radiation Sensor - Type 5 (T-5PGRS), and recommendations on future iterations of similar experiments.[1]

What is Gamma Radiation?

Gamma-rays are the most energetic of wavelengths in the electromagnetic spectrum. Gamma is but one type of radioactive decay, of which there are two other main types: alpha and beta. Radioactive decay, in general, occurs when unstable atomic nuclei lose energy, which is then emitted. In the case of alpha, nuclei emit a particle composed of two protons and two neutrons akin to a helium atom. Beta particles consist of high-speed electrons or positrons, whereas gamma radiation is released as a photon. Alpha and some beta particles are positively charged, while other beta particles are negatively charged. Gamma radiation, being a photon, is electrically neutral. Both alpha and beta particles have low penetrative powers due to their mass, while gamma radiation easily passes through materials such as metal and will not stop until it is absorbed by a material such as lead due to its density. This type of cosmic radiation is emitted by stars including the Sun during coronal mass ejections, as well as more distant celestial objects such as supernovae and neutron stars. These ultra-short wavelength photons require precise instruments in order to detect them, as they are able to pass through the empty space of atoms that make up other detectors. Many gamma-ray detection systems utilize a process known as Compton scattering. This creates charged particles which the Geiger counter is then able to detect. The most common medium through which these interactions occur are Geiger-Muller tubes, in which noble gases become ionized during interactions with gamma rays. Other systems use crystal blocks, inside of which electrons are energized, then enabling detection. There are many possible ways to measure gamma radiation; we chose to measure gamma radiation in microsieverts per hour (μSv/h), which is equivalent to one millionth of a joule of absorbed radioactive energy into the body per hour.[2]

Payload Design and Testing

As our main focus was understanding the changing amounts of gamma radiation with respect to altitude, there were two key sensors which collected the data we needed: a T-5PGRS and a pressure sensor from SparkFun that was recycled from our initial test payloads. The other pieces of equipment in our payload were an internal temperature sensor and 3.94"L x 1.97"W heating pad from SparkFun, were installed in order to keep our key sensors at an operational temperature. All of these components were assembled onto a Qwiic Shield from SparkFun and hooked up to an Arduino Uno (also recycled from a test payload), which logged the data to a SparkFun Openlog. Everything was powered by 4, lithium alkaline 9V batteries. Though the number of batteries could certainly have been reduced, as we were unable to do a power draw test, we overestimated for safety. Everything besides the Openlog was run with 5V bus power and the Openlog was connected to the 3.3V pin.

Table 1: Parts Used and Total Cost

Part Name	Ordered / Recycled	Cost
Arduino Uno	Recycled from test kit	–
SparkFun Qwiic Shield for Arduino	Ordered	$7.50
SparkFun Temperature Sensor - TMP36	Recycled from test kit	--
SparkFun Type -5 Pocket Geiger Radiation Sensor	Ordered	$74.95
SparkFun Pressure Sensor	Recycled from test kit	–
SparkFun Heating Pad - 5x10cm	Ordered	$4.50
SparkFun OpenLog	Ordered	$16.95
SparkFun N-Channel MOSFET 60V 30A	Ordered	$1.05
SparkFun Schottky Diode	Ordered	$0.25
SparkFun Resistor 10K Ohm 1/6th Watt PTH - 20 pack	Ordered	$0.95

9V batteries	Recycled	–
LED	Recycled from test kit	–
Low-Temperature Polyethylene Foam Rubber Insulation	Recycled from test kit	–
Elmer's Black Foam Board - 3/16" (5mm)	Recycled from test kit	–
⅜" Polyethylene Flight Tube	Recycled from test kit	–
		TOTAL COST: $106.15

Table 2: Subsystem Requirements

Subsystem	Parts Involved	Requirements
Exterior and Structure	Foam core, insulation, aluminum tape, flight tube	Provide structure to ensure payload will withstand flight, burst, and landing
Data Collection Sensors	Internal temperature	Monitor the internal temperature [ºF]; dictate when heating pad should turn on to keep radiation sensor within operating temperature
	Pressure	Record pressure data [psi] throughout flight
	Radiation	Record gamma radiation data [µSv/h] throughout flight
Data Storage	OpenLog, micro SD card	Store the data that is collected from each sensor
Heating	Heating pad	Receive signal from internal temperature sensor to turn on periodically to keep radiation sensor within operating temperature
Power	Four lithium alkaline 9V batteries, switch	Power the thang

We initially intended to use an altitude sensor which we purchased from SparkFun. However, the sensor did not have a range of operation that would have supported our experiment, as we expected to reach a maximum altitude of approximately 100,000 ft. The next best option was to utilize pressure data to calculate altitude, using a pressure sensor from the test launch that we knew worked accurately. We considered two radiation sensors from SparkFun: the MightyOhm Geiger Counter Kit++ ($133.95) and the Type-5 Pocket Geiger Radiation Sensor ($74.95). The MightyOhm uses a classic Geiger-Muller tube made of mica, meaning this sensor would potentially be too fragile to survive the balloon flight. On the other hand, the T-5PGRS is made with a ceramic carrier, therefore making it the more durable and cost-effective option.

We knew that the construction of our payload would depend on the size and placement of the heating pad and the number of batteries needed. In realizing this, we prolonged the building of the structure until we understood our power capacity needs.

After successfully compiling the code for the T-5PGRS, it was tested using a sample of Cobalt-60 (^{60}Co). We initially used a ten-year-old sample of Cobalt-60, which presented us with readings of approximately 8 μSv/h. Upon testing the sensor with a much newer sample, we saw readings of over 90 μSv/h. Between the two tests with known samples, we were confident that the T-5PGRS was mission capable. At this point, we moved to more rigorous testing of the T-5PGRS sensor, where our focus shifted to understanding how various materials might impede the sensor's detection of the radiation produced by the Cobalt-60 sample. Specifically, we examined how the foam board and polyethylene foam rubber insulation -- materials that we intended to construct the payload with -- would affect the readings. We tested the effect of the foam board alone, the insulation alone, and finally, both materials together under otherwise identical circumstances. We discovered that the foam board alone caused negligible interference but that when a layer of insulation was placed, either on its own or in combination with the foam board, there was a noticeable change in the frequency of radiation readings. While this observation went against previous notions of the penetrative power of gamma radiation, it had to be taken into consideration for our payload design. This noticeable decrease in detections was reason enough to reconsider the method in which our payload was built. On the one hand, we needed to meet the requirement of protecting the payload contents from harsh high-altitude conditions, but on the other, we needed to ensure the collection of a useful quantity of data. To circumvent the issue of insulation, our group interposed the temperature sensor and T-5PGRS between two foam board walls, which were held together using aluminum tape. The heating pad was placed between the wall of the main compartment (which held the Arduino and batteries) and the double wall subassembly. and was secured using electrical tape. The inner wall of the Geiger subassembly was then perforated to allow heat from the heating pad to reach the radiation and temperature sensors more easily. The double-wall subassembly was then secured to the main box with aluminum tape (see Figure 1 below).

Our payload's structural design was based on the test payload from the previous semester, with the addition of the double-wall being the main difference. We opted to build our payload structure using the materials left over from the previous boxes and recycled some components from a test kit. The dimensions of our payload are 6.5” L x 5” W x 4” H, including the double wall for the T-5PGRS. Recycled materials were used to make the shell, composed of foam core and insulation. The inner layer of the double-wall had a hole cut into it, allowing wires to run from the Arduino to the Geiger subassembly.

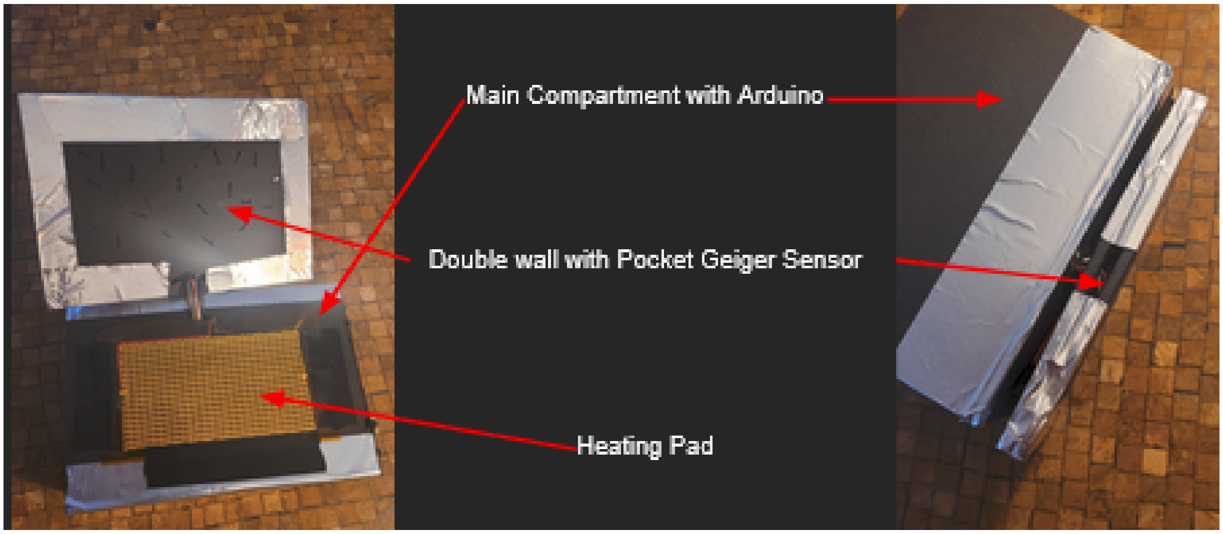

*Figure-1 payload structure.

After the box itself was assembled, the flight tube was integrated, running through the middle of the payload above the Arduino. The power switch and power-indication LED light were both placed at the top of the payload next to the flight tube, reducing the chance of being hit during launch and flight and accidentally turning off the payload.

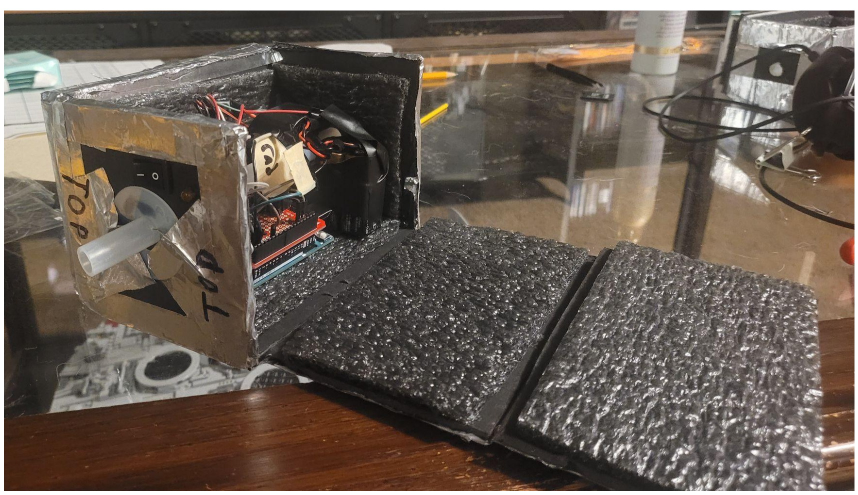

*Figure-2 payload structure.

Once the payload was assembled, the first test we ran was the bench test. This was completed by leaving the payload on for just under two hours undisturbed. With this being done indoors in Estes Park, the data expected was the temperature would be read roughly 70°F and the air pressure would be just over 10 psi and based on the previous testing with the Geiger sensor, intermittent readings of 0.10 µSv/h. The air pressure and Geiger readings were as expected, but the temperature sensor was reading high, roughly in the 90°F range. We believe that the temperature was reading high due to being inside coupled with the Arduino creating a small heat source, warming the compartment.

After the bench test, we did short shake/whip tests to simulate the movement throughout the flight. This was to ensure that the Arduino and the Geiger subassembly were secure and that nothing would come loose mid-flight. This test showed no issues.

The next test we ran was the cold test. This test aimed to simulate the cold temperatures the payload would experience during the flight and was done by placing our payload into a styrofoam cooler with blocks of dry ice. We left the payload in the cooler for 15 minutes with the payload off to allow the payload to cool before turning it on so we could attempt to test the heating pad. Once the payload was turned on, it was left in the cooler for an additional 30 minutes to gather data and test the operation of the heating pad. Upon reviewing the data, there were no gaps in readings and the temperature stayed within the operability range for the T-5PGRS.

The last test was a variation of the bench test to record known changing values in both pressure and radiation readings. This was achieved by leaving the payload on while driving from Longmont to Estes Park. We knew that the air pressure in Longmont is generally above 12psi, while the pressure in Estes Park is typically under 11psi. From previous tests, we established that the radiation readings in Longmont were typically about 0.05 µSv/h, while Estes Park has levels of around 0.11 µSv/h. The drive between the two towns also includes driving through a canyon of exposed granite. Since granite contains elevated levels of radioactive isotopes, elevated radiation readings were expected and detected during the drive. During the drive, the air pressure did start at the expected value for Longmont and slowly changed as the drive went on, finally reaching the expected value for Estes Park. When driving through the canyon at speeds exceeding 40 mph, the Geiger sensor was picking up frequent readings of up to 0.16 µSv/h. This proved that the payload would pick up not only changing values throughout the flight but that it was able to pick up the radiation readings while in motion since all of our previous tests with radiation were conducted at rest.[3]

Type-5 Pocket Geiger Radiation Sensor Review

The T-5PGRS was developed as a personal dosimeter for radiation levels after the nuclear meltdown at Fukushima. This personal Geiger counter is ideal for usage in high-altitude balloon payloads attempting to measure gamma radiation due to its small size, low weight, and low cost. One caveat is that the T-5PGRS is only able to detect either beta or gamma radiation, and the user must choose which they would like to detect. The T-5PGRS uses a 100 mm^2 solid state PIN photodiode and a ceramic carrier with light blocking epoxy encapsulant. An additional caveat is that the T-5PGRS has a warm-up/calibration period on startup that takes roughly five minutes. However, this was not an issue as there was ample time between startup and take-off on launch day.

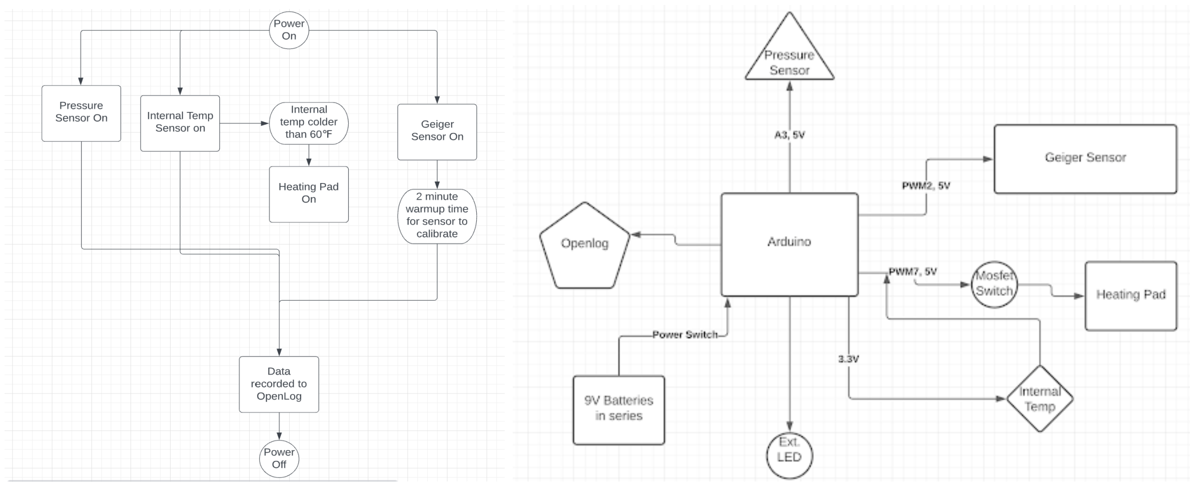

*Figure-3 hardware flowchart.

Unfortunately, we ran into issues when it came to coding as there were many different approaches to the code on Github. However, our group found the most effective approach was to include the library "RadiationWatch.h" and add the following in the topmost section of code before the VoidSetup and VoidLoop:

```
//Geiger sensor functions
  RadiationWatch radiationWatch;

 void onRadiation()
  {
   Serial.print(radiationWatch.uSvh());
   Serial.print(",");
   Serial.print(" uSv/h +/- ");
   Serial.print(radiationWatch.uSvhError());
   Serial.print(",");
  }
```

*Figure-4 Code Definitions

Then in the voidSetup we had:

```
//Geiger Code set up-------------------------------------
 radiationWatch.setup();
  // Register the callbacks.
 radiationWatch.registerRadiationCallback(&onRadiation);
 radiationWatch.registerNoiseCallback(&onNoise);
 //-----------------------------------------------------
```

*Figure-5 Code setup

And lastly in the voidLoop all we had for code was:

```
//geiger code
radiationWatch.loop();
```

*Figure-6 Code loop

We faced two main obstacles when coding the Geiger counter. The first obstacle was that the individual libraries for the temperature and radiation sensors were incompatible. The only explanation that seems logical is that both libraries had a function or line of code that shared a name and caused conflict within the code.

The second problem with the Geiger counter's code was that its original intended purpose was to measure radiation exposure over short amounts of time during relief efforts. There were a lot of "different versions" of the code tailored to various uses of the T-5PGRS. However, the only real distinction was how the source code counted time. The source code for the T-5PGRS had a large amount of code dedicated to accurately counting time in seconds. The source code based this process on the amount of processing time one loop takes, then uses a variety of complex algorithms to convert said time to seconds; finally, it takes the stored arrays of time in seconds and converts them further to minutes. The original code was made to max out the count at 20 minutes as this was the time limit for volunteers in Fukushima. Other iterations of this code expanded upon this idea, including hours, while other versions just edited the time it took for that specific loop to process, keeping the measurement accurate.

We did not need the time loop as it was not only unnecessary for our readings but would have been very hard to adjust to the length of time our code took to process. Our group originally tried programming the Geiger counter not to need the library but rather to rely solely on uploaded code. However, it proved to have too many small bugs. In the interest of time, the easiest option was to fall back on the external library and run the "radiationWatch.loop" at the beginning of our main voidLoop code. This is something we recommend future groups do only when a better process cannot be developed or time does not allow for in-depth coding changes.

One bonus of this library is that it also prints out the uncertainty level for each detection. At the same time, if the T-5PGRS does not detect a high enough level of gamma radiation, it simply does not print anything. This can be misinterpreted as not functioning if a radioactive source is not present. Future iterations of this experiment may consider programming the T-5PGRS to print zeros when the sensor does not make a detection.

The T-5PGRS has a built in noise function designed to improve the accuracy by decreasing readings when it detects vibration. In testing however, this function caused massive interference. To circumvent this issue we did not apply power to this section of the sensor so that it was unable to function and interfere with our data

The T-5PGRS has an operating temperature range (-4°F-158°F) over which it is functional, meaning regulation of temperature within our payload was crucial. Therefore, while the internal temperature sensor and the heating pad were not directly contributing to the data we set out to analyze, they were deemed necessary for ensuring the best possible functioning of the T-5PGRS. While the minimum operating range is -4° F, the heating pad was set to keep temperatures above 10° F. It is worth noting that the temperature data we collected is in units of Fahrenheit, as this was more intuitive to each team member and therefore reduced the number of errors in the code as well as data analysis.

Results and Analysis

In investigating the relationship between gamma radiation and altitude, the first thing we had to do after collecting our payload was successfully calculate altitude throughout the flight. We did this by taking our pressure data (Figure 8) and converting it from psi to altitude in feet (figure 9). We did this using a formula published by NOAA (Figure 7), we converted first to Millibars and from there calculated the altitude.

$$145366.45\left[1-\left(\frac{\text{Station pressure in millibars}}{1013.25}\right)^{0.190284}\right]$$

*Figure-7 Pressure in millibars to altitude conversion formula (ft)

This allowed our pressure data to be converted to altitude data as such:

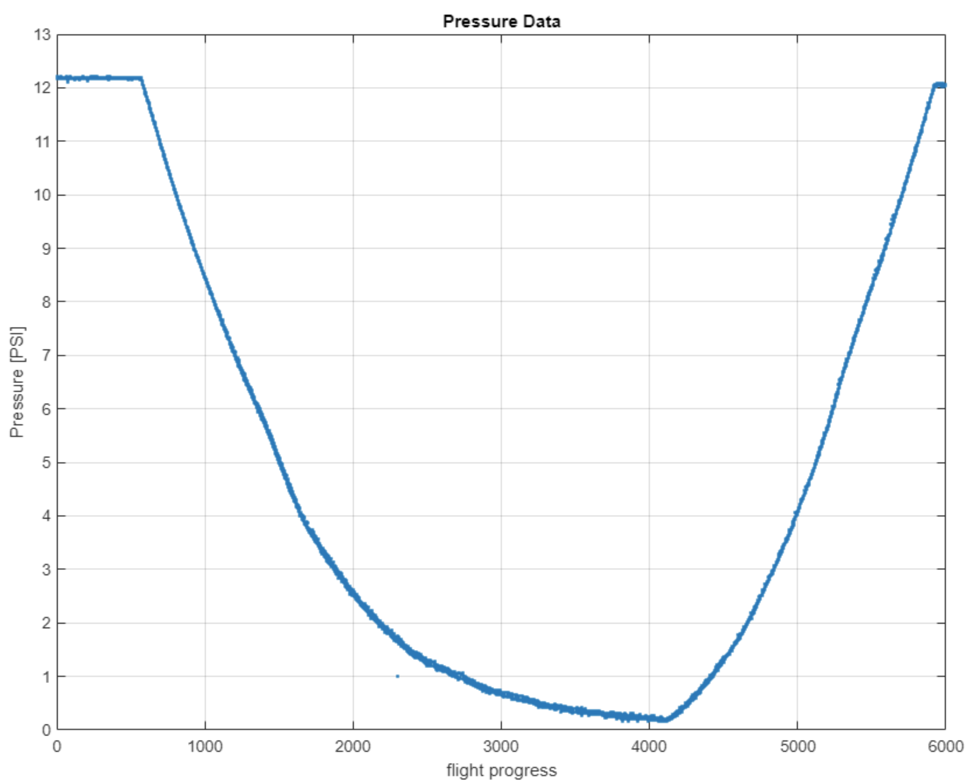

*Figure-8 Pressure [PSI] during flight

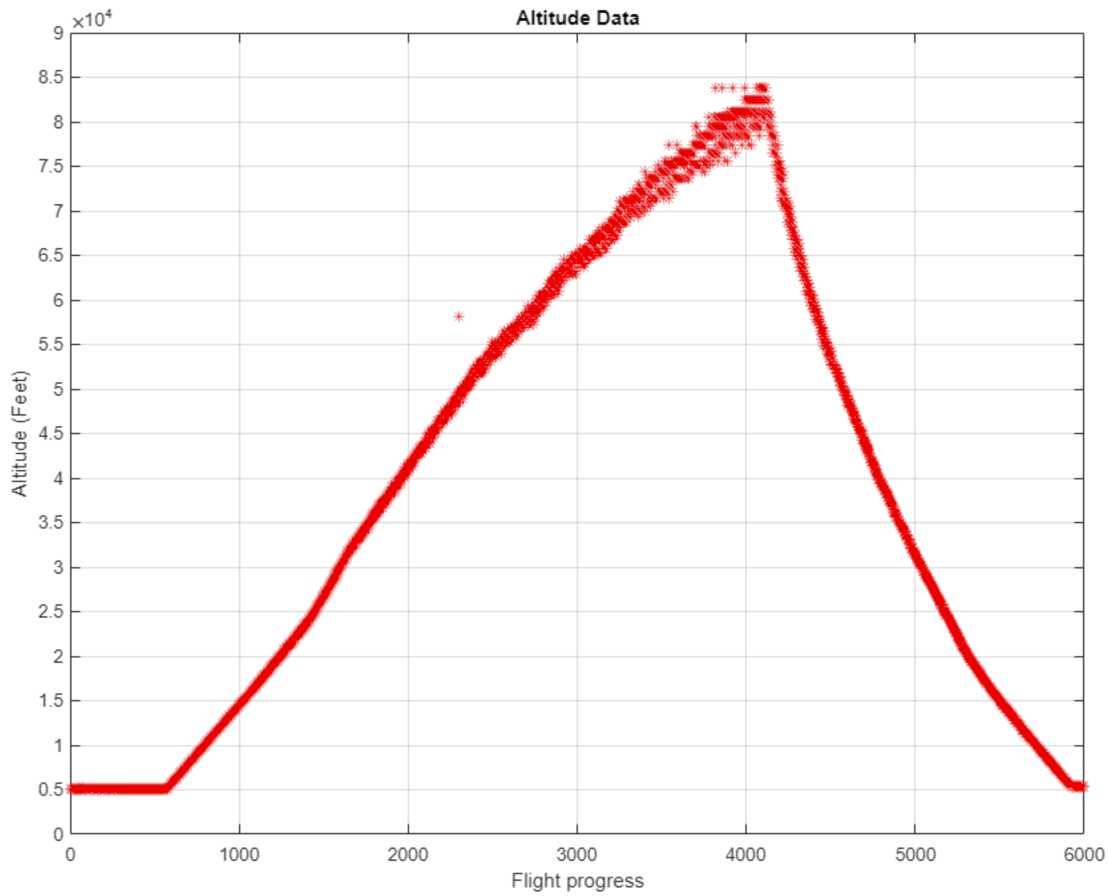

*Figure-9 Altitude [ft*10^4] during flight

We can see from our calculated altitude that we did pass through the Regener-Pfotzer Maximum between 60,000 and 80,000 ft. As is evident in our graph, once we approached the top 20,000 ft of our flight, the pressure readings became much more erratic (see Figure 8 above). The cause for the fluctuating readings is unclear, but it is worth noting as it brings into question where the gamma levels we detected at this portion of the flight actually occurred. In addition, during this period of flight, the data we collected had large amounts of interference and error. These concerns will be addressed in the next section.

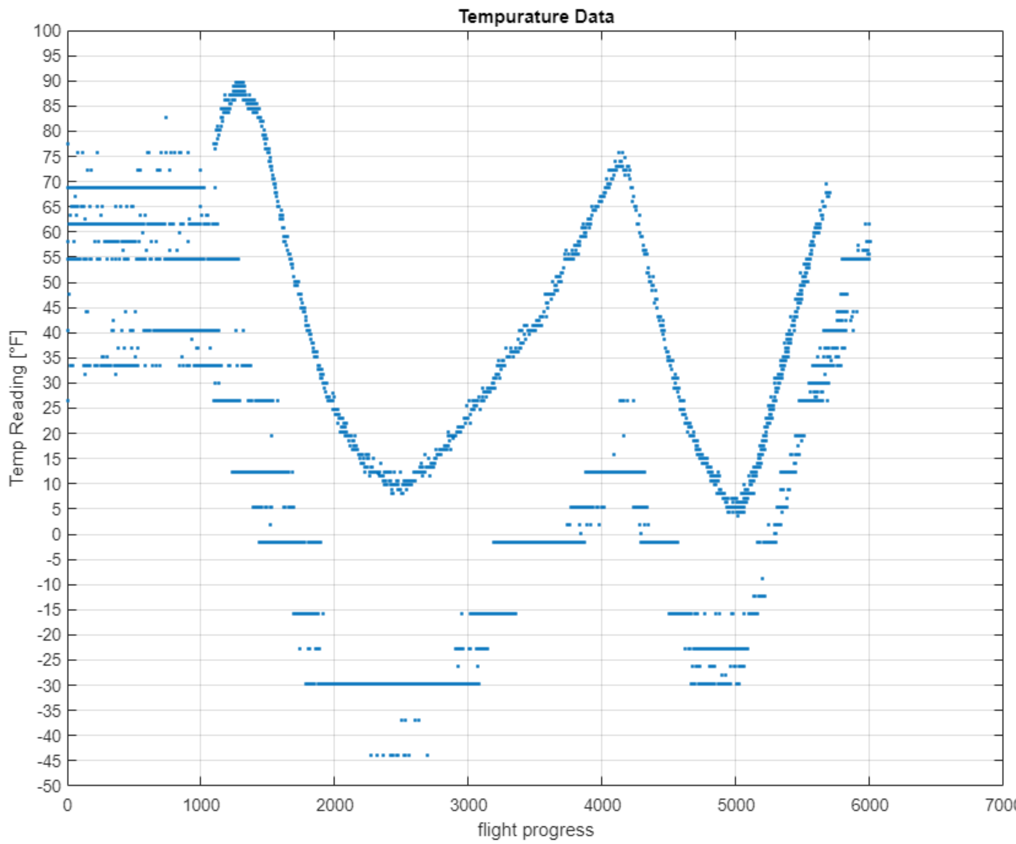

*Figure-10 Temperature Graph

At first glance it would seem to indicate that our heating pad worked. The heating pad has an initial period upon turning on, where it heats up slowly. Then the heating pad can begin to radiate heat outward from the nature of how it's built. Due to this, we initially believed these large dips in heat and slow rises were due to the way in which the heating pad operated. However, it more likely displays what the natural progression of temperature we could have expected for our payload during flight. As the first phase of the flight took place, the temperature dropped to around 7° F. The first trough in the data indicates where our payload passed through the tropopause into the stratosphere. Once in this ozone-rich region, the ultraviolet rays likely began to warm our payload from that time to roughly when the balloon burst. This progression is then mirrored during the descent. Regardless of whether the heating pad turned on or not, the temperature data suggests that the compartment housing the Radiation detector stayed within the operating bounds of the sensor.[4]

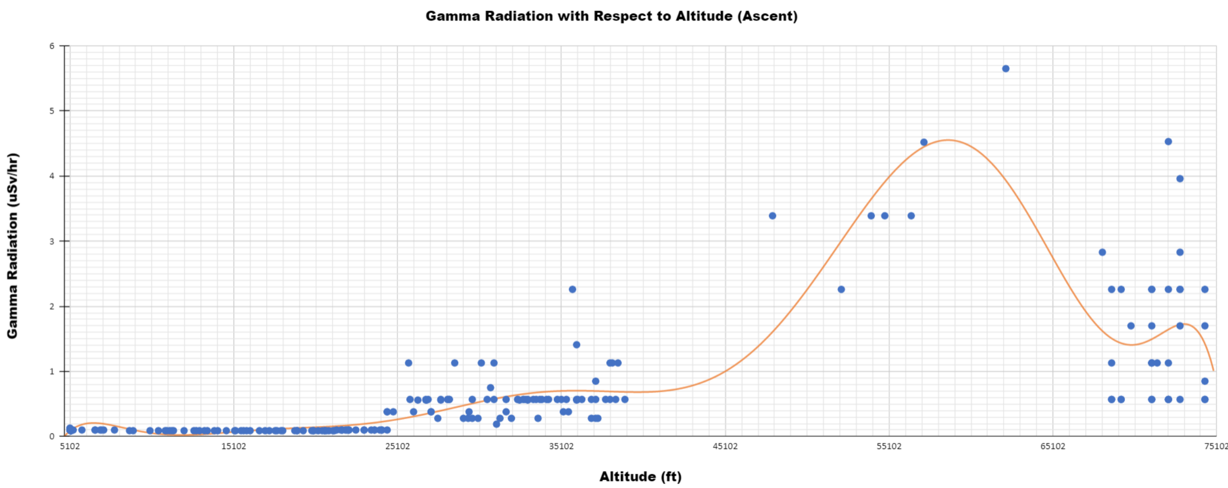

Figure-11 Line chart detailing radiation detections in μSv/h and their respective altitudes for the payloads ascent

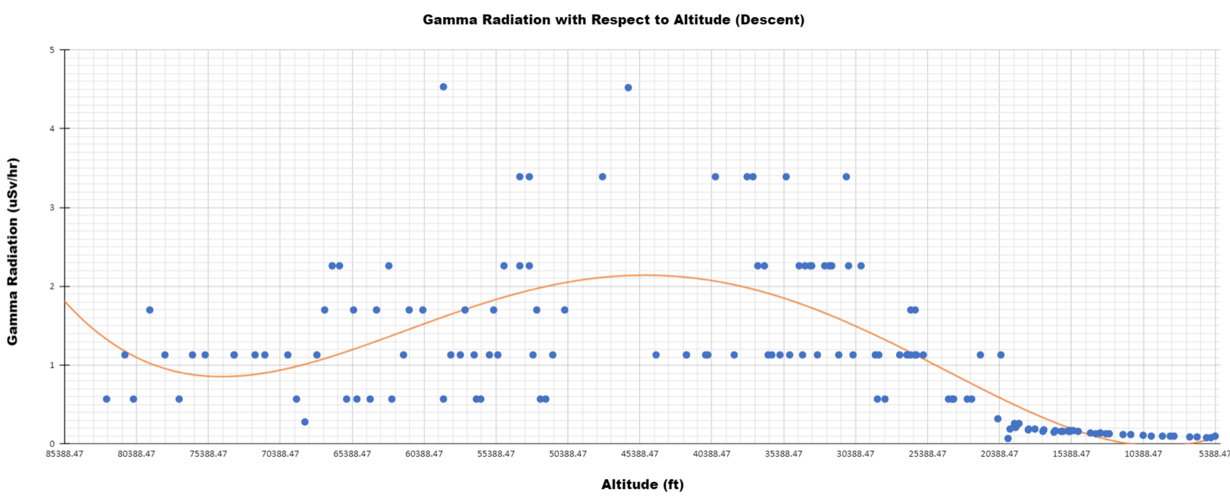

Figure-12 Line chart detailing radiation detections in μSv/h and their respective altitudes for the payloads descent

While the overall shape of the trendline accurately reflects the levels of gamma radiation detected by the T-5PGRS, there are a large volume of duplicate and misprinted readings. Our group believes that during the calculation for current gamma values, once the calculated value reached a certain number, that value was reported. This scenario explains the repeating and equal values. So we believe the top-most points represent the real value at that altitude, and the overall trend line is massively lowered by the extra data. We believe that this is the result of a power draw issue, which will be discussed further in a later section of the paper.

One of the more difficult aspects of our experiment was extrapolating the data we gathered and compiling it into a logical format. This was particularly challenging due to interference readings that were printed during portions of the flight in higher altitude (see image below). The reason behind these readings will be discussed below. However, the process our team went through to 'clean up' the data involved going through and removing those lines of interference, compiling the "good data" we received into a spreadsheet where then, charting allowed us to see the trends of gamma radiation detection over the course of our flight. In addition to the interference readings, we also got a collection of what we termed "weird symbols" throughout the portions of our flight that experienced interference. These "weird symbols" were scrubbed from the final data used to create our charts as they seemingly occurred at random and prevented the data they surrounded from being graphed. Overall, while arduous at times, this was a fairly straightforward process that resulted in our initial data, which looked as if it would not be usable, becoming valuable data.

A	B	C	D	E	F	G
ÿgeiger		pressure	temp			
		0.78	-1.7		Misprints	
þgeiger		pressure	temp		gama reading	
		0.78	-1.7		temp reading [F]	
Interference					Repeating temp [F]	
0		uSv/h 0.00	0.82	50.21	pressure reading	
1.13		uSv/h 0.80	0.8	-1.7		
ÿgeiger		pressure	temp			
		0.8	-1.7			
Interference						
		0.86	49.33			
1.7		uSv/h 0.98	0.82	-1.7		
ÿgeiger		pressure	temp			
		0.82	-1.7			
Interference						
0		uSv/h 0.00	0.87	48.45		
2.26		uSv/h 1.13	0.82	-1.70ÿgeiger	pressure	temp
		0.82	-1.7			
Interference						
		0.91	51.09			
0.57		uSv/h 0.57	0.82	-1.7		
ÿgeiger		pressure	temp			
		0.84	-1.7			
þgeiger		pressure	temp			
		0.86	-1.7			
Interference						
0		uSv/h 0.00	0.89	49.33		
1.7		uSv/h 0.98	0.87	-1.7		
ÿgeiger		pressure	temp			
		0.87	-1.7			
Interference						
0		uSv/h 0.00	0.93	45.81		
1.13		uSv/h 0.80	0.87	-1.7		
ÿgeiger		pressure	temp			
		0.87	-1.7			
Interference						
0		uSv/h 0.00	0.93	48.45		
		0.89	-1.7			

One way in which we were able to determine that the data we recovered could be deemed "good data" was by comparing it to studies done in the past that had measured cosmic radiation using high altitude balloon payloads that also passed through the Regener-Pfotzer Maximum as a benchmark for what we expected to see. One such study we compared our data to was performed by Earth to Sky Calculus (EtSC), a fellow student research group based in California, who have performed over 140 high-altitude balloon experiments centered around cosmic radiation. While EtSC's data is much more continuous than ours, it is unclear whether EtSC experienced the same technical difficulties we did. Additionally, EtSC used four Polimaster PM1621M radiation sensors, which are both much more expensive (roughly $900 per sensor) and heavy (185g) than the SparkFun Type-5 Pocket Geiger which weighs only 7 grams and costs $74.95. It is great to see that while more sporadic and less continuous, our data follows a similar trendline to EtSC using more advanced equipment.

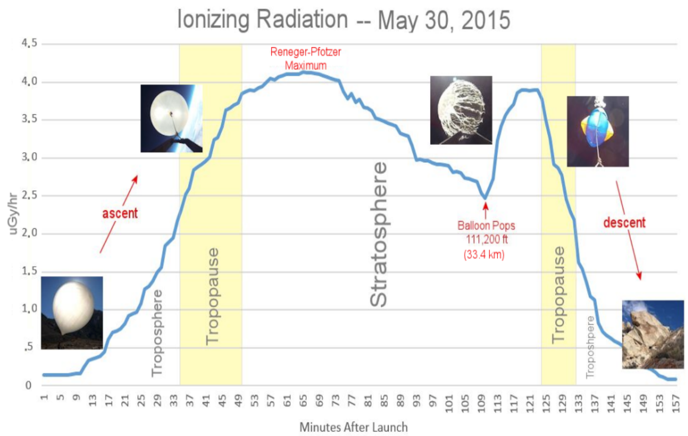

Figure 13: The curve is an average of data collected by four identical PM1621 radiation sensors, https://doi.org/10.1002/2016SW001410

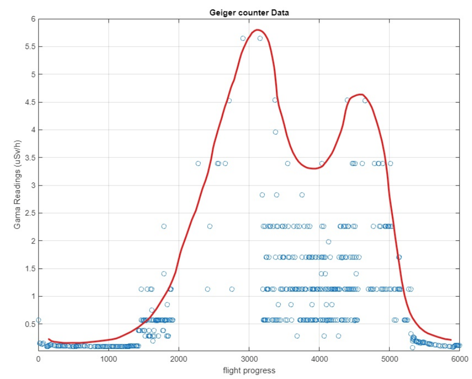

Figure 14: Trend line of gamma radiation levels over the course of our flight

A key component of our hypothesis was the decrease in radiation detection we expected to see above 80,000 ft. As other studies such as Earth to Sky Calculus' experiment indicate, we should have seen a substantial drop-off in detections above 80,000 ft. As the graph from the aforementioned study indicates, their payload reached a maximum altitude of 111,200 ft. Due to the fact that we did not reach as high of an altitude as EtSC, we have a sharper dip between our peaks that does not reach as low on the y axis. This is because our payload was approximately 15,000 ft closer to the Regener-Pfotzer MaximumEquipment from Edge of Space Sciences indicated that the balloon had reached a maximum height of roughly 95,000 ft. However, our pressure sensor indicated that our maximum altitude was approximately 85,000 ft. The reason for this discrepancy of approximately 10,000 ft is unclear, which brings us to our next section: what exactly went wrong, and how might future groups combat these difficulties.[5]

Error Analysis

There are many factors that could have contributed to the issues experienced with our collected data. The first, which is perhaps both the most tantalizing and least likely, is the effect of geomagnetic storms that bookended our flight by a matter of a couple of days. As evident by the geomagnetic storm that took down 40 of 49 Starlink satellites back in February. These events caused by coronal mass ejections are well known to disrupt electronic devices such as GPS. However, because our payload is *meant* to measure the gamma rays that are ejected during these events, being able to secure our system's operating equipment whilst also providing minimal interference with the radiation measuring device on board led to a vulnerability of the system's temperature resistance. [6]

One contributing factor to the error in our data and disrupted readings could be moisture. Sealing our payload at ground level trapped humidity from the air inside the payload. Once the payload achieved a certain altitude in flight, temperature and pressure differences could have caused condensation to form on the electronics from the previously present humidity. The presence of the partially insulated heating pad could have exaggerated this effect if it turned on by creating warm air around the cold Arduino leading to excess moisture formation on the exposed electronics.

We also suspect that the low temperatures experienced at high altitudes may have caused interference with our components or put the internal temperature of our payload's main compartment that housed the Arduino, below the operating temperature of the Arduino. Additionally, it could have been that the batteries were below the operating temperature rather than the Arduino itself. When carrying out our error analysis we realized that the recommended operating temperature range for lithium alkaline 9V batteries is between 0°C and 60°C (32°F to 140°F). We compared our flight data with our data from our test launch using the same Arduino and battery set up, which had similar problems. Therefore we believe this could have been a contributing factor to the interference we saw in our data.

The possible power cycling issues arose from either the heating pad, where the heating pad's warm-up and current draw could have exceeded overall operational voltage; or from the batteries being at too low of a temperature. This could have caused a brown out where the T-5PGRS lost operating power and had to re-enter its calibration period leading to additional errors in the readings. By "brown out" we mean when the operating system lost sufficient power to continue functioning properly but did not lose 100% of its power and was able to continue printing into the same script file.

Anomalously high radiation detections often happened in conjunction with interference readings. It was common over the course of testing to receive a data line that printed "interference" as the second line printed after the payload was turned on. If there were power cycling issues, then it would explain the repeating values when using the T-5PGRS where, as it took readings, the sensor would print indexing numbers as it climbed to the current reading, so any value above, for example, three µSv/h would first print one, then two, then three, and finally the actual level. This caused excessive data that threw off trend lines.

Future Recommendations

The factors which could have contributed to our interference readings -- including the moisture levels, temperature levels, and heating pad power requirements -- were tested via our cold test. However, due to scheduling issues, our cold test was only conducted over a period of 30-45 minutes. Ideally, the cold test should have taken place over the course of our expected flight time of 2.5 - 4 hours and served as both a cold and bench test. Had this happened, our team would have been better prepared to deal with the effects of temperature at high altitudes. We therefore recommend future teams perform their cold test for the estimated time of flight.

The code used for the T-5PGRS is not the most ideal and should be used only as a last-minute solution. The radiation loop acts as an independent loop, causing values to be printed intermittently compared to the more consistent main loop.

Vibration during flight can contribute to faulty reading by creating intermittent connections inside the circuitry, so consider making future payloads vibration-resistant. An easy way to ensure a solid payload is hot gluing loose or unsupported components. If moisture is to blame for error in our readings, we recommend coating the exposed circuitry in a hydrophobic substance such as conformal coating or vaseline to prevent water from interfering with the electronics. For future iterations of this experiment, having a heating pad with less heat-up time or one that runs constantly at a lower temperature may be a good solution, as well as a heating pad inside the same compartment as the Arduino and batteries to mitigate any chance of those components getting too cold. As lithium ion batteries perform significantly better in low temperatures than lithium alkaline batteries they are likely a better choice. To prevent power-cycling issues, it may be worthwhile to utilize two separate Arduinos -- the first would be used for the radiation and pressure sensors, and the second would be used for the heating pad and to ensure consistent power, measure maximum current and adjust accordingly. These are steps that subsequent groups should take into account and act upon in order to ensure the functionality of their payload.[7]

Conclusion

Our hypothesis expected a semi-linear rise in radiation until peaking at an altitude of between 60,000-80,000 ft inside the range known as the Regener-Pfotzer Maximum. While there were many possible factors that could have contributed to the errors throughout our flight, our trend line did follow the expected trajectory of gamma radiation detections. The peak detections happened at 62,000 ft during the ascent and stayed elevated, albeit sporadic, at altitudes higher than 70,000 ft. The sporadic nature of these detections is nominal and expected due to high levels of gamma radiation in the Regener-Pfotzer Maximum. During the descent, our payload experienced another spike as it approached 60,000 ft. This series of detections further corroborates our expected trend of data over the flight. The detections of gamma radiation below 60,000 ft appear to trend more linearly, as expected, with respect to altitude. On the descent, there was an unexpected reading on the Geiger counter, which could be due to an abnormally high radiation detection, a cosmic ray, or as a result of our payload experiencing technical issues after the peak of the flight; this data point occurs just above 45,000 ft during the descent portion of our flight. There were numerous issues experienced throughout the building and data analysis processes of our payload, but hopefully future groups will be able to learn from our experience. Overall the functionality of the Type-5 Pocket Geiger Radiation Sensor met expectations and project budget. The data collected required significant work to become data considered useful for charting and analysis. However, compared to other radiation sensors on the market, this is a great option with both lower weight and a far cheaper price point.

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