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Kenzy O’Neill,
Robert Sewell
Revision Log

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<tr>
<td>A/B</td>
<td>Conceptual and Preliminary Design Review</td>
<td>2/24/2015</td>
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<tr>
<td>C</td>
<td>Critical Design Review</td>
<td>4/9/2015</td>
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<td>D</td>
<td>Analysis and Final Report (First Draft)</td>
<td>4/25/2015</td>
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1.0 Overview and Mission Statement

1.1 Mission Statement

The overall mission of Big Gamma, is to adhere to all Gateway to Space requirements and to send a BalloonSat to an altitude of approximately 30km to measure the electromagnetic radiation experienced from the gamma to X-ray spectrum (~$10^{-5}$ - $10^1$ nm) through varying thicknesses of polyethylene, in order to provide a better understanding of whether high-density plastics are a viable option for radiation shielding aboard air and spacecraft.

1.2 Mission Overview

Radiation is one of the greatest risks involved with spaceflight. As such, there is an increased interest in developing an efficient, lightweight, and cost effective material for shielding. Such a development would allow for longer sustained human flights, both for systems functionality and for deep space exploration.\(^1\)

While aluminum is currently the primary material used for spacecraft construction, there has been recent investigation into new materials that are more effective at shielding radiation by weight. One such material being studied is polyethylene, due to its high hydrogen content, as hydrogen atoms are effective at absorbing and dispersing radiation.\(^2\) Additionally, the use of a high-density polyethylene would be advantageous because of the property of denser materials to shield more effectively.\(^3\) Although polyethylene's shielding abilities have been tested previously, it was not until recently that NASA's Lunar Reconnaissance Orbiter's CRaTER payload found that plastics can serve as effective shielding in a high cosmic ray environment.\(^4,5\) These advancements and discoveries are what inspired Big Gamma's mission to investigate, and possibly confirm similar findings, of the effectiveness of high-density polyethylene to shield against the radiation experienced at high altitudes.

From this investigation, the team plans to discover the relationship between the thickness of high-density polyethylene and its ability to shield radiation. This will be done by measuring

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The radiation exposure during a given exposure inside varying thickness of polyethylene containments, which will be compared to the control radiation levels experienced without shielding, throughout the flight. Through these comparisons, the relative effectiveness of high-density polyethylene at shielding radiation can be determined. Furthermore, by establishing the relationship that thickness has on reducing radiation exposure, it can be determined at which thicknesses high-density polyethylene becomes effective at dampening radiation exposure.

With these results, Big Gamma will compare the found properties of high-density polyethylene with known properties of current spacecraft materials to determine if polyethylene can service as a viable option for radiation shielding aboard spacecraft. This comparison will include the relative shielding effectiveness, weight, cost, and strength of each material. From the Brooklyn Project's results and post flight analysis, this will provide a better understanding of plastics' effectiveness at shielding radiation and its potential for use on future spacecraft and exploration missions.

2.0 Requirements Flow Down

In order to ensure that the goals of Big Gamma are met, a number of objectives have been established and derived from the Mission Overview. Said objectives shall give an overview of the Brooklyn Project's mission details, as well as what will be accomplish.

2.1 Level 0 Objectives

<table>
<thead>
<tr>
<th>Objective</th>
<th>Mission Objective</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>The Brooklyn Project shall measure and record the effective radiation experienced through varying shielding thicknesses.</td>
<td>Mission Statement</td>
</tr>
<tr>
<td>0.1</td>
<td>The Brooklyn Project shall measure the temperature, pressure, humidity, acceleration, and imaging in compliance with the Gateway to Space (ASEN 1400/ASTR 2500) requirements.</td>
<td>Mission Statement</td>
</tr>
<tr>
<td>0.2</td>
<td>Big Gamma shall analyze the data collected and create a comparison report between HDPE and current spacecraft materials, to determine if HDPE is a viable shielding material.</td>
<td>Mission Statement</td>
</tr>
<tr>
<td>0.3</td>
<td>The Brooklyn Project shall be securely attached to the balloon flight</td>
<td>Mission</td>
</tr>
</tbody>
</table>

Figure 2 Shielding effectiveness of HDPE when exposed to Thorium 232. Averages are 110.4, 95.9, and 104 cpm respectively.
The Brooklyn Project

string, ascend to an altitude of approximately 30 km, and be successfully retrieved and intact.

| 0.4 | Big Gamma shall maintain an internal temperature above -10 degrees Centigrade. |
| 0.5 | The BalloonSat shall not exceed 1150 g in mass. |
| 0.6 | The BalloonSat's exterior shall have an American flag decal and contact information. |
| 0.7 | Big Gamma's BalloonSat shall be restored to working order for future flights. |

**2.2 Level 1 Objectives**

**Objective 0.0:** The Brooklyn Project shall measure and record the effective radiation experienced through varying shielding thicknesses.

<table>
<thead>
<tr>
<th>Objective</th>
<th>Mission Objective</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0.0</td>
<td>Radiation data of gamma irradiance shall be taken via Geiger counters and recorded via the experimental Arduino and micro SD card.</td>
<td>0.0</td>
</tr>
<tr>
<td>1.0.1</td>
<td>Two Geiger tubes shall be secured inside different HDPE thickness tubes, and one mounted on the Geiger board as a control.</td>
<td>0.0</td>
</tr>
</tbody>
</table>

**Objective 0.1:** The Brooklyn Project shall measure the temperature, pressure, humidity, acceleration, and imaging in compliance with the Gateway to Space (ASEN 1400/ASTR 2500) requirements.

<table>
<thead>
<tr>
<th>Objective</th>
<th>Mission Objective</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1.0</td>
<td>Balloon shield sensors shall record their respected data sets during flight and record via the environmental Arduino and micro SD card.</td>
<td>0.1</td>
</tr>
<tr>
<td>1.1.1</td>
<td>Camera shall record images via COSGC programming and record to the internal SD card.</td>
<td>0.1</td>
</tr>
</tbody>
</table>

**Objective 0.2:** Big Gamma shall analyze the data collected and create a comparison report between HDPE and current spacecraft materials, to determine if HDPE is a viable shielding material.

<table>
<thead>
<tr>
<th>Objective</th>
<th>Mission Objective</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2.0</td>
<td>Tensile strength, cost, and shielding effectiveness of each material shall be acquired.</td>
<td>0.2</td>
</tr>
<tr>
<td>1.2.1</td>
<td>Onboard radiation data will be handled and processed for analysis.</td>
<td>0.2</td>
</tr>
<tr>
<td>1.2.2</td>
<td>Conclusions shall be drawn from comparison analyses on HDPE shielding effectiveness.</td>
<td>0.2</td>
</tr>
</tbody>
</table>

**Objective 0.3:** The Brooklyn Project shall be securely attached to the balloon flight string, ascend to an altitude of approximately 30 km, and be successfully retrieved and intact.

<table>
<thead>
<tr>
<th>Objective</th>
<th>Mission Objective</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.3.0</td>
<td>Holes shall be cut in the center of the top and bottom of the satellite, washers shall be mounted around the holes, and paperclips shall be</td>
<td>0.3</td>
</tr>
</tbody>
</table>
1.3.1 Flight tube shall be secured through the center of the box. 0.3
1.3.2 Flight string shall be secured through the flight tube and secured to the helium balloon. 0.3

**Objective 0.4**: Big Gamma shall maintain an internal temperature above -10 degrees Centigrade.

<table>
<thead>
<tr>
<th>Objective</th>
<th>Mission Objective</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4.0</td>
<td>A heater shall be placed centrally in the satellite to heat the contents.</td>
<td>0.4</td>
</tr>
<tr>
<td>1.4.1</td>
<td>Insulation shall cover the inside of the satellite and aluminum tape shall be placed around all edges.</td>
<td>0.4</td>
</tr>
<tr>
<td>1.4.2</td>
<td>Internal temperatures shall be recorded to verify internal temperature.</td>
<td>0.4</td>
</tr>
</tbody>
</table>

**Objective 0.5**: The BalloonSat shall not exceed 1150 g in mass.

<table>
<thead>
<tr>
<th>Objective</th>
<th>Mission Objective</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5.0</td>
<td>Hardware mass shall be researched and accounted for.</td>
<td>0.5</td>
</tr>
<tr>
<td>1.5.1</td>
<td>Payload shall be weighed during integration process to confirm that the Brooklyn project is under mass.</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**Objective 0.6**: The BalloonSat's exterior shall have an American flag decal and contact information.

<table>
<thead>
<tr>
<th>Objective</th>
<th>Mission Objective</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6.0</td>
<td>Contact information shall be securely and visibly placed on the exterior of the satellite.</td>
<td>0.6</td>
</tr>
<tr>
<td>1.6.1</td>
<td>American flag decal shall be securely and visibly placed on the exterior of the satellite.</td>
<td>0.6</td>
</tr>
</tbody>
</table>

**Objective 0.7**: Big Gamma's BalloonSat shall be restored to working order for future flights.

<table>
<thead>
<tr>
<th>Objective</th>
<th>Mission Objective</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.7.0</td>
<td>Satellite shall be tested to ensure its ability to withstand flight conditions.</td>
<td>0.7</td>
</tr>
<tr>
<td>1.7.1</td>
<td>All hardware shall be secured to satellite walls to ensure no damage is done by lose parts.</td>
<td>0.7</td>
</tr>
<tr>
<td>1.7.2</td>
<td>BalloonSat shall be recovered from landing site and all hardware shall be restored post-flight from any damages that occurred.</td>
<td>0.07</td>
</tr>
</tbody>
</table>
The Brooklyn Project

3.0 Design

3.1 Design Overview

The Brooklyn Project BalloonSat shall fulfill the following design-based items in order to complete the aforementioned objectives in the Mission Statement: (1) Collect sufficient and usable data from all onboard BalloonSat instruments, including internal/external temperature sensors, a pressure sensor, a three-axis accelerometer, a humidity sensor and three Geiger counters (2) Protect and insulate all onboard components from damage and failure from the harmful environment of near-space. (3) Complete the experiment aforementioned in the Mission Statement. This includes the use of all subsystems onboard the satellite, which are: C&DH, Software, Experimental and environmental systems, structure/launch vehicle, thermal, power, and ground ops.

Team Big Gamma will design a weather balloon satellite, or 20.8x20.8x18 cm by outside compiled almost entirely out of FoamCore. This satellite will be assembled using hot glue and aluminum tape, and by gluing the seams together and covering these glued seams in aluminum tape. The satellite shall contain two primary sensor hubs: an experimental system and an environmental system. The environmental system shall collect data from one external temperature sensor, one internal temperature sensor, a pressure sensor, a humidity sensor, a tri-axis accelerometer, and a bare Geiger-Mueller tube with an Arduino-compatible Geiger board, whose purposes are to collectively monitor the environment in and around the BalloonSat. The bare Geiger-Mueller tube will be the control. The experimental system shall collect data from two separate Geiger-Mueller tubes, each connected to its own private Geiger Counter board. Both of these Geiger-Mueller tubes will be placed inside cylinders of HDPE of different thicknesses. Both the experimental and environmental systems will be directly based on two separate Arduino Uno micro controllers. In addition to these two sensor hubs, a Canon A3400 IS Digital Camera will also be utilized to take pictures. In order to ensure that there is no damage to the electronic components on the BalloonSat from the extreme temperatures of near space, the satellite will be lined with 25.4mm black foam insulation and a small heater shall be placed in close proximity to the experimental system and the environmental system. For power

![Figure 3 Top view of satellite design (20 x 18 x 18cm cube).]
requirements, Team Big Gamma shall use 9 T-Energy 9V 500mAh Li-on rechargeable batteries. Switches for the environmental and experimental systems as well as the heater shall be placed on the outside of the box with LED indicators for each. In order to attach the BalloonSat to the launch vehicle, a plastic tube will run through the center of the BalloonSat, where the flight cord will be run through. Metal washers will be placed on both attachment points to ensure the plastic tube does not rip through the satellite, and figure-eight knots will be tied on each end of the flight cord. Finally, the US flag, a pink University of Colorado Boulder Seal, and information about the satellite in the event that it is lost will be placed on the outside of the satellite.

**C&DH** – In order to manage all of the sensors and the actual onboard experiment, as well as data collection, two Arduino Uno micro-controller boards will be the foundations of Big Gamma's BalloonSat. Each Arduino will have a switch with an LED indicator to verify on the outside of the BalloonSat that both are functioning properly, and both shall be connected to 9V batteries. One Arduino will be controlling the required sensors, e.g. humidity, external and internal temperature, accelerometer, and pressure, and the control Geiger counter. The second Arduino will be controlling the two shielded Geiger-Mueller tubes, and will be the foundation for the experiment. It is possible to connect and use only up to two Geiger Counters to one Arduino Uno, due to the fact that each Geiger counter must be connected via the digital interrupt pins (digital pins 2&3). Big Gamma believes that timing issues with two interrupts will not be a problem, because through extensive Geiger testing Big Gamma has found that the Geiger Counters and tubes work without fault or issue in any timing or any other issue. One Geiger Counter will be connected to the environmental systems Arduino and will also have to be written to that Arduino’s MicroSD card. Both Geiger Counters will be powered through the 5V connections on the Arduino shield. The physical position of the actual Arduinos is shown in figure 3. The data for both Arduinos shall be written onto and stored on a 2GB MicroSD Card.
Experimental System – Team Big Gamma shall measure how the thickness of High-Density Polyethylene (HDPE), when shielding an SBM-20 Geiger-Mueller Tube in the form of a round housing, affects the level of gamma radiation detected by the tubes. The dimensions of the Geiger-Mueller tubes are 1.1 cm in diameter x 10 cm in length. This shall be accomplished by placing two of the three Geiger-Mueller tubes into hollow rods of HDPE, so that the thickness of shielding material surrounding the Geiger-Mueller tubes is constant. HDPE was selected as a shielding material because it is one of the densest plastics commercially available, in addition to still being very lightweight and cheap when compared to certain metals. All three Geiger-Mueller tubes will be placed on the inside of the BalloonSat, due to the operating temperatures of the Geiger-Mueller tubes and the complicated modification of the BalloonSat by placing the Geiger-Mueller tubes on the outside of the BalloonSat. It was also determined that the Geiger-Mueller tubes could suffer critical damage in the event that the BalloonSat landed on the ground where the Geiger-Mueller tubes were mounted. Each Geiger-Mueller tube is also connected to its respective Geiger board. The first Geiger-Mueller tube shall be the 'control' tube, with no HDPE housing at all. This is the Geiger-Mueller tube that will be placed with the environmental system. The minimum operating temperature of these SBM-20 tubes is -60°C, and since Big Gamma expects the environment on the inside of the craft to drop to -10°C, we expect to have little problem exposing the tube directly to the environment. The second Geiger-Mueller tube shall be placed inside of a hollow HDPE rod of 2.2 cm in diameter x 13 cm long, which gives an effective shielding of .50 cm. The third Geiger-Mueller tube will be placed inside of a thicker, also hollow, rod of HDPE of 4.2 cm in diameter x 13 cm long, which gives an effective thickness of 1.5 cm. The combined weight of these shielding housings shall not exceed 300 g. These rods of HDPE will be hollowed out with a drill press, making a bore of 1.2 cm. Both rods of HDPE will be capped and sealed with pieces of HDPE in order to ensure there is also shielding at the tops and bottoms of both tubes. The tubes will output a certain number of ‘pings’ of radiation while in flight, which will increase with the amount of radiation detected. The way these tubes detect radiation is that when a certain type of radiation, such as gamma, passes through the tube, the atoms inside become ionized, and therefore outputting an electric pulse, which then produces a ‘ping’. The pings must be measured over a unit of time, which will be number of ‘pings’ per 30 seconds, which will give the team the number of ‘pings’ for each individual tube in a 30-second time span. This is necessary because one particle will physically not pass through all three tubes at once. Specifically how all of this shall be accomplished will be discussed in the next section, Software, and Hardware Overview. Furthermore, in order to maintain consistency among our Geiger counters, we will calibrate them against known radiation sources on campus via the help of faculty in the physics department, and other known sources.

Software – Although the Arduinos onboard the BalloonSat are the foundation for Big Gamma's experiment, Big Gamma's experiment would be entirely in vain if Big Gamma were not to
The Brooklyn Project

develop code for it. Big Gamma will develop the code for the environmental systems Arduino, which contains the required sensors of the flight, while building and learning about Arduino. However, developing the code for the experimental systems in order to integrate the Geiger counters into the Arduino will be a challenge in itself. Although the Geiger kits do come with their own code to run, they must be modified to work with an Arduino writing to a MicroSD card, instead of just a laptop. First, we must set up 'basic' code for each Geiger counter to verify that it works and runs properly. Second, we must develop code to turn the 'pings' that each counter registers into logable data because the counter does not output voltage. Specifically, when the Geigers are connected to the interrupt pin on the Arduino (which are digital pins 2&3), they ‘interrupt’ the signal going through the pin, which will be recorded, converted into logable data, and written to the MicroSD card. Third, which is also the most critical part, code would need to be developed in order to write the 'pings' the counter is outputting to a MicroSD card. Big Gamma will use the code provided from RH electronics as a foundation for the flight code for each Geiger Counter, pictured below.

```cpp
#include <SPI.h>
#define LOG_PERIOD 15000  //Logging period in milliseconds, recommended value 15000-60000.
#define MAX_PERIOD 60000  //Maximum logging period
unsigned long counts;  //variable for GM Tube events
unsigned long cpm;    //variable for CPM
unsigned int multiplier;  //variable for calculation CPM in this sketch
unsigned long previousMillis;  //variable for time measurement

void tube_impulse(){  //procedure for capturing events from Geiger Kit
counts++;  
}

void setup(){  //setup procedure
counts = 0;
cpm = 0;
multiplier = MAX_PERIOD / LOG_PERIOD;  //calculating multiplier, depend on your log period
Serial.begin(9600);  // start serial monitor
// uncomment if you have time-out problem to connect with Radiation Logger
// delay(2000);
// Serial.write('0');  // sending zero to avoid connection time out with radiation logger
// delay(2000);
// Serial.write('0');  // sending zero to avoid connection time out with radiation logger
pinMode(2, INPUT);  // set pin INT0 input for capturing GM Tube events
digitalWrite(2, HIGH);  // turn on internal pullup resistors, solder C-INT on the PCB
attachInterrupt(0, tube_impulse, FALLING);  //define external interrupts
}

void loop(){  //main cycle
unsigned long currentMillis = millis();
```
Environmental System – This system shall consist of a number of different sensors, including two temperature sensors (one external and one internal), a humidity sensor, a three-axis accelerometer, and a pressure sensor. The precise purpose of this system is to monitor the environment directly in and around the BalloonSat, so that conclusions can be made about the environment of the BalloonSat during flight when all of the data is retrieved.

Thermal – In near space, temperatures drop to nearly -65°C, meaning that insulation and heating of a spacecraft is absolutely critical. On Big Gamma's BalloonSat, this will be accomplished by using two distinct thermal systems; one passive and one active. First, The entire inside of the BalloonSat will be surrounded and insulated with black foam and, which will not create a seal but will keep the temperature of the inside of the BalloonSat relatively constant. Second, a 9V-battery powered electric heater will sit inside the box BalloonSat to warm the critical electrical components. This will be activated by a switch that will have an LED to indicate that it is working properly.

Power – Big Gamma will use a total of eight T-Energy 9V 500mAh Li-on rechargeable batteries, to power the entire BalloonSat. Each battery weighs 30g, giving a weight savings of 15g per
battery over standard 9V batteries, and giving a total of 270g in batteries. These batteries are also significantly less susceptible to low temperatures. The environmental system shall use 2 9V batteries, the experimental system will be powered by three, and the heater will be powered by three. These batteries will either be situated in such a way to allow for equal weight distribution around the box, or situated in such a way to counter-balance the weight of the Geiger-Mueller tubes and their respective housings. With respect to powering the Geiger boards and their respective tubes, each Board has two pins for power. These are 5V and GND. Each GND pin on each Geiger board will be connected to a GND pin on its respective Arduino. For the Geiger-Mueller tube connected to the environmental system and one Geiger-Mueller tube on the experimental system, their respective 5V pins will be connected to the 5V pins on each respective Arduino. Both Geiger Counters on the experimental system will be powered by 5V pins on its respective MicroSD shield. LED indicators for both the experimental and environmental systems Arduinos will be used to determine if each is powered up before the flight. In addition to LED indicators for both Arduinos and the heater, there will be two LED indicators from the environmental system Arduino, an orange LED indicating that there is a MicroSD card present, and a second blue LED indicating that data is being written to the MicroSD card.

Launch Vehicle & Structure – The launch vehicle is a large Hydrogen Balloon that will ascend to an altitude of approximately 30km, complete with a parachute, GPS tracking devices for recovery, and all of the individual BalloonSats. Big Gamma's BalloonSat shall consist of a box of dimensions 20x18x18 cm, built of sheets of foam core, and put together with hot glue and aluminum tape. This shall ensure the BalloonSat is able to withstand extreme conditions of launch, ascent, burst, and landing. This shall also ensure that there is sufficient room to install all three Geiger tubes flush with the BalloonSat without compromising structural integrity.

Special Features – The primary special feature of this BalloonSat is the way the rods of HDPE will be mounted inside the box, and the way the box is designed to accommodate these. The BalloonSat was designed with such dimensions so that the rods of HDPE, with their end caps, will fit snugly, or very close to snug, inside the box, with the black foam installed. The purpose of this is so that in the event the HDPE rods become dislodged, they are still partially constrained and will not move around inside the box in comparison to a rod that would not fit snugly. The idea is that it would move around less on the inside of the box and cause less damage. A more apparent and blatant special feature of this mission is the experiment itself, which is using three Geiger-Mueller tubes to determine how shielding the Geiger-Mueller tubes with varying thicknesses of HDPE affects radiation detection. This shall help Big Gamma to collect a plethora of data which will help us succeed in its mission because the more data that the team collects, the better analysis of the data can be done, resulting in clearer conclusions.
3.2 Functional Block Diagram (FBD)

![Functional Block Diagram](image)

3.3 Hardware Overview

*Geiger Counters (DIY kit version 3)*

The mission objective is to send three Geiger counters to 30 kilometers to record gamma radiation. The Geiger counters will be purchased from eBay and shipped from Israel by the company RHelectronics. The Geiger counters will be assembled by the hardware team once delivered. Extreme care must be used in handling the Geiger Tubes due to the fact that they are extremely fragile. Big Gamma already broke one Geiger Tube when taping wire to the tube. Thankfully, Big Gamma was able to receive another Tube from a fellow team. The Geiger counters are Arduino compatible and will produce a digital interrupt signal indicating radiation. This digital signal will be recorded and stored onto the SD card in counts per minute. Because the Geiger counters send...
out a digital interrupt signal and the Arduino Uno only has two external interrupt pins (pins 2 and 3), only two Geiger counters will be wired to the experimental Arduino Uno and the third one will be wired to the environmental Arduino Uno. Each Geiger counter will be equipped with a SBM-20 Geiger tube. The tubes are filled with a gaseous mixture of neon, bromine and argon. When hard beta and gamma radiation penetrate the tube and come in contact with the gas the atoms become ionized. The free electrons will be attracted towards the metallic anode wire through the middle of the tube. The cations will be attracted to the stainless steel cathode shell. When enough of these atoms ionize the anode will become reduced and produce an electrical current known as a count that the Geiger kit will translate into a digital output.

**Temperature sensors**

The payload will include two temperature sensors as part of the environmental system and will be provided by COSGC. Both of the sensors will be on the environmental Arduino Uno and record internal temperature while the other will placed in a small opening through the side of the structure, approximately 1” from the craft. The sensor will send out an analog signal to the Arduino which is then turned into a digital signal to write onto the SD card via the Arduino’s analog-to-digital converter. This temperature sensor will record external temperature throughout the mission.

**Barometric Pressure Sensor**

A barometric pressure sensor will also be included as part of the environmental system and will be provided by COSGC. The sensor will be connected to the environmental Arduino Uno and will collect data on the pressure levels through-out the mission. It will also be interface in the same way as the temperatures with respect to the fact that it will be interfaced through an analog connection and then run through the Arduino’s analog-to-digital converter.

**Canon A3400 IS Digital Camera**

The camera will be secured inside the payload with the camera lens pointing outside of an opening in the side of the structure. The camera will be provided by COSGC and will be pre-programmed to take a picture every 10 seconds through-out the mission.

**3-axis accelerometer**

The accelerometer is another sensor that will be provided by COSGC. The sensor will detect the payloads motion in the X, Y and Z planes. The recorded data will be later evaluated so a further understanding of the motion of the payload during the mission can be made. This sensor will be interfaced through an analog sensor and then run through the Arduino analog-to-digital converter.
**Humidity Sensor**

A humidity sensor will be provided by COSGC. It will be connected to the environmental Arduino Uno and record humidity levels throughout the mission. It will be interfaced through an analog connection and then run through the Arduino analog-to-digital converter.

### 3.4 Conceptual Operations (CONOPS)

![Figure 12 Concept of operations diagram.](image)
**4.0 Management**

Team Big Gamma will meet from 5:30pm to 8:30pm every Tuesday and Thursday, and will schedule additional meetings when needed. Every team member will be a part of a minimum of 2 sub-teams, the leaders of which are expected to ensure that their deadlines are met.

**4.1 Team Hierarchy**

![Team Hierarchy Diagram]

**4.2 Schedule**

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/09/15</td>
<td>Proposals Due</td>
</tr>
<tr>
<td>2/10/15</td>
<td>Team Meeting: Start gathering materials</td>
</tr>
<tr>
<td>2/12/15</td>
<td>Team Meeting: Continue gathering materials, Start on structures, Learn Arduino code</td>
</tr>
<tr>
<td>2/13/15</td>
<td>Authority to Proceed, Order Hardware</td>
</tr>
<tr>
<td>2/17/15</td>
<td>Team Meeting: Finish building structure, Whip Test, Stair Test</td>
</tr>
<tr>
<td>2/19/15</td>
<td>Team Meeting: Create PDR presentation</td>
</tr>
<tr>
<td>2/24/15</td>
<td>Team Meeting: Continue PDR presentation, Start on DD Rev A/B</td>
</tr>
<tr>
<td>2/26/15</td>
<td>Team Meeting: Receive Hardware, Finish DD Rev A/B, Practice PDR Presentation</td>
</tr>
<tr>
<td>3/03/15</td>
<td>Team Meeting: PDR Presentation, Build Geiger Counters, Program Geiger Counters</td>
</tr>
<tr>
<td>3/05/15</td>
<td>Team Meeting: Finish Programming Geiger Counter</td>
</tr>
</tbody>
</table>
### The Brooklyn Project

<table>
<thead>
<tr>
<th>Date</th>
<th>Task Description</th>
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</thead>
<tbody>
<tr>
<td>3/10/15</td>
<td>Team Meeting: Ground Test Geiger Counters</td>
</tr>
<tr>
<td>3/12/15</td>
<td>Team Meeting: Start HDPE Casings</td>
</tr>
<tr>
<td>3/17/15</td>
<td>Team Meeting: Finish HDPE Casings</td>
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<tr>
<td>3/19/15</td>
<td>Team Meeting: Ground Test Geiger Counters ½</td>
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<tr>
<td>3/31/15</td>
<td>Team Meeting: Start LRR Presentation, Temperature Test, Insert Environmental System and Geiger Counters</td>
</tr>
<tr>
<td>4/02/15</td>
<td>Team Meeting: Work on LRR Presentation, Practice LRR Presentation, Finish Satellite, Work on DD Rev C</td>
</tr>
<tr>
<td>4.06/15</td>
<td>Team Meeting: Finish LRR Presentation, Finish DD Rev C</td>
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<tr>
<td>4/07/15</td>
<td>LRR Presentation</td>
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<tr>
<td>4/09/15</td>
<td>Team Meeting: Last Minute Preparation</td>
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<tr>
<td>4/10/15</td>
<td>BalloonSat Weigh-in and Turn in</td>
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<tr>
<td>4/11/15</td>
<td>Launch Day</td>
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<tr>
<td>4/14/15</td>
<td>Team Meeting: Create Quick Look Post Launch Presentation, Practice QLPLP</td>
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<td>4/16/15</td>
<td>Team Meeting: Quick Look Post Launch Presentation, Start Final Presentation</td>
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<td>4/21/15</td>
<td>Team Meeting: Design Expo Booth, Continue Final Presentation</td>
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<tr>
<td>4/23/15</td>
<td>Team Meeting: Practice Final Presentation</td>
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<td>4/25/15</td>
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<td>4/28/15</td>
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### 5.0 Budget

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<tr>
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<td>$130</td>
<td>135</td>
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<td>Geiger Tubes</td>
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<td>Provided</td>
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<td>COSGC</td>
<td>Provided</td>
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<table>
<thead>
<tr>
<th>Item</th>
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<td>Switches</td>
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Kenzy O’Neill will be in charge of managing team Big Gamma’s budget. Kenzy will ensure that all purchases are approved by him, and will be responsible for seeking reimbursement from Chris. For any expenses outside of the budget, Kenzy will ensure that the expenses are split evenly among all team members.

6.0 Test Plan and Results

6.1 Safety

Throughout the course of Project Brooklyn, each team member will act in a professional manner at all times. All construction and tests will be performed in an appropriate environment so that no harm will come to any person or property. This applies particularly during testing, as the team will take special care to not test around building windows and to be careful around others. In addition, each member must be familiar with the operation of any equipment they use, or must be under the supervision of an instructor. Furthermore, all prototype and ground experimental testing will take place in the proper laboratories with permission and advising from the lab supervisor.

6.2 Test Plan

- **Spin Test:** The spin test will test the BalloonSat’s structural ability to withstand the g-forces it will undergo during the whipping which will occur after the weather balloon bursts at maximum altitude. The maximum forces the BalloonSat will experience are expected to be around 3-4 g’s. The BalloonSat will be attached to a rope to simulate the rope that it will be connected to during flight. Within the structure of the BalloonSat will be weights that will simulate the actual weight of all of the internal components, in order to keep the delicate parts undamaged. Once attached to the end of a rope, the BalloonSat will be spun overhead vigorously, as well as whipped from side to side. This test will be done away from windows and people to avoid damages and injury.

- **Stair Test:** To test for the BalloonSat’s durability in the chance that there is a strong wind during landing, leading to the satellite being dragged over the ground, the BalloonSat (with mass simulators inside) will be thrown down a set of stairs of at least 10 steps.

- **Drop Test:** In order to test for a scenario in which there is a very rough landing, the BalloonSat (with mass simulators inside) will be dropped from approximately 6 meters, onto concrete and dirt.

- **Temperature Test:** Testing the BalloonSat’s ability to undergo extremely cold temperatures will be done in a cooler. The BalloonSat will be placed in a cooler,
surrounded by dry ice to reach the coolest temperature. This test will be done while the electronics are within the satellite and powered on. Temperature testing will test the functionality of the heater, sensors, and battery life. The BalloonSat will be exposed to extremely cold temperatures for 3 hours to simulate the exposure during the actual flight.

- **Mission Simulation Test:** A 3 hour mission simulation will be done on the ground to check that all sensors and systems are fully functioning and can function the duration of the mission. This test will be done by activating all of the switches and monitoring the BalloonSat over the length of the simulation this will also include testing each sensor, such as by shaking the box every 30 minutes, which will show data via the accelerometer. Placing fingers on the external temperature sensor will elevate the temperature, and will show in the data. Breathing inside the box will elevate the humidity, and this will also show in the data.

- **Geiger Counter Test:** The Geiger tubes will be exposed to background radiation, and Big Gamma has tested each Geiger tube in a lab by comparing recorded cpm values to a larger, and most likely more accurate, Geiger Counter in the University of Colorado Physics Department, facilitated by Scott Pinegar. Big Gamma will use $^{232}$Thorium for a radiation source, provided by the Physics department. A piece of acrylic placed on top of a piece of cardboard will be placed to block out Alpha and Beta radiation, and only let Gamma through to the Geiger Tube. The number of counts over 60 seconds will then be recorded from the Geiger Counter from the physics department, and then Big Gamma’s Geiger Counters will be placed over the radiation source above the acrylic, to determine its readings.

- **Sensor Testing:** Sensors will be tested to ensure that all are fully functioning and transmitting data correctly to the Arduinos. Sensors will also be calibrated during testing. The thermometer, accelerometer, barometric pressure sensor, and the humidity sensor will be exposed to varying environments to check for proper data collection.

- **Camera Test:** Testing of the camera will take place during the temperature test. The camera will be tested for functionality and longevity at extremely cold temperatures by taking a photo every 10 seconds throughout the temperature test.
6.3 Testing Results

- **Spin Test:** The prototype box held together well during the spin test and took no physical damage after being spun for 90 seconds. Abrupt movement tests were also done while the box was attached to the string and no damage was done to the box.

- **Drop Test:** The box was dropped about 6 meters onto concrete twice, to simulate the possible forces experienced during impact. The box sustained only a slightly dented corner where it impacted the ground.

- **Stair Test:** The box was kicked down a flight of stairs two times. The prototype split at one seam during one of the stair tests. To prevent any splitting in the final structure, the box will be made out of one solid piece of foam core, rather than six individual pieces. The edges of the final box will be more thoroughly reinforced as well.
- **Geiger Test** - The readings obtained from Big Gamma’s Geiger Counters were sufficiently close to the readings obtained by the physics department Geiger Counter. The physics department Geiger Counter obtained a reading of 105 cpm and Big Gamma’s Geiger tubes all obtained average readings of 105 cpm, averaged over 20 data points. Big Gamma therefore has accurate Geiger Tubes that can be used on the flight and give accurate readings and data.

- **Cooler Test** - The primary purpose of the cooler test was to ensure that all electronics are able to work in extreme cold, by placing the assembled craft into a craft and surrounding it with approximately 10 pounds of dry ice. Big Gamma’s original design was to use 9 T-Energy 9V 500mAh Li-on rechargeable batteries; 3 for the heater, 3 for the experimental system, and 3 for the environmental system. However, during the test, Big Gamma decided to use 2 for the heater, 2 for the environmental system, and 3 for the experimental system, which would bring Big Gamma’s craft underweight. The results of the 3-hour test showed that the environmental system is capable of running on just 2 batteries and the experimental system on 3 batteries for the full 3 hours. Unfortunately, running on just 2 batteries, the heater ran out of charge approximately 1 hour into the test. Big Gamma concluded that one or both of the batteries used were not fully charged, and caused the heater to work for a very short amount of time. For the flight, Big Gamma shall certainly use 3 batteries for the heater. Big Gamma also found that the camera died approximately 30 minutes into the test, although this was due to the fact that camera battery was quite insufficiently charged. Unfortunately, other than these mishaps, there were larger and more major ones. The test results and data from the Geiger tubes show that approximately 1/3 of the way into the test, all three Geiger tubes showed an extremely dramatic increase in counts per minute recorded, up to nearly 400 at one point. After this enormous spike occurs, the Geiger Tube that is shielded by .5cm HDPE flatlined, meaning that it continuously recorded zero
counts for the remainder of the cooler test. Also, both of the other tubes also recorded lower overall counts per minute after the spike. Big Gamma originally concluded that this enormous spike in counts per minute recorded was due to a solar flare through a small amount of research. However, this seemed extremely improbable, and therefore Big Gamma therefore decided to conduct yet another cooler test, this time in a colder environment, using more dry ice. For the first cooler test, the internal temperature sensor achieved a low of 20.3°F inside the box a period of time after the heater died, but maintained a temperature of approximately 80°F until then. The outside temperature reached a minimum of -16.7°F. For the second cooler test, the outside temperature reached a minimum of -35.4°F, and the inside a minimum of 15.6°F. Big Gamma also decided to use just 2 batteries on the heater again, and the heater again died approximately 1 hour into the flight. Most importantly, just as in the first cooler test, all three Geiger tubes experienced an enormous spike in radiation about 1/3 of the way into the test, and again, after this occurred, the Geiger Tube being shielded by .5cm thickness of HDPE flatlined and continuously gave 0 counter per minute for the remainder of the test. In fact, for all three tubes in both tests, the data appeared almost identical. Big Gamma concluded that this enormous spike in radiation approximately 1/3 of the way into the test was due to temperature, where when the internal temperature reaches approximately 40°F, this spike in counts per minute occurs. Big Gamma will discuss the reasons for approaching and arriving at this conclusion in the next section, Missions Test.

- **Missions Test:** Due to the unexpected and unexplained spikes in counts per minute recorded, and the apparent failure of one of the Geiger tubes to fail to record any radiation, Big Gamma decided to conduct a separate missions test at room temperature to determine whether or not cold temperatures were in fact the culprit for this major skew in data. Ultimately, after a complete 3-hour missions test, Big Gamma collected the data and found the following results.

**Temperature:** The following graph shows the external and internal temperature for the Missions Test, over a total time of 3 hours. The craft was not placed in a cooler in order to keep the temperature variable constant. Big Gamma also used 3 batteries for the heater
and found these supplied sufficient charge for approximately one hour and 45 minutes before finally running out of charge.

**Radiation:** As expected, Big Gamma found that none of the three Geiger tubes experienced an enormous spike in counts per minute, as was encountered in both cooler tests. Also, the Geiger tube shielded by .5cm of HDPE worked consistently and accurately throughout the duration of the test. Therefore, Big Gamma can conclude that the spikes in radiation detected during the cooler tests in all three tubes were caused by low temperatures. What this implies for the flight is that some rigorous thermal changes will need to change place in order to prevent this from happening during the flight. Big Gamma will replace all black foam insulation currently in use with significantly thicker black foam, to retain heat in the craft as much as possible.

**Figure 18** Graph depicting external and internal temperatures during missions test.

**Figure 19** Graph depicting the shielded Geiger tubes during the missions test.
Other Sensors and Data:

These are graphs of the data from each of the other sensors off of the environmental systems Arduino, which remained powered on for the duration of the systems test. The first graph, depicting acceleration in the X and Z directions, shows constant acceleration, except for the three large spikes, when the craft was shaken several times, and reflects exactly what Big Gamma predicted for acceleration for this test. Pressure actually steadily increased over the 3-hour test by a minimal amount, from 12.02 psi to a maximum of 12.05 psi. Big Gamma also witnessed a sharp decrease in humidity as the test commenced, starting out at 50%, dropping down to 20% and final equalizing at approximately 30%.

7.0 Expected Results

Team Big Gamma will save all data onto MicroSD cards provided by Space Grant. The data is formatted to fit into .csv format files, which can be opened in Microsoft Excel without any further modification. These files will then be plotted using Microsoft Excel for a preliminary look at the data and then in Wolfram Alpha Mathematica for detail. From the plots generated by these two programs, Big Gamma will be able to analyze the data to determine if it matches the predicted trends described below, as well as report on our experimental findings.
7.1 Temperature
Team Big Gamma expects the external temperature of the payload to reach a minimum temperature of -60 degrees Celsius as it rises from the troposphere and into the stratosphere at an altitude of 20km. After 20 km we expect the temperature to rise to about -40 degrees Celsius as the payload approaches its goal altitude of 30km. The interior temperature will be regulated by the heater and will not go under -10 degrees Celsius to maintain operations of all electronics.

7.2 Humidity
The humidity is expected to change along with pressure and temperature. As the payload rises toward 30 km the air pressure decreases and temperature decreases causing humidity to decrease as well. The temperature difference between the interior and exterior of the payload may result in additional humidity build up. This potential for additional humidity must be recognized when interpreting results.

7.3 Pressure
Big Gamma expects an inverse relationship between altitude and pressure. As altitude increases there will be a decrease in measured pressure. As this is a well known phenomenon, we can use our pressure measurements as a comparison of altitude for our other measurements.
7.4 Acceleration

Big Gamma expects to observe a relatively constant velocity (little to no acceleration) in the z-axis on the ascent, besides initial take off. During the ascent and descent it is difficult to predict the exact acceleration trends in the x and y axes, due to the erratic motion on the flight string. Because of this, it is predicted that there will be abrupt acceleration measurements along the x and y directions. Upon burst, Big Gamma also expects to record large and erratic acceleration measurements along all three axes.

![Figure 25](https://example.com/image.png) Relationship between acceleration and altitude as expected during the flight.

7.5 Radiation

Big Gamma expects an increase in radiation levels with an increase in altitude. It is also expected that the two Geiger Counters that are shielded will receive less radiation than the control. Big Gamma expects the Geiger tube with more shielding to receive lower amounts of radiation dosage.

When doing ground testing on the Geiger tubes, Big Gamma will discover the attenuation coefficient of HDPE, which will later be used to calculate the theoretical emerging intensity that the Geiger Counters will receive. From the Fundamental Law of Gamma-Ray Attenuation, the theoretical experienced dosage by the shielded tubes during the flight can be calculated. The expected radiation intensity will therefore be, $I = I_0 e^{-\mu r}$, where $I_0$ is the experienced intensity by the control tube, $r$ is the radius of effective shielding, and $\mu$ is the found absorption coefficient. After Ground testing the Geiger Counters in the physics department, detailed in Test Results section, the absorption of the coefficient of HDPE was determined to be $0.115 \text{ cm}^{-1}$.

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In addition, Big Gamma can then conclude the accuracy of the data received from the Brooklyn Project by comparing it to the theoretical values found through the Fundamental Law of Gamma-Ray Attenuation. This will be accomplished by running a regression of the data, which will require a minimum of three data points. These data points will be determined by an average of all the data points in every layer of the atmosphere. The resulting multiple regressions will provide a strong basis to draw a conclusion on the efficiency of HDPE shielding.

Lastly, Big Gamma will then compare the tensile strength, mass, cost, and radiation shielding of HDPE to that of other materials, in order to determine whether HDPE is a viable radiation shielding substitute for current spacecraft materials.

8.0 Launch and Recovery

8.1 BalloonSat Recovery

After launch is completed and the BalloonSat payloads complete the flight to approximately 30km and back down, the payloads have the potential to land extremely far away from the launch site, possibly even in another state. This will require some team members to retrieve Big Gamma’s payload. Kenzy O’Neill will be the person responsible for preparing the craft for launch and actually launching on launch day, due to the fact that he has the most hands-on experience with the BalloonSat itself. Ian Cooke will complete Navigation Training in order to qualify himself for BalloonSat recovery in the lead vehicle. Rong Li and Robert Sewell will drive the members of Big Gamma to the launch site located in Eaton, CO. After the BalloonSat is recovered, preliminary external inspection of the craft is completed, and the craft safely returned to Boulder, data retrieval and recovery will commence.

8.2 Data Retrieval

Big Gamma’s data retrieval plan, once the craft has been safely transported back to Boulder, is the following:

- Allow satellite to warm up to room temperature
- Observe and note any damage done to the craft, then take pictures of exterior of BalloonSat for damage analysis.
- Carefully cut aluminum tape and seams to open box, and take pictures of inside of the box to compare with images from before launch.
- Note any apparent damage done to the electronics, and then carefully remove MicroSD cards from their respective systems.
- After the MicroSD cards have been removed, data analysis will commence.

Before Launch, Big Gamma will take pictures of our payload, from as many angles as possible, and all internal electrical components, to detail the condition of the craft after flight and compare it to conditions before flight, or in case of a catastrophic failure for failure analysis. With regard to knowing that this plan works, Big Gamma can be sure that this data retrieval plan will work
because of its numerous tests on the craft, using all subsystems at once, which included two separate cooler tests and one missions test. Data retrieval has been successful each and every time.

8.3 Data Analysis

Data analysis commences as soon as Big Gamma sees the BalloonSat on the earth after landing. This includes qualitative observations taken by any members of Big Gamma. This also includes taking pictures of both the exterior and interior of the BalloonSat, to compare with images from before launch. Primary data analysis will commence as soon as both MicroSD cards have been extracted from their respective systems. The data from these cards will be extracted from their respective .csv files off of the cards and loaded into excel, where plots, graphs and visuals, will be created to draw conclusions about the nature of the flight and fulfill Big Gamma’s mission statement.

8.4 Launch Recovery Account

Flight of Big Gamma’s BalloonSat commenced promptly as planned at approximately 6:30am on April 11, 2015 in Eaton Colorado along with 7 other BalloonSat payloads on EOSS flight 207. According to the EOSS flight data, the payloads reached an altitude of 24,433.1 m above sea level before the balloon burst and the payloads descended. The payloads landed softly, approximately 600 feet from the road in the middle of nowhere, Eastern Colorado. Upon inspecting the cable connecting the beacon to the transmitter, Big Gamma discovered that it had snapped, which is why the transmitter stopped sending data packets to the tracking stations at approximately 54,000 feet and needed to be traced by eye to the ground. The members who went on recovery were Ian Cooke, Robert Sewell, and Olagappan Chidambaram. Physical recovery of the payloads was very lively, with nearly every member of each team sprinting towards the payloads. Upon initial inspection of Big Gamma’s payload, the craft appeared to be undamaged at first glance, and although the heater LED indicator was off, the experimental system Arduino, environmental system Arduino, MicroSD card present, and writing to MicroSD LED indicators were all still on, indicating that all electronics were functioning except for the heater. Big Gamma then took a few post-landing pictures, cut the flight string, turned off all systems and took the craft back to Boulder for results and data analysis.

9.0 Results, Data Analysis, Failure Analysis and Conclusions

9.1 Results & Data Analysis

In this section, Big Gamma will attempt to analyze all of the data recovered from flight; from visual data to Geiger counter data and everything in between. These analyses and results will then be used to make conclusions about the mission as a whole, using data from each sensor and combining the understandings of each set of data.

9.1.1 Physical Inspection

Before flight on April 11, 2014, Big Gamma documented the condition of the BalloonSat using photography in order to compare pre-flight conditions of both the interior and exterior of the box to post-flight conditions. Photography was also used to document the condition of both the interior and exterior and interior post-flight. This visual data is intended to help Big Gamma
determine the causality of minor to major damage sustained during the flight. For example, if there is a large dent in a corner of the BalloonSat upon post-flight inspection, Big Gamma can infer that the craft either suffered a heavy collision with another BalloonSat after burst, or suffered a heavy landing. On the interior, for example, if a module became dislodged from its Velcro mounting point and caused damage to other modules and wiring, Big Gamma would be able to completely determine the extent of the damage done to the craft by comparing the interior to post-flight conditions. The following photos display the conditions pre and post flight, and include full analyses of the conditions.

**Interior**

![Image of interior and modules before flight](image26)

![Image of interior and modules after flight](image27)

Based solely on the images displayed above of the interior of the craft pre and post flight, Big Gamma concludes that no damage was sustained to any of the systems, wires, or modules. Initial post-flight inspection by Olagapan and Robert further support this claim based on the data presented. Essentially what this means, as far as the mission, is that Big Gamma successfully crafted a structure that helped complete the team’s mission. From the box construction to the Velcro mounts for all of the modules and systems, as well as wiring, Big Gamma succeeded in creating a structure that did it’s job, as outlined in the mission.
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statement and objectives.

Exterior

Based solely on the images above, Big Gamma concluded that no significant or noticeable damage occurred to the structure itself. There were no noticeable dents, marks, indents, or scratches anywhere on the outside of the craft after landing. Compared to the images taken before launch, the craft looks essentially the same. The only damage recorded during the preliminary post-launch inspection was that washers on both sides of the satellite had separated from the craft due to inadequate gluing, which under high loads, most likely after burst, caused the washers to separate. However, after interior inspection, Big Gamma concluded that no damage had been sustained due to this mishap. What this data tells us is that Big Gamma’s structure had been built successfully and allowed the craft to be carried up to approximately 100,000 feet, and so far, had insulated and protected all internal components from failure and damage.

Figures 30&31 Images of craft directly after landing on launch day.
9.1.2 Best In-Flight Pictures

Figures 32-25 Images of ascent taken by in-flight camera.

9.1.3 Sensor Data Analysis

Data was collected from a barometric pressure sensor, an accelerometer recording accelerations in the X and Z directions, a relative humidity sensor, 2 temperature sensors, one internal and one external, and three Geiger tubes, one of which was an unshielded control tube, and the other two are shielded by .5cm and 1.5cm HDPE, respectively. The shielded Geiger tubes are the ones that
run on the experimental system. All of these sensors are outlined in the Hardware overview section. Overall, Big Gamma received wonderful, accurate, and expected data from all environmental systems sensors. This means that all sensors ran as predicted and recorded data that they were predicted to record. Essentially, Big Gamma will be able to understand each step of the data that the Geiger Counter’s data and apply that to understand that specific data and make conclusions about the mission.

*Humidity*

![Humidity Graph](image)

*Figure 36* Plot of Humidity versus time displaying key events.

Overall, humidity from Big Gamma’s humidity sensor almost perfectly matched the data shown for humidity in the expected results section. Measured here is relative humidity, which is the percentage of moisture in the atmosphere. Relativity Humidity sharply dropped shortly after launch and slowly rose while the craft was in the tropopause before dropping sharply at burst. It then rose sharply after conditions during descent became calmer. Relative Humidity continued to rise until landing, which was at approximately 116 minutes. It then decreased to 60% before being recovered by Big Gamma. Compared to Big Gamma’s expected results, humidity recorded during flight is almost identical up until landing. Humidity at launch was about 35%, which matches with expected results. The minimum relative humidity, about 5%, also matched expected results for relative humidity. Before landing is where the data from Big Gamma’s flight deviates from expected data. As seen in the graph above, relative humidity reached a maximum of approximately 80% at time of landing, before dropping to approximately 58% at recovery.

The humidity recorded during flight was significantly higher than expected. The maximum humidity reached in the expected results was 52%, which was at landing. This figure decreased
to 28% at recovery. Although launch conditions with respect to relative humidity were quite normal, the data shows that humidity at landing was significantly higher than what is shown in the expected results. This could be attributed to the fact that Big Gamma had a shorter flight than previous EOSS (Edge Of Space Sciences) flights, and therefore landed earlier in the morning when humidity was higher before the sun evaporates most moisture on the ground.

**Pressure**

![Pressure Graph](image)

Big Gamma has found that barometric pressure is the most accurate way to determine the times at which the craft launched, reached burst, and landed. This is due to the fact that the pressure readings do not ‘jump’, such as in the accelerometer and temperature sensors. As a result, a smooth curve is given when the data is plotted. The barometric pressure, according to the data, was 12.3 psi at launch, and was almost the exact same at landing. Pressure reached a minimum of .5psi, at burst, before it sharply rose during descent to 12.3psi at time of landing, 116 minutes after launch. The data also show that ascent rate was, on average, slower than descent rate. This is given by the slopes of the curve before and after burst. This analysis makes sense because the craft descends quicker than it ascends during flight.
**Acceleration**

Big Gamma’s accelerometer recorded accelerations in the X and Z directions, where the black line in the graph above is the X direction and the green as the Z direction. The most erratic portions of the graph are launch and burst. Launch is at the very beginning of the graph, where the spike occurs as the craft is lifted into the sky. Up until burst, acceleration remains almost zero, because there is almost no net force on the box during ascent. At burst, and during whip, the craft experienced enormous accelerations. Burst is where the enormous spike occurs in the middle of the graph. Acceleration readings do not subdue until the craft lands due to the fact that it is constantly moving and being whipped around during descent. During burst, the craft experiences a maximum of 4 g’s in both the X and Z directions. Compared to expected results, Big Gamma’s craft experienced significantly greater accelerations at and after burst, and during descent. The expected data show a maximum of only 1 g in the X and Z directions compared to Big Gamma’s 4. This stark difference in maximum and average g-force tells Big Gamma that burst, whip and descent were extremely violent. Supporting this claim is the discovery at recovery that the cable connecting the GPS beacon on the bottom of the Launch Vehicle to the top of the vehicle had snapped.

*Figure 38* Plot of Acceleration versus time displaying key events.
The data recorded during flight for internal and external temperature closely matched expected results. Approximately 25 minutes into the flight, the payload enters a very brief stage of tropopause. Shortly after the craft enters the stratosphere at approximately 10km and external temperature steadily rises until burst. The absolute minimum temperature recorded was -59.1°F, which is a few degrees below the expected minimum external temperature. The external temperature increased to approximately -15°F at 80,161 ft when burst occurred. The temperature then sharply dropped to approximately -50°F. Temperature then sharply rose until landing. The external temperature at launch was 31°F and 61°F at recovery. This means that the BalloonSat experienced a relatively typical ascent and descent, with no particular outliers or unexpected deviations in external temperature. This is further supported by the fact that the external temperature closely matches expected external temperature, from the expected results section. With respect to internal temperature, this did not reach quite the low temperature Big Gamma originally expected, which is a good circumstance, since Big Gamma is aware that the Geiger Tubes are susceptible to low temperatures (will be discussed at length in failure analysis).

The absolute minimum internal temperature recorded was -1.1°F, though this was only for a very brief period. Big Gamma was originally hoping to be able to determine the approximate time at which the heater ceased to function based on the internal temperature. Unfortunately, this is nearly impossible to tell based on the data recovered due to the fact that there is no clear indication as to when this may have occurred. However, based on previous cooler testing and the data received from these tests, Big Gamma can estimate that the heater most likely ceased to
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function between 1 and 1.5 hours into the flight, since this is how long the heater lasted during both three hour cooler tests. This is because temperature was kept relatively constant during the tests and there is a clear indication as to when the heater stopped functioning in both tests.

**Geiger Tubes**

*Control & .5cm Shielded Tubes*

This section is unique due to the fact that two of the three Geiger Counters returned zeroes for a significant portion of the flight, or about 80% of the time the Geiger Counters recorded data.

![Graph of CPM from control and .5cm Shielded Geiger counters versus time displaying key events.](image)

**Figure 40** Plot of CPM from control and .5cm Shielded Geiger counters versus time displaying key events.

Depicted here is the data for Big Gamma’s control Geiger tube, the one that had no shielding, and the Geiger tube that had .5cm shielding. Unfortunately, as one can quite obviously see, both these tubes constantly returned zero cpm 20 minutes into the flight, until about 13 minutes after landing, when both tubes began to return values other than zeroes, but the data after this point made no sense, due to the enormous spike in cpm recorded almost 10 minutes after the tubes started reading values other than zero again. Please note that this failure will be discussed at length and in great scrutiny in the next section, failure analysis. However, there is data to be extracted from the first 20 minutes, when accurate data was being recorded. Data recorded just before launch, given the limited amount of time cpm were recorded on the ground before launch, indicate that both tubes were recording the expected cpm at ground level, approximately 35 cpm, as expected. Big Gamma has also taken note that both tubes show an increase in cpm recorded as the Balloon ascended right before both tubes started returning zeroes. The maximum recorded
before this occurred was 124 cpm, from the .5cm shielded tube. Interestingly enough, the shielded tube recorded noticeably higher counts than the control tube during this time that both tubes were returning cpm other than zero. Based on the data, one can conclude that the .5cm shielded tube actually recorded more cpm than the control tube, and the .5cm shielded tube actually did the opposite as expected. However, due to the major failure of the tubes to record values other than zero for 80% of the flight, it is very difficult to make any sort of conclusion of this matter since there is a very big possibility that the external factor that caused both tubes to return zeroes also affected the tubes before this also caused this phenomenon where the .5cm shielded tube actually experienced greater cpm than the control tube.

1.5cm Shielded Tube and Control Tube

![Graph of Radiation Rates during Flight](image)

**Figure 41** Plot of CPM from Team1’s control Geiger data and 1.5cm Shielded Geiger counters versus time displaying key events.

Fortunately, Big Gamma did retrieve excellent data from the 1.5cm shielded tube from the entire duration of the flight. Unlike the other two tubes flown, the 1.5cm shielded tube did not return zeroes for any portion of the flight. This data has been specifically plotted against control tube data to analyze the extent to which this shielding is effective against radiation from the gamma to x-ray spectrum. Although the control tube on Big Gamma’s flight returned zero cpm for 80% of the flight, Team 1, Ozone Express, graciously and generously permitted Big Gamma to use the data from their control Geiger tube, which also recorded excellent data. Big Gamma can use this data because Ozone Express used the same Geiger Tubes that Big Gamma used. However, instead of recording counts every 15 seconds, as Big Gamma did, Ozone Express’s code was set up so that cpm was recorded every 60 seconds, so there are ¼ as many data points for the control tube as there are for the 1.5cm shielded tube. Here is where Big Gamma will analyze the data that it originally set out for in order to reach conclusions and fulfill its original mission statement.
and objectives. Originally, Big Gamma set out to use data from both .5cm and 1.5cm tubes to reach conclusions about the effectiveness of HDPE as a radiation shield, but unfortunately the .5cm shielded tube data is not usable in this circumstance due to aforementioned reasons.

At launch, one can clearly see that the 1.5cm shielded tube in fact recorded higher cpm on average than the control tube. After launch and as the payload ascended, both tubes recorded approximately equivalent cpm, which is bizarre, since Big Gamma expected that the 1.5cm shielded tube would actually receive significantly lower cpm than the control tube. Approximately 40 minutes into the flight, readings of cpm for both tubes begin to plateau, and continue to do so for another 36 minutes. Finally, after the plateau ends and cpm recorded dips back down as the payload descends; recorded cpm for both tubes is approximately the same until landing. Cpm recorded at launch and after landing, on average, are the same, which is consistent with what was expected. Now is an appropriate time to calculate the attenuation coefficient for the 1.5cm HDPE shielding, given by the equation $I = I_0e^{-\mu r}$. Since the control tube only has $\frac{1}{4}$ the data points as the 1.5cm shielded tube, calculating the attenuation coefficient only used values taken at the same time for both tubes. The attenuation coefficient, using these values, is .0049 cm$^{-1}$. The average difference between the values of cpm recorded between the control tube and the shielded tube is 10.1391 cpm. What this means for Big Gamma is that although the 1.5cm shielded tube was successful in the notion that it did record lower cpm than the control tube, it managed an average difference of 10.1391 cpm less.

### 9.2 Failure Analysis

One of the Gateway to Space requirements was to ensure that the BalloonSat would remain at an internal temperature of -10 degrees Celsius or higher. Team Big Gamma recorded a lowest temperature of -18 degrees Celsius. This failure is due to the heater not being able to last the whole flight. In order to fulfill the mission requirement of keeping the BalloonSat above -10 degrees Celsius, Big Gamma will install a second heater and more insulation. The second heater will help keep the box warm longer. The extra insulation will help keep the heat within the box and prevent the box from getting cold very quickly.

The second failure for the Brooklyn Project, was the .5 cm shielded Geiger counter and the Control Geiger counter recorded a value of zero counts per minute after 20 minutes into the flight until the end of flight. Temperature change is able to drastically effect the accuracy of a Geiger tube\textsuperscript{11}. Around 20 minutes into flight the internal temperature of the BalloonSat began to decrease dramatically. Big Gamma was able to conclude that the two Geiger counters recorded zeroes during the flight due to a drastic temperature drop.

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In order to prove that temperature was the reason for the two Geiger counters shutting down, team Big Gamma made an attempt to duplicate the results of the flight by doing some ground testing. In order to prove that the failure was due to temperature Big Gamma placed the Geiger tube directly on dry ice. The Geiger tube would transition from room temperature and suddenly be placed on the dry ice to simulate a dramatic temperature change. As expected, the Geiger counters returned zero when the temperature change was drastic. After some time on the dry ice the Geiger counters were taken off and left at room temperature to show how the Geiger Counter recovers after becoming cold. After these tests Big Gamma was able to successfully conclude that the dramatic temperature drop was the reason for the failure of the Geiger counters.

To fix the failure of the Geiger counters, it is necessary to prevent such a dramatic temperature decrease and keep the box as warm as possible. Big Gamma will install a second heater inside of the BalloonSat to help keep the Geiger counters warmer to ensure they collect accurate data throughout the flight. The second heater will keep the internal temperature higher, and help make sure that the Geiger counters will provide useful values for the majority of the flight. Big Gamma will also add more insulation to the BalloonSat to help prevent the internal temperature from decreasing at such a steep rate.

A particular notion that Big Gamma intended to determine while performing failure analysis was what exactly was happening inside the Geiger Tubes when the drastic temperature changes occurred, causing the tubes to record zero cpm. This is due to the fact that the gas inside the tube becomes significantly harder to excite when there is a drastic temperature drop, meaning that the tubes get significantly lower readings, and in this case zero. As the tube heats up again, the gas becomes very easy to excite, causing the massive spike in readings Big Gamma recorded.
9.3 Conclusions

Team Big Gamma successfully designed, built, and launched a payload to retrieve the scientific as laid out in the Mission Overview. The majority the data collected depicts the environmental conditions during a high altitude flight, as was taken from our environmental system along with the provided balloon shield. In addition, The Brooklyn Project successfully recorded the radiation experienced inside one of the HDPE rods during the balloon flight. This data, along with the control data provided by team Ozone Express, was used in comparing the effectiveness of HDPE at shielding radiation in a high altitude environment.

9.3.1 Environmental System

As shown in the data analysis, The Brooklyn Project successfully measured the experienced internal and external temperature, pressure, humidity and acceleration during flight. As the recorded data is similar to that of other Gateway to Space groups and display the known and expected trends, The Brooklyn Project was able to characterize the conditions experienced during a high altitude balloon flight.

9.3.1 Experimental System

Despite having two Geiger Counters fail during the majority of the balloon flight, team Big Gamma was still able to draw conclusions regarding the effectiveness of high density polyethylene at shielding gamma radiation. Using the control radiation data, acquired from team Ozone Express, team Big Gamma preformed a two sample Kolmogorov-Smirnov Test to compare the shielded and non-shielded distributions. The tested hypothesis was as follows:

\[ H_0: \text{The shielded and non-shielded sets come from the same distribution.} \]
\[ H_a: \text{The non-shielded set is greater than the shielded set.} \]

Performing a one-tailed test with a 95% confidence interval Big Gamma accepts the null hypothesis as the test produced a statistic \( p = 0.3019 \) outside this interval. From this Big Gamma concludes that high density polyethylene was not significantly effective at shielding gamma radiation during the balloon flight. Similarly, the calculated average attenuation coefficient of HDPE found during flight was only 0.005 cm\(^{-1}\) and an average difference between the non-shielded and shielded radiation rates of only 10.14 cpm. This analysis provides strong evidence that HDPE is an ineffective material at shielding gamma radiation and it in itself is not a viable option for shielding aboard spacecraft.

While this evidence is strongly against the use of HDPE as a shielding material, there are some sources of uncertainty that could lead to error in these results. Primarily, because we acquired control data from another team, their process for calibrating and coding was most likely different than ours, which would have lead to a difference in readings. Furthermore, the accuracy of the tubes are limited, especially at high sampling rates, which could have contributed to receiving a different than actual result, had a more accurate tube been used. However, these uncertainties are relatively insignificant in comparison to how similar the data sets are, and would likely not change this result. These uncertainties could be further accounted for by more extensive ground testing with known calibrated high accuracy tubes to see if the result is
replicated. This should be preformed prior to re-flight, in order to see if it is even necessary to repeat the experiment without in-flight failures.

10.0 Ready For Flight

The Brooklyn Project added extra insulation all around the camera to close any gaps in the previous insulation. This will prevent cool air from flooding directly into the BalloonSat. In addition, a secondary heater was added to be in the proximity of the two Geiger tubes that previously recorded no data as a result of rapid change to cold temperatures. These new changes will keep the internal temperature above its goal internal temperature of -10ºC. The warmer internal temperature will prevent a rapid temperature drop and all three Geiger tubes will function properly. All three Geiger Tubes will be run with two heaters in a separate missions test to determine if the internal temperature of the box gets high enough in order to predict whether the tubes would fail during flight or not. If the craft were to pass this test, this would be an indication that the payload is ready for flight. The washers that were part of attaching the flight tube were glued back on with more glue to have them better secured as a part of the BalloonSat. The payload will be wrapped in saran wrap and safely stored in a Russian cave. The payload will be activated just before launch by flipping the switches for the experimental and environmental system, the heater, and one more new switch for the newly installed heater. If the payload is not launched within 6 months it would be wise to check all systems are running, check for any damages, and check the voltages on all batteries before flight. After the Brooklyn Project has passed those three checks, it will be ready for flight.

11.0 Lessons Learned

- The BalloonSat box should be constructed from as few pieces of foam core as possible. Big Gamma’s initial test box was made from six individual pieces, leading to separation of the sides during structural testing. Making the final BalloonSat from one single piece of foam core proved successful, as the box never split at any edges.
- Geiger tubes are very fragile and should be handled with extreme care. While preparing the tubes for insertion into the HDPE casings, the end cap of one tube separated from the tube itself, breaking a wire. In order to not break any more Geiger tubes, the tubes should be held very gently so as to avoid too much force on any part of the instrument. Geiger tubes should be transported carefully in some form of padded container.
- Cooler tests must be done using a correctly sized cooler. To ensure the cooler test is simulating near space temperatures, the cooler must be able to fully seal allowing for very low temperatures. In the future, cooler testing shall be done in a cooler in which the BalloonSat is able to be fully encapsulated.
- Proper amounts of insulation within the BalloonSat must be used in order to reduce the rate of change of the internal temperature. Rapid changes in temperature affect the Geiger counter readings. Big Gamma’s BalloonSat insulation would have been increased had the cooler tests been more efficient. In future scenarios, better cooler testing would have shown more extreme external and internal temperatures leading to additional insulation being added.
- Soldering points or wires which are not insulated can lead to severe problems. In order to prevent shorted circuits, electrical tape, hot glue or any other insulator can be used to cover the exposed metal.
- The hole for the camera lens in the wall of the BalloonSat should be cut in the shape of a circle rather than a square to minimize cold leaks. In the future, the hole could be circular and more insulated.
- Keeping the weight of the BalloonSat within the restrictions set forth should be a focus from the very beginning of the design process. It is very easy to underestimate the weight of all materials, so planning on being underweight from the beginning is advised. If Big Gamma were to build a BalloonSat again, the mission criteria may be rethought in order to reduce overall weight.

12.0 Message To Next Semester

Get started early. Plan to complete your BalloonSat a week or two before launch, as it will be very useful to have extra time when unexpected problems come up. Thorough testing will be helpful to assure a successful mission without any failures. The BalloonSat will weigh more than you expect. If weight becomes an issue think about using lithium ion batteries to save weight, and to prevent having issues with cold temperatures. Only drawback to using lithium ion batteries is a lot of time is required to recharge them (so make sure they are fully charged well before launch). Larger sized payloads will become an issue with heating and weight so try minimizing the size as much as possible. If using Geiger counters, use extreme caution when handling the Geiger tubes. They are very fragile and can easily break. Do your research and know your systems very well. There are many helpful people around and resources to use to help you along the way. Also, on recovery be prepared to drive faster than five miles over the speed limit despite what professor Koehler may tell you. Good luck!