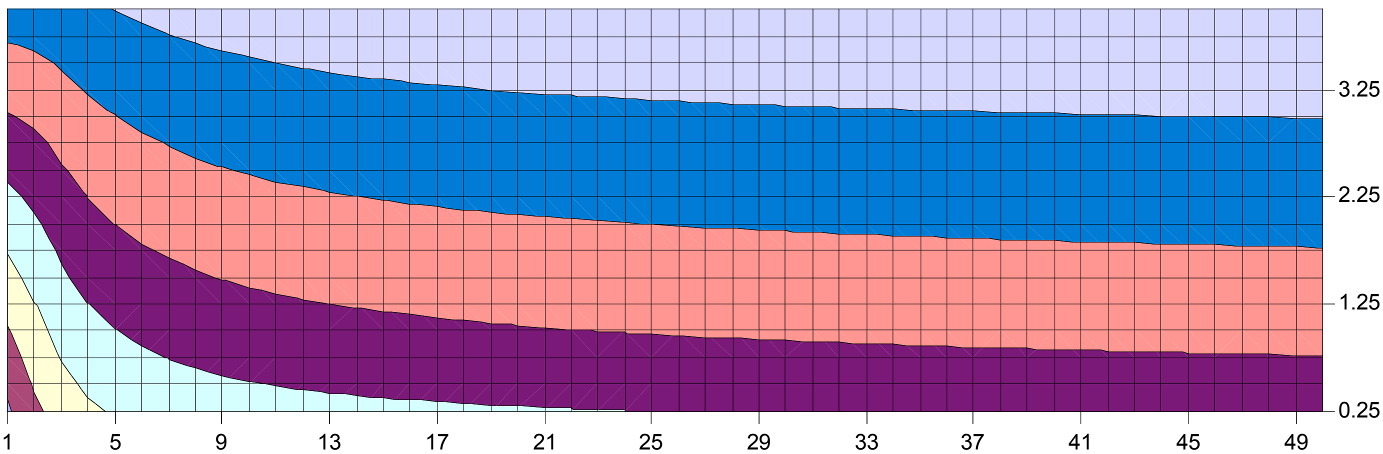
Solar Particle Event Risk Analysis



Joshua Lande

August 2004

School

H-B Woodlawn
4100 Vacation Lane
Arlington, VA 22207

Mentor

Dr. Ronald Turner
ANSER
2900 South Quincy Street
Shirlington, Virginia 22206

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Abstract

NASA wrote a computer program called BRYNTRN3 that calculates the radiation dose received by a person in outer space during a Solar Particle Event. I used and modified this code to analyze the danger of Solar Particle Events. This research will help reduce their risk to astronauts

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1. Introduction

As astronauts venture into outer space, they lose the protection of the Earth. The Earth's atmosphere and magnetic field shield humans from dangerous ultraviolet light and cosmic radiation. Without this protection, humans are exposed to dangerous radiation. Radiation is harmful because it can mutate DNA, resulting in both short-term and long-term damage.

Cosmic Radiation comes in two forms, Galactic Cosmic Rays, and Solar Particle Events (SPEs). SPEs are of particular concern to astronauts because they can deliver large bursts of potentially fatal proton radiation over very short periods of time. In order to ensure the safety of our astronauts, it is necessary to design an effective risk mitigation strategy.

But, in order to minimize the risk of these events, one must fully understand the potential harm they could cause. Therefore, this report will evaluate the danger of SPEs to astronauts in outer space. In order to accomplish this, the theoretical model of an SPE is analyzed, as well as historically bad events.

To aid in this endeavor, NASA created BRYNTRN3, a computer program written in FORTRAN, to evaluate the radiation dose an astronaut would receive under a variable thickness amount of material during several historically significant events, all over a variable duration of time. As well as being used to investigate several historical events, the code was modified in order to analyze theoretical SPEs based on mathematical formulas used to simulate them. The results of this analysis will be important in developing a comprehensive risk management plan for our astronauts.

2. Background Information

2.1. Galactic Cosmic Rays

Throughout the universe, there is an ever-present source of radiation from Galactic Cosmic Rays (GCRs). Originating outside of our solar system, GCRs consist of every natural element, but 90% of its radiation comes from hydrogen and 9% comes from helium. GCRs are high energy but low flux, meaning that the radiation can be quite penetrating, even through thick layers of shielding. Despite its high energy, there is not enough of it to cause short-term harm. The real danger from GCRs is from long term exposure, which can cause delayed effects over long periods of time. Long-term radiation harm can include sterility and cancer.

2.2. Solar Particle Events

Radiation can also come from Solar Particle Events (SPEs) that are quite different from GCRs. SPEs can cause great short-term danger to astronauts in outer space because they are relatively short lived and can deliver a very high fluency (number of radioactive particles). Therefore, SPEs could easily lead to severe short-term radiation damage such as nausea and vomiting.

SPEs are primarily proton radiation emitted from the sun. The National Oceanic and Atmospheric Administration defines a SPE as a period of time when the integral flux of protons with energy greater than 10 MeV exceeds 10 particles/s-cm^2-sr. Typical cosmic radiation is in the realm of 1 particle/s-cm^2-sr. SPEs can be characterized by an increased flux in the order four or five magnitude within a few hours. They can last tens of hours with an exponential decline in flux after the peak.

It was previously thought that SPEs were caused by solar flares, but now it is becoming accepted that larger ones are caused by the shock created during fast coronal mass ejections (CMEs). CMEs are large releases of mass from the sun. A CME can discharge between 10^{14} and 10^{16} grams of mass into space at speeds of 1,500 km/s. The ejection causes a shockwave that pushes protons at high speeds into the solar winds. These protons (as well as some other particles) are what create SPEs.

The frequency of solar particle events varies with the solar cycle, but there can likely be ten to twenty significant SPEs within a ten-year cycle with up to four being able to cause potential harm to astronauts. Because of the potential danger of SPEs, proper steps must be employed to ensure the safety of our astronauts.

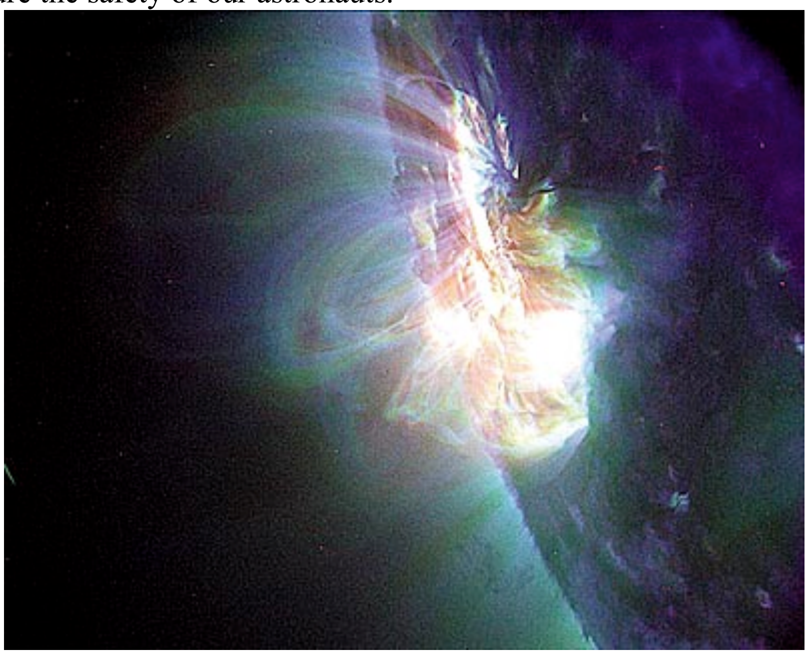

Image 1: A fast coronal mass ejection[1]

2.3. Harm from Radiation

Radiation dose is defined as the amount of energy absorbed by an amount of mass. The standardized unit of dose is a gray. One Gray is defined as one Joule of energy absorbed by one kilogram of mass. Because certain types of radiation can be more harmful than others, a new unit was formed, the Sievert (Sv). It measures the dose equivalent. The dose equivalent equation includes a quality factor that accounts for the difference in harmfulness of various types of radiation. The more common unit is centiSievert, one one-hundredth of a Sievert. The general equation is:

Dose Equivalent = Dose x Quality Factor

Through detailed research, certain legislative and biological limits have been determined concerning the amount of radiation that a person can safely withstand. Legislative limits are in

[1] Found at www.stardate.com

the form of monthly limits, annual limits, and career limits. These are limits that should never be exceeded by an astronaut, but they are also very conservative. Furthermore, NASA works off of the ALARA principal: As Low As Is Reasonably Achievable. This states that any steps that can reasonably be taken to lower the radiation dose received by a person should be taken. The National Council on Radiation Protection (NCRP) has stated that a 30 day radiation limit to the Blood forming organs should be 25 cSv, the annual limit should be 50 cSv and the lifetime limit varies depending on gender and age, but ranges anywhere from 100 cSv to 400 cSv. These limits are intended to minimize the increased risk of cancer to an acceptable level. Although there are more recent limits, they are not significantly different and use units incomparable to the output of BRYNTRN. Therefore, these slightly obsolete numbers are used instead.

In addition to legislative limits, there are biological limits to the amount of radiation someone can withstand. Biological limits are what your body would actually withstand when exposed to radiation. Here is what the Medical Management of Radiological Casualties Handbook has determined to be accurate biological limits.

•35 – 75 cGy:
  Nausea; mild headache
•75 – 125 cGy:
  5 to 30 % experience nausea and vomiting within 3 to 5 hrs
•125 – 300 cGy:
  20 to 70 % experience nausea and vomiting within 2 to 3 hrs
  5 to 10 % probability of death with no treatment
•300 – 530 cGy:
  50 to 90 % experience nausea and vomiting within 2 hrs
  10 to 50 % probability of death with no treatment
•530 – 800 cGy:
  50 to 90 % mild to severe nausea and vomiting within 2 hrs
  50 to 90 % probability of death with no treatment

Unfortunately, these units are in centiGray (cGy), not centiSievert. These are the only limits that are currently available, and are somewhat comparable to measurements in centiSievert. Therefore, we will assume for the rest of this report that these numbers are equivalent to cSv in order to make comparisons.

Remember that if an astronaut were to vomit within a space suit, they would likely suffocate to death. Therefore, the point at which an astronaut vomits is very important.

2.4. About BRYNTRN

BRYNTRN is a computer program written in the programming language FORTRAN70. It was created to simulate the effects of cosmic radiation on astronauts. It takes in a varying input spectrum of charged proton particles and simulates those particles going through a variable thickness amount of aluminum (a typical shielding material). The program determines the radiation as it diffuses through the aluminum, and the resultant particles created as the aluminum breaks down. It can then calculate the type and number of particles that exits the aluminum, and from that the total radiation a person would receive.

This program is also smart enough to simulate the radiation going though every angle of the person's body. It can finally decide the dose equivalent that a person should be exposed to. The dose equivalent is given in centiSievert (cSv) and can then be used to compare to biological as well as legislated radiation limits. BRYNTRN can also do these calculations over a large period of time and it gives many different doses per hour. Unfortunately, due to the inherent uncertainty in measurements and calculations, this program is only accurate to within 20% of the actual dose.

3. Using BRYNTRN

3.1. The Input Spectrum

During an SPE, there is a varying energy of particles. Every proton can have different energy levels, or speeds, measured in MeV, Mega Electron Volts. This varying distribution of particles over the change in energy is what creates the energy spectrum for a SPE. This spectrum also varies over time. Here is an example of the particle spectrum for the August 72 SPE, an event which will be covered more later:

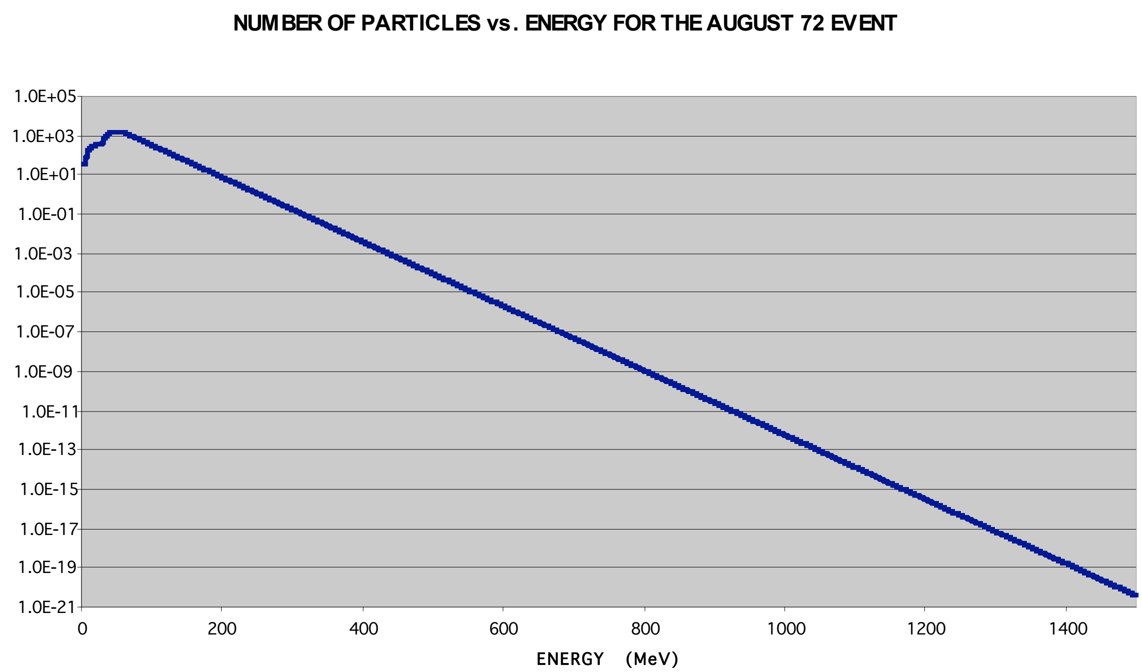

Figure 1: An Example Particle Spectrum

BRYNTRN has two different ways of creating the input spectra. One is by generating a particle spectrum in five MeV step increments going from 1 to 1500, for particles of energy 1 MeV through 1500 MeV. The program places all 300 numbers into the file INSPEC.DAT, and reads them from the file later, reconstructing a new curve to that data. This method is used by default to calculate the August 72 SPE which it has hourly data for. A sample INSPEC.DAT is in appendix B. The other method is reading from the code a curve that represents the entire spectrum, and using that code to do the calculations. This second method is used to calculate several historical events' total radiation dose.

3.2. The August 72 Event

BRYNTRN requires two input files to run. One is CAM1.DAT, which holds the many different thickness for different angles of the radiation. The other file is ATOMIC.DAT, which stores information on the breakdown of proton radiation within aluminum. Given this information, BRYNTRN, when initially run, will try to simulate the August 72 SPE. The August 72 SPE was chosen because of its particular severity and brevity. Here is the initial display:

```
THERE ARE 240 HOURS OF SPE DATA FOR AUG. 1972,
AT THE RATE OF ONE DATA POINT/HOUR. YOU MUST INPUT
THE RANGE OF HOURS YOU ARE INTERESTED IN.
THE STARTING HOUR INDEX RANGE IS 1 TO 240 AND
THE ENDING HOUR INDEX IS 2 TO 241
INPUT STARTING & ENDING HOURS
```

When the starting and stopping hours are entered, the program starts to run the simulation. It does so for however many different hours the user wishes. In function RRDFLUX(), the file INSPEC.DAT is filled with a flux calculated based on recorded integral flux data for all particles greater than 10, 30, and 60 MeV. It uses this information to fit an assumed "differential" flux (or flux versus particle energy), and pads INSPEC.DAT with this information. Now, given the input spectrum, the program calculates the dose equivalent. Each dose comes out as follows:

```
0.0  REM   0.107E-01 0.132E-01 0.308E-02
```

The first number is the hour of the event, but for some unknown reason, hour 0 is the number for simulation hour 1, and so on. REM means dose equivalent, and the three following numbers are the dose equivalent which is received by three different parts of the body, the skin, the eyes, and the blood forming organs (BFO) respectively. This information is also placed inside the text file CAMREM.DAT for further access. A sample CAMREM.DAT file and INSPEC.DAT file are in appendix A and B.

A complete run of the entire program will produce 240 different radiation levels, with each level having a dose for the skin, the eye, and the BFO. Each hour takes approximately 3 minutes to run, so running all 240 hours of the event can become quite time consuming. A graph of this data appears as follows. Note the logarithm scale on the y-axis. This is because of the rapid nature of SPEs.

DOSE EQUIVALENT vs. TIME for the AUG 72 EVENT

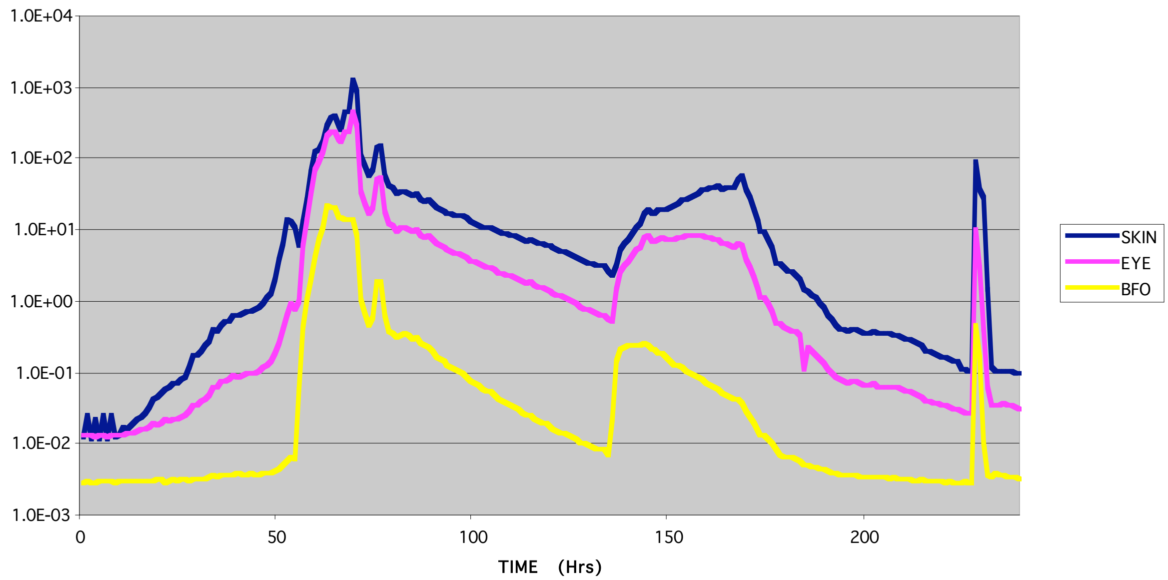

Figure 2: The Aug 72 Event

3.3. Modifying the Aluminum Thickness

Most of the calculations done in this program are controlled by a very large function called BRYNTRN(). BRYNTRN() early on calls the function MATTER() and half way through MATTER() there appears the line

XLAY = 0.3

XLAY is the variable that controls the thickness of the aluminum. Its units are grams/centimeter^2 (G/CM^2). 0.3 G/CM^2 would be a typical thickness for a space suit, so it is the default value, and also the value used in the section above.

But astronauts do not necessarily always have the same amount of protective shielding while in outer space. Therefore, it is necessary to run BRYNTRN using different thicknesses. 5 G/CM^2 would be a typical thickness for a pressure vessel. 10 G/CM^2 would be a standard thickness for the equipment room of a space ship, and 30 G/CM^2 would be a reasonable thickness for a radiation shelter. By running BRYNTRYN with a value of 0.3, 5, 10, and 30, one can compare the effect of different thicknesses of shielding on the radiation dose. This can help in determining appropriate shelter during an SPE. Note that G/CM^2 is not the actual distance through the material. To find the actual distance, one would have to divide the density of Aluminum (2.7 G/CM^3) into the thickness measurement. This would produce the length in centimeters.

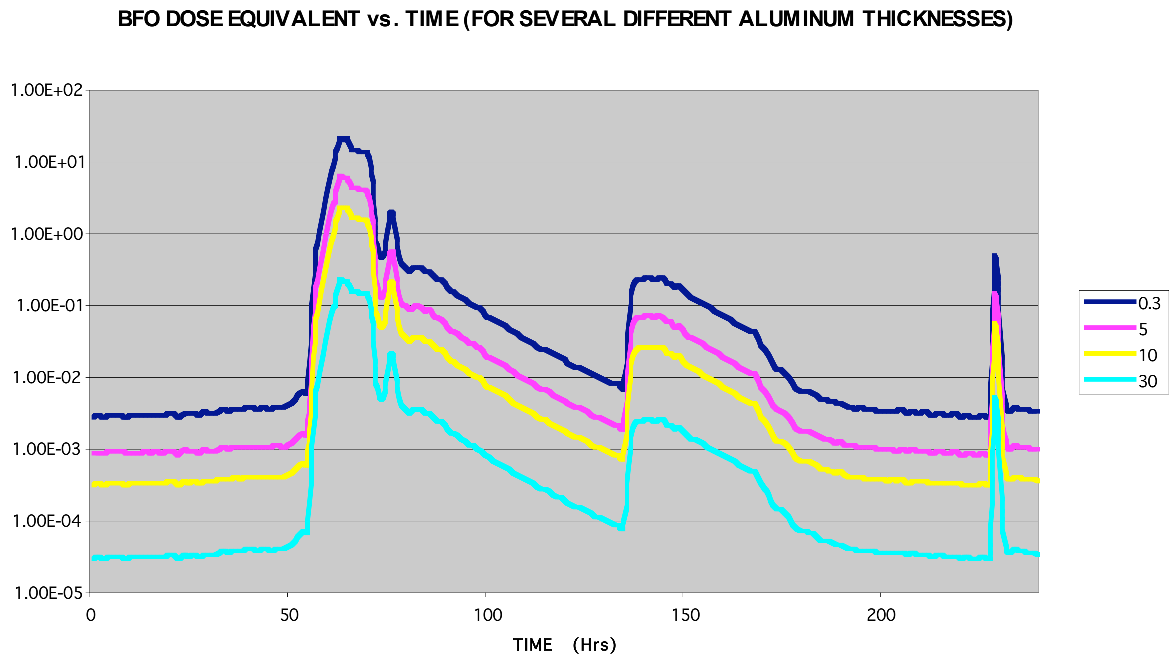

Figure 3: Dose vs. Time for Different Thicknesses

3.4. How Dangerous Was the August 72 Event?

To analyze the danger of the August 72 SPE, below is a somewhat complicated, but very useful graph. This graph's x-axis is time, and its corresponding y-axis is the largest possible dose that could be received by a person during that amount of time. This allows the maximum dose one could receive to easily be determined depending on the length of exposure desired. Layered over the graph are the legislative and biological limits discussed earlier. This chart can therefore show what the largest total amount of radiation that a person could receive is over a given period of time. This graph is BFO dose equivalent with a 0.3 G/CM^2 aluminum thickness.

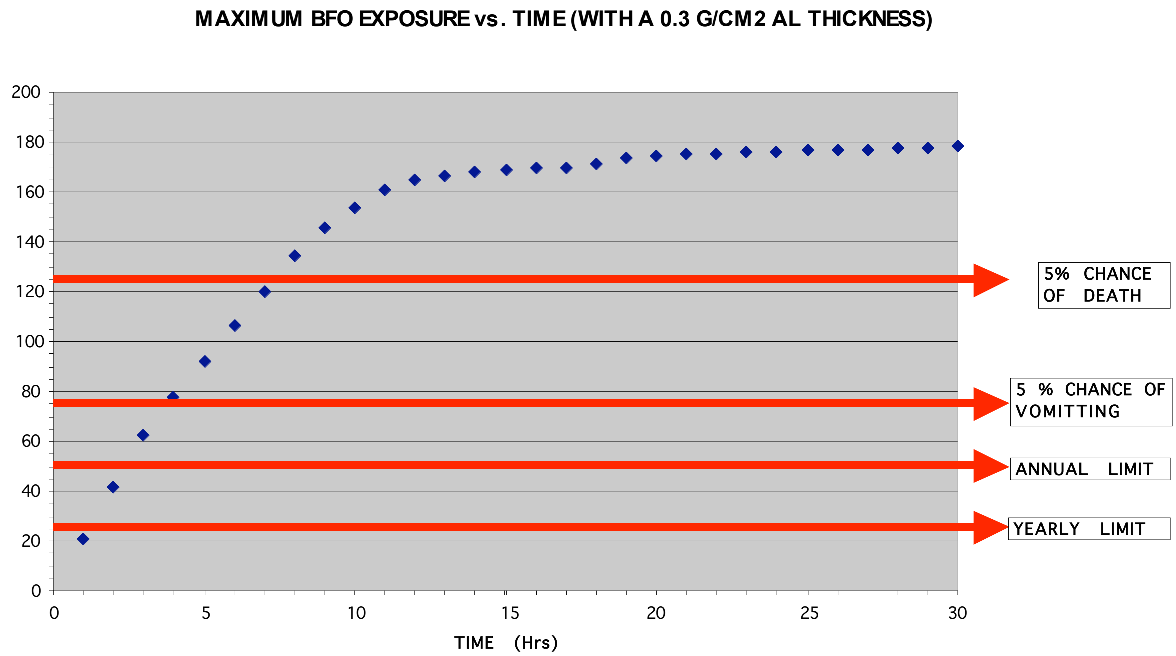

Figure 4: Worst hours of event

What should be taken from this chart is that exposure to only a few hours of a SPE can cause fatal damage. Even though a SPE can occur over many days, almost all of the actual damage occurs over a very short period of time. For example, if an astronaut, under little shielding, were to be exposed to this particularly harmful event during its peak, they would have a five percent chance of vomiting (which could become fatal) after only 5 hours. Unfortunately, an astronaut could very easily become exposed to radiation during a time frame like that. Therefore, This information helps to emphasize the actual danger of SPEs and the real need to protect astronauts.

4. The 7 Historical Events

In addition to the first way of creating an input spectrum using the function RRDFLUX(), BRYNTRN can also construct the flux in a function called SPECTOR(). The reason for having two ways of calculating flux is because SPECTOR creates the flux based on a curve. This curve is of the entire event's fluency, not only of an hour. Therefore, the dose given from a simulation done the second way is the dose received during the entire SPE. In order to switch to the second mode, the variable IFIELD in the main program must be changed from 3 to 2.

This method has been used to simulate 7 historical SPEs. These events are titled FEB 56 LARC SPE, NOV 60 LRC SPE, AUG 72 LARC SPE, AUG 72 KING SPE, AUG 89 SPE, SEP 89 SPE, OCT 89 SPE respectively. Notice that there are two spectra for the AUG 72 event. Here is an example of what the code looks like. This one is the curve of the AUG 89 SPE event.

```
SPECTRA=(86520000000/59.261)*EXP(-SQRT(E*(E+1876.))/59.261)*(E+938.)/SQRT(E*(E+1876.))
```

Here is a graph of spectra for the 7 historical events

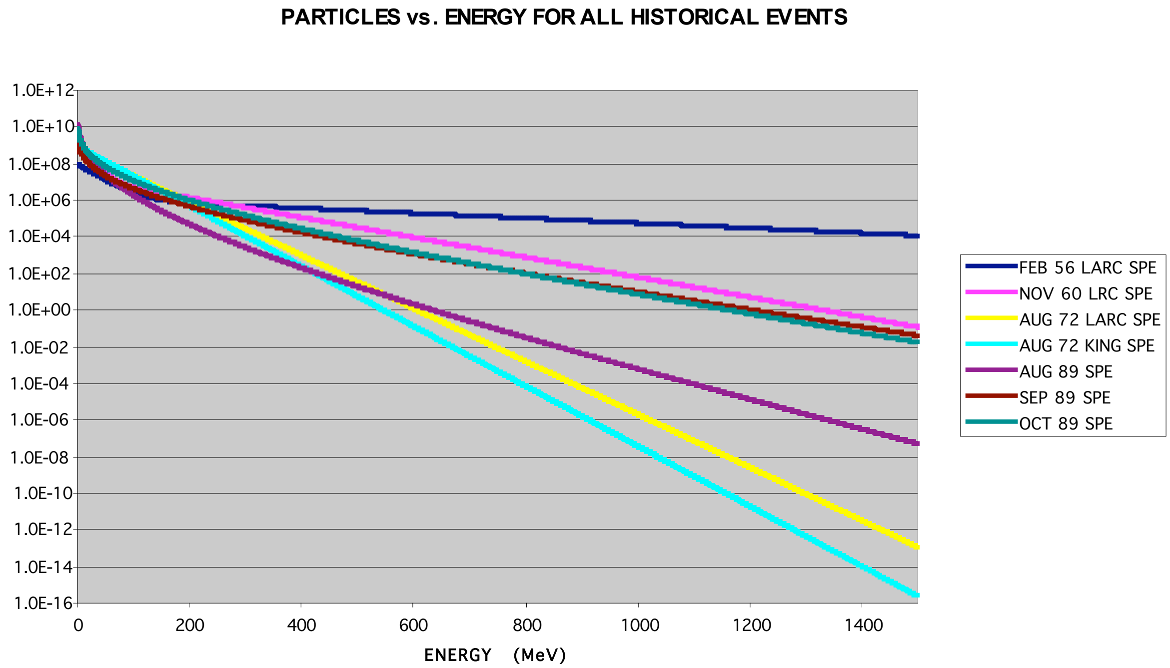

Figure 5: Spectra For All Historical Events

In the main program, the variable ISPEC controls which event is used in the simulation, so to run the FEB 56 event would require the statement ISPEC=5.

The output of a historical event looks just like the output from the first way of running the code except the simulation produces total radiation over the entire event instead of radiation per hour.

The graph below shows the integral fluency (total event dose equivalent) for all seven historical events. For each grouping, there are the four different thicknesses.

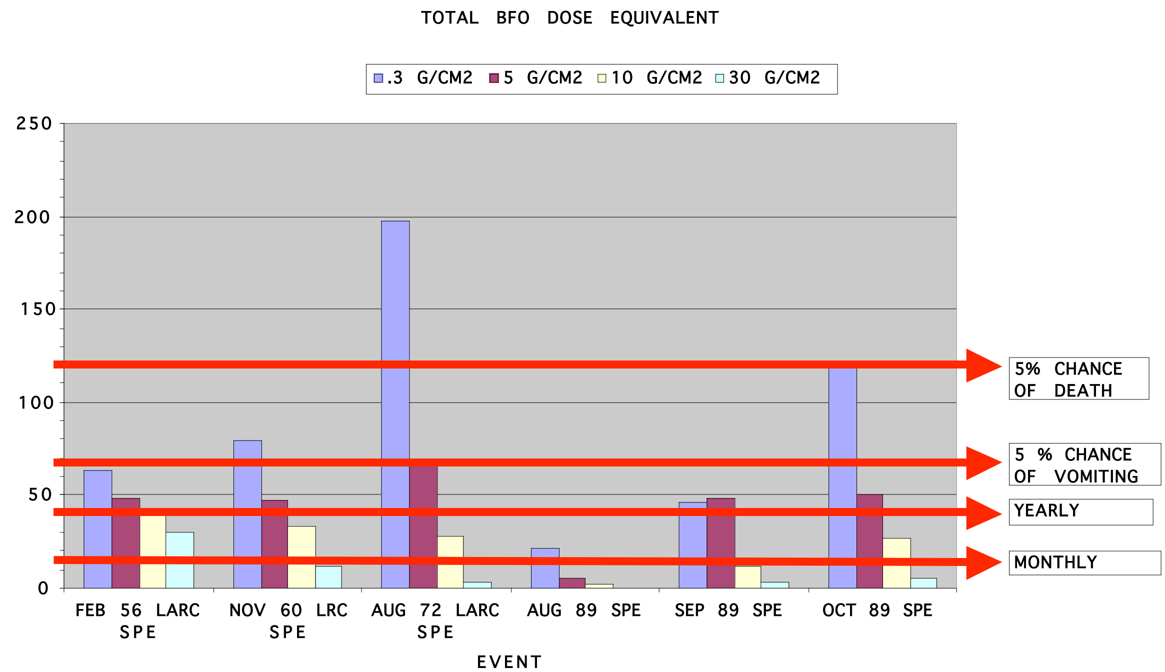

Figure 6: Dangerousness of the 7 Historical Events

This graph makes it apparent that the August 72 event was much worse than many other historically recorded SPEs, but it also shows that many other events have clearly exceeded safe limits. With this historical reference, it is easy to see that SPEs can be quite hazardous.

5. Analyzing a Theoretical Event

5.1. The SPE Curve

The Spectrum of all SPEs can be approximately represented by the curve that follows:

$$SPECTRUM(ENERGY) = K \times ENERGY^{-GAMMA} \times e^{-\left(\frac{ENERGY}{ENERGY_0}\right)}$$

This general equation should be able to represent the flux for any event, even though in actuality this is not always the case. In this equation, the spectrum varies depending on the three constants. The first constant is K, which is a skinners constant; it scales the curve up or down. The other two constants, Gamma, and $Energy_0$ (E0) can change the actual shape of the spectrum. By moving the three values around, one can usually find a curve that mostly fits an actual event. For example, looking at the AUG 89 SPE (the same one used above), the following curve matches it very closely.

$$\text{SPECTRUM (E)} = 170000000000 \times E^{-2} \times e^{-\frac{E}{50}}$$

With K=170000000000, Gamma=2, and E0=50, one gets a curve which looks very similar to the actual spectra, and also produces a very similar radiation output. The Spectral graph of these 2 curves is shown below.

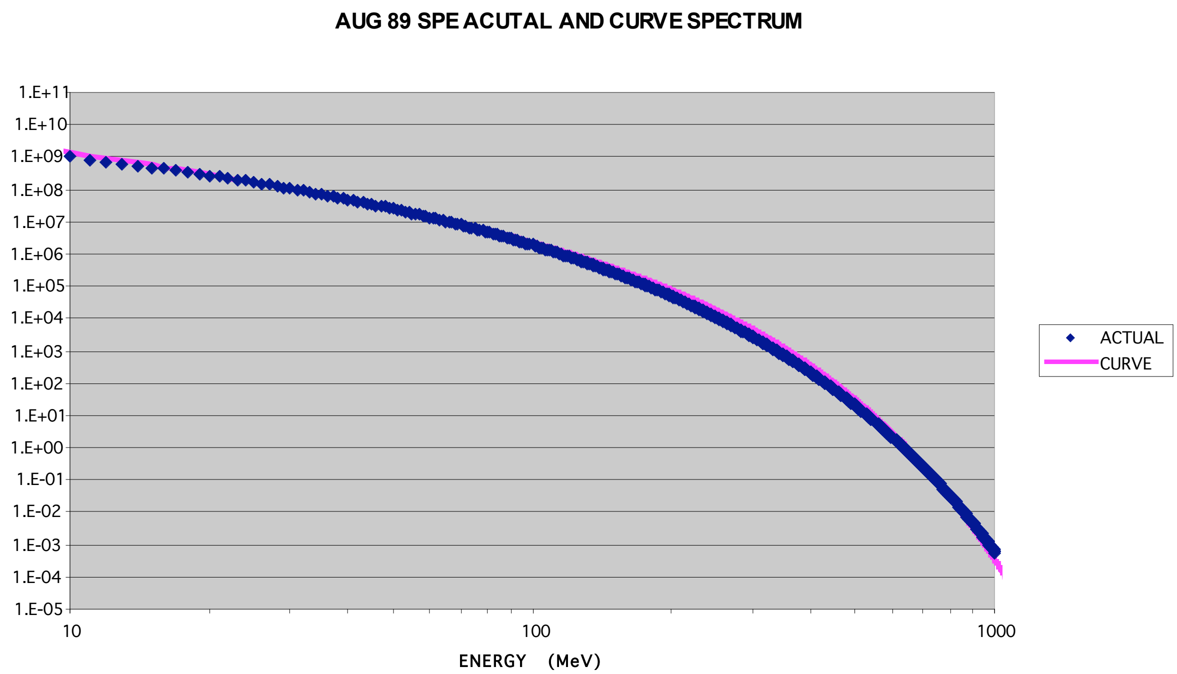

Figure 7: A Curve Fit to an Actual SPE Spectrum

With a thickness of 0.3 G/CM^2, the BFO dose output for the original curve is 3390 cSv and for the new fit curve is 3360 cSv. Note that these curves are created in the historical part of the code; this is different from the modifications below.

5.2. Modifying RRDFLUX()

In order to determine the dose output for every theoretical event (based on the Gamma and E0), BRYNTRYN needed to be modified. Function RRDFLUX() was changed in order to create an ideal input spectrum based on the variable Gamma and E0. Instead of the 1500 element spectrum being filled with the august 72 SPE, it was filled based on the above formula. K, Gamma, and E0 were variables passed to it by the main program. The most important line of the new function appears as follows:

```
PHIE(LOOP)= REAL(LOOP)**(-GAMMA)*2.71828183**(- LOOP/E0)
```

Using this formula, we can apply different E0s and different Gammas to the program and see how different spectral shapes produce different radiation outputs.

But there is no point in comparing different gamma and E0's yet because the total particle flux (number of particles) changes when E0 and Gamma change. In order to ensure that the total number of particles stays constant when there are different E0 and Gammas, one needs to normalize each curve so that the total number of particles over a certain energy level is the same. First one must decide what that normalization number should be. A simple number turns out to be one. Second, one must decide at what value to normalize the curve from. Because different particle ranges can be more or less effective at causing damage to different parts of the body, the range of particles to include in the normalization should be left as a variable. Therefore, the new code works by having a variable NORMALIZEFROM, which normalizes the graph so that the total number of particles above that energy value has a total of 1. The code to do the normalization looks like this:

```
SUMOFPHIE=SUM( PHIE(NORMALIZEFROM:IENG) ) !calculate sum

DO LOOP=1, IENG, 1

    PHIE(LOOP)=PHIE(LOOP)/SUMOFPHIE

    IF (PHIE(LOOP) .LT. 10.**(-17) ) PHIE(LOOP) = 10.**(-17)

END DO
```

The IF statement ensures that no value is 0, making every number at least 10^{-17}. This flux will not noticeably affect the output. Instead, it ensures that underflow issues and logarithms of 0 do not occur later on.

With this code in place, effective simulations can be run using different normalizations of reasonable Gamma and E0. Note that the code effectively uses a different K for each run.

Having to run hundreds of different data points (taking minutes each) for every desirable normalization becomes incredibly time consuming. It is with that in mind that the line of code PHIE(LOOP)=PHIE(LOOP)/SUMOFPHIE was removed from the code. This removed the normalization from the code, which creates a situation where K equals 1 for every value.

As mentioned above, this makes it difficult to compare results because different SPEs have different total number of particles. To fix this, essentially the same normalization as before was done, but instead to the dose equivalent output after the code had run.

This was done in Microsoft Excel using a fairly straightforward algorithm. First it sums up every value of K*E^-GAMMA*e^-E/E0 for E between the normalization number and 1500. Then, the dose equivalent is divided by that sum. This is done separately for each dose. This algorithm produces almost identical results, but in a very short period of time. The RDDFLUX() function used to create a general curve (without a normalization) is presented in appendix C, and the Excel macro to normalize that dose is presented in appendix D.

A three dimensional contour graph of a sample output is shown next. It contains the dose equivalent for all spectrums with a Gamma between 0.5 and 4, and an E0 between 10 and 500. The thickness used is 10 G/CM^2, and the graph has every dose normalized for all particles greater than 30 MeV to equal 1.

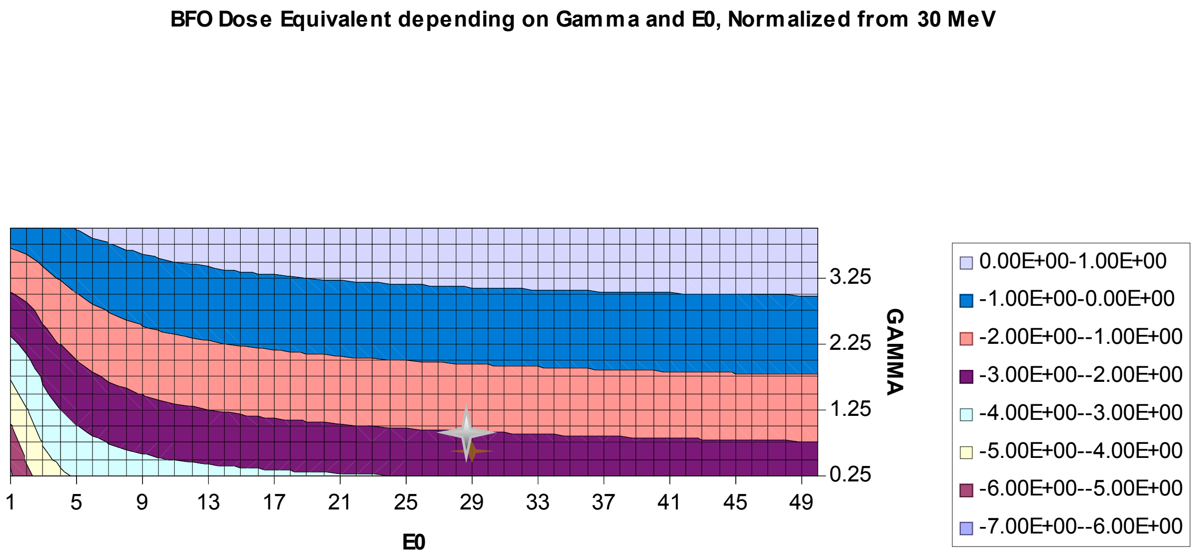

Figure 8: Gamma and E0 vs. Dose

This graph (along with others) can be very useful, especially in future research. One can discern many different things from it. For example, it was discovered that a close fit to the Aug. 72 event would have a Gamma of 0.5 and an E0 of 30. Looking at this point marked on the graph, one can discover that the Aug. 72 event could have been several orders of magnitude less or more harmful depending upon the distribution of it's particles.

6. CONCLUSION

The purpose of this report was to analyze the danger of SPEs. This report was successful because it showed that SPEs could be a serious threat. We cannot overlook them because they can cause real harm to and even kill astronauts.

In addition to researching historical SPEs, the generic model of an event was analyzed. With these radiation maps, which vary depending on the values of Gamma and E0, one can see that the particle spectrum affects the radiation dose. This is a very important conclusion, but this report only lays down the groundwork for a great deal of research that must be done in the future.

It is with this knowledge that further analysis must be done into SPE forecasting and prediction. Hopefully this report will help in the ultimate goal of ensure the safety and protection of our astronauts on future missions to the Moon, Mars and beyond.

Acknowledgements

I would like to thank ANSER, the George Washington University, and the Science and Engineering Apprentice Program (SEAP) for providing me with this opportunity.

I would like to thank my friends and family for helping me during my summer internship. I would like to give special thanks to my mother, who woke up every day far earlier than should ever be expected of a person in order to drive me to work. I would also like to thank my two fellow interns, Srinivas Gopalan and Andrew Thal, who provided countless hours of support and company over the summer.

I would like to thank John Wilson over at NASA Langley for approving of this project and I would like to thank Francis Badavi at Langley for providing BRYNTRN's source code as well as much technical support.

Most importantly, I would like to express my gratitude toward Dr. Ronald Turner. He gave me this wonderful opportunity to work with him and he made my summer research more fulfilling than I could have possibly imagined.

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Appendices

Appendix A – A Sample CAMREM.DAT File

This is the CAMREM.DAT file for hours 1 to 50 of the Aug. 72 SPE using a shielding of 0.3 G/CM^2:

```
 0.0  REM   0.124E-01 0.131E-01 0.285E-02
 1.0  REM   0.250E-01 0.135E-01 0.293E-02
 2.0  REM   0.118E-01 0.128E-01 0.283E-02
 3.0  REM   0.226E-01 0.126E-01 0.286E-02
 4.0  REM   0.114E-01 0.128E-01 0.300E-02
 5.0  REM   0.246E-01 0.134E-01 0.304E-02
 6.0  REM   0.116E-01 0.127E-01 0.305E-02
 7.0  REM   0.256E-01 0.136E-01 0.299E-02
 8.0  REM   0.126E-01 0.132E-01 0.281E-02
 9.0  REM   0.132E-01 0.134E-01 0.293E-02
10.0  REM   0.171E-01 0.135E-01 0.291E-02
11.0  REM   0.165E-01 0.143E-01 0.297E-02
12.0  REM   0.181E-01 0.141E-01 0.292E-02
13.0  REM   0.189E-01 0.144E-01 0.301E-02
14.0  REM   0.228E-01 0.152E-01 0.292E-02
15.0  REM   0.241E-01 0.158E-01 0.300E-02
16.0  REM   0.276E-01 0.159E-01 0.306E-02
17.0  REM   0.323E-01 0.170E-01 0.297E-02
18.0  REM   0.409E-01 0.191E-01 0.305E-02
19.0  REM   0.448E-01 0.186E-01 0.316E-02
20.0  REM   0.520E-01 0.196E-01 0.311E-02
21.0  REM   0.575E-01 0.218E-01 0.281E-02
22.0  REM   0.610E-01 0.211E-01 0.303E-02
23.0  REM   0.695E-01 0.221E-01 0.326E-02
24.0  REM   0.722E-01 0.227E-01 0.307E-02
25.0  REM   0.788E-01 0.237E-01 0.314E-02
26.0  REM   0.880E-01 0.248E-01 0.314E-02
27.0  REM   0.118E+00 0.295E-01 0.302E-02
28.0  REM   0.178E+00 0.358E-01 0.328E-02
29.0  REM   0.169E+00 0.345E-01 0.313E-02
30.0  REM   0.199E+00 0.389E-01 0.315E-02
31.0  REM   0.235E+00 0.433E-01 0.321E-02
32.0  REM   0.273E+00 0.480E-01 0.337E-02
33.0  REM   0.393E+00 0.632E-01 0.352E-02
34.0  REM   0.370E+00 0.628E-01 0.343E-02
35.0  REM   0.471E+00 0.730E-01 0.358E-02
36.0  REM   0.509E+00 0.766E-01 0.368E-02
37.0  REM   0.530E+00 0.783E-01 0.362E-02
38.0  REM   0.630E+00 0.908E-01 0.371E-02
39.0  REM   0.623E+00 0.876E-01 0.377E-02
40.0  REM   0.633E+00 0.877E-01 0.377E-02
41.0  REM   0.681E+00 0.938E-01 0.368E-02
42.0  REM   0.719E+00 0.967E-01 0.365E-02
43.0  REM   0.738E+00 0.950E-01 0.378E-02
44.0  REM   0.755E+00 0.966E-01 0.371E-02
45.0  REM   0.836E+00 0.104E+00 0.369E-02
46.0  REM   0.941E+00 0.116E+00 0.384E-02
47.0  REM   0.113E+01 0.127E+00 0.389E-02
48.0  REM   0.130E+01 0.140E+00 0.384E-02
49.0  REM   0.198E+01 0.186E+00 0.404E-02
```

Appendix B – A Sample INSPEC.DAT File

This file is the INSPEC.DAT file for hour 1 of the Aug. 72 event

```
TESTING INSPEC.DAT
       300
0.5000E+000.3600E+020.5500E+010.3600E+020.1050E+020.1693E+030.1550E+020.2596E+03
0.2050E+020.3185E+030.2550E+020.3607E+030.3050E+020.4535E+030.3550E+020.9633E+03
0.4050E+020.1281E+040.4550E+020.1456E+040.5050E+020.1526E+040.5550E+020.1523E+04
0.6050E+020.1448E+040.6550E+020.1199E+040.7050E+020.9927E+030.7550E+020.8220E+03
0.8050E+020.6806E+030.8550E+020.5636E+030.9050E+020.4667E+030.9550E+020.3865E+03
0.1005E+030.3200E+030.1055E+030.2650E+030.1105E+030.2194E+030.1155E+030.1817E+03
0.1205E+030.1504E+030.1255E+030.1246E+030.1305E+030.1032E+030.1355E+030.8542E+02
0.1405E+030.7073E+020.1455E+030.5857E+020.1505E+030.4850E+020.1555E+030.4016E+02
0.1605E+030.3325E+020.1655E+030.2754E+020.1705E+030.2280E+020.1755E+030.1888E+02
0.1805E+030.1563E+020.1855E+030.1295E+020.1905E+030.1072E+020.1955E+030.8877E+01
0.2005E+030.7350E+010.2055E+030.6086E+010.2105E+030.5040E+010.2155E+030.4173E+01
0.2205E+030.3456E+010.2255E+030.2862E+010.2305E+030.2369E+010.2355E+030.1962E+01
0.2405E+030.1625E+010.2455E+030.1345E+010.2505E+030.1114E+010.2555E+030.9224E+00
0.2605E+030.7638E+000.2655E+030.6325E+000.2705E+030.5237E+000.2755E+030.4337E+00
0.2805E+030.3591E+000.2855E+030.2974E+000.2905E+030.2462E+000.2955E+030.2039E+00
0.3005E+030.1688E+000.3055E+030.1398E+000.3105E+030.1158E+000.3155E+030.9586E-01
0.3205E+030.7938E-010.3255E+030.6573E-010.3305E+030.5443E-010.3355E+030.4507E-01
0.3405E+030.3732E-010.3455E+030.3090E-010.3505E+030.2559E-010.3555E+030.2119E-01
0.3605E+030.1754E-010.3655E+030.1453E-010.3705E+030.1203E-010.3755E+030.9961E-02
0.3805E+030.8249E-020.3855E+030.6830E-020.3905E+030.5656E-020.3955E+030.4683E-02
0.4005E+030.3878E-020.4055E+030.3211E-020.4105E+030.2659E-020.4155E+030.2202E-02
0.4205E+030.1823E-020.4255E+030.1510E-020.4305E+030.1250E-020.4355E+030.1035E-02
0.4405E+030.8572E-030.4455E+030.7098E-030.4505E+030.5877E-030.4555E+030.4867E-03
0.4605E+030.4030E-030.4655E+030.3337E-030.4705E+030.2763E-030.4755E+030.2288E-03
0.4805E+030.1895E-030.4855E+030.1569E-030.4905E+030.1299E-030.4955E+030.1076E-03
0.5005E+030.8908E-040.5055E+030.7376E-040.5105E+030.6108E-040.5155E+030.5058E-04
0.5205E+030.4188E-040.5255E+030.3468E-040.5305E+030.2872E-040.5355E+030.2378E-04
0.5405E+030.1969E-040.5455E+030.1630E-040.5505E+030.1350E-040.5555E+030.1118E-04
0.5605E+030.9257E-050.5655E+030.7665E-050.5705E+030.6347E-050.5755E+030.5256E-05
0.5805E+030.4352E-050.5855E+030.3604E-050.5905E+030.2984E-050.5955E+030.2471E-05
0.6005E+030.2046E-050.6055E+030.1694E-050.6105E+030.1403E-050.6155E+030.1162E-05
0.6205E+030.9619E-060.6255E+030.7965E-060.6305E+030.6596E-060.6355E+030.5462E-06
0.6405E+030.4523E-060.6455E+030.3745E-060.6505E+030.3101E-060.6555E+030.2568E-06
0.6605E+030.2126E-060.6655E+030.1761E-060.6705E+030.1458E-060.6755E+030.1207E-06
0.6805E+030.9996E-070.6855E+030.8277E-070.6905E+030.6854E-070.6955E+030.5676E-07
0.7005E+030.4700E-070.7055E+030.3892E-070.7105E+030.3222E-070.7155E+030.2668E-07
0.7205E+030.2210E-070.7255E+030.1830E-070.7305E+030.1515E-070.7355E+030.1255E-07
0.7405E+030.1039E-070.7455E+030.8602E-080.7505E+030.7123E-080.7555E+030.5898E-08
0.7605E+030.4884E-080.7655E+030.4044E-080.7705E+030.3349E-080.7755E+030.2773E-08
0.7805E+030.2296E-080.7855E+030.1901E-080.7905E+030.1574E-080.7955E+030.1304E-08
0.8005E+030.1080E-080.8055E+030.8939E-090.8105E+030.7402E-090.8155E+030.6129E-09
0.8205E+030.5075E-090.8255E+030.4203E-090.8305E+030.3480E-090.8355E+030.2882E-09
0.8405E+030.2386E-090.8455E+030.1976E-090.8505E+030.1636E-090.8555E+030.1355E-09
0.8605E+030.1122E-090.8655E+030.9289E-100.8705E+030.7692E-100.8755E+030.6369E-10
0.8805E+030.5274E-100.8855E+030.4367E-100.8905E+030.3616E-100.8955E+030.2994E-10
0.9005E+030.2480E-100.9055E+030.2053E-100.9105E+030.1700E-100.9155E+030.1408E-10
0.9205E+030.1166E-100.9255E+030.9653E-110.9305E+030.7993E-110.9355E+030.6619E-11
0.9405E+030.5481E-110.9455E+030.4538E-110.9505E+030.3758E-110.9555E+030.3112E-11
0.9605E+030.2577E-110.9655E+030.2134E-110.9705E+030.1767E-110.9755E+030.1463E-11
0.9805E+030.1211E-110.9855E+030.1003E-110.9905E+030.8306E-120.9955E+030.6878E-12
0.1000E+040.5695E-120.1006E+040.4716E-120.1010E+040.3905E-120.1016E+040.3234E-12
0.1020E+040.2678E-120.1026E+040.2217E-120.1030E+040.1836E-120.1036E+040.1520E-12
0.1040E+040.1259E-120.1046E+040.1042E-120.1050E+040.8632E-130.1056E+040.7148E-13
0.1060E+040.5919E-130.1066E+040.4901E-130.1070E+040.4058E-130.1076E+040.3360E-13
0.1080E+040.2783E-130.1086E+040.2304E-130.1090E+040.1908E-130.1096E+040.1580E-13
0.1100E+040.1308E-130.1106E+040.1083E-130.1110E+040.8970E-140.1116E+040.7428E-14
0.1120E+040.6151E-140.1126E+040.5093E-140.1130E+040.4217E-140.1136E+040.3492E-14
0.1140E+040.2892E-140.1146E+040.2394E-140.1150E+040.1983E-140.1156E+040.1642E-14
0.1160E+040.1359E-140.1166E+040.1126E-140.1170E+040.9322E-150.1176E+040.7719E-15
0.1180E+040.6392E-150.1186E+040.5293E-150.1190E+040.4382E-150.1196E+040.3629E-15
0.1200E+040.3005E-150.1206E+040.2488E-150.1210E+040.2060E-150.1216E+040.1706E-15
```

```
0.1220E+040.1413E-150.1226E+040.1170E-150.1230E+040.9687E-160.1236E+040.8021E-16
0.1240E+040.6642E-160.1246E+040.5500E-160.1250E+040.4554E-160.1256E+040.3771E-16
0.1260E+040.3123E-160.1266E+040.2586E-160.1270E+040.2141E-160.1276E+040.1773E-16
0.1280E+040.1468E-160.1286E+040.1216E-160.1290E+040.1007E-160.1296E+040.8335E-17
0.1300E+040.6902E-170.1306E+040.5715E-170.1310E+040.4733E-170.1316E+040.3919E-17
0.1320E+040.3245E-170.1326E+040.2687E-170.1330E+040.2225E-170.1336E+040.1842E-17
0.1340E+040.1526E-170.1346E+040.1263E-170.1350E+040.1046E-170.1356E+040.8662E-18
0.1360E+040.7173E-180.1366E+040.5939E-180.1370E+040.4918E-180.1376E+040.4072E-18
0.1380E+040.3372E-180.1386E+040.2792E-180.1390E+040.2312E-180.1396E+040.1915E-18
0.1400E+040.1585E-180.1406E+040.1313E-180.1410E+040.1087E-180.1416E+040.9001E-19
0.1420E+040.7454E-190.1426E+040.6172E-190.1430E+040.5111E-190.1436E+040.4232E-19
0.1440E+040.3504E-190.1446E+040.2902E-190.1450E+040.2403E-190.1456E+040.1990E-19
0.1460E+040.1648E-190.1466E+040.1364E-190.1470E+040.1130E-190.1476E+040.9354E-20
0.1480E+040.7746E-200.1486E+040.6414E-200.1490E+040.5311E-200.1496E+040.4398E-20
```

Appendix C – The RRDFLUX() Code

This is the code designed to create the input spectrum for a curve dependent on Gamma and E0, assuming K=1. The curve is placed inside INSPEC.DAT

```
       SUBROUTINE RRDFLUX(JJJ)
       PARAMETER(IENG=1500)

            REAL GAMMA
            REAL E0

      C
      C     THIS   SUBROUTINE   GIVES   THE   TIME   DEPENDENT   FLUX   RATE
(PROTON/CM2-SEC)
      C   FOR AUGUST 4 AND 5, 1972.
      C
             COMMON/HOURS/HR
             DIMENSION HRX(240),E10(240),E30(240),E60(240)
             DIMENSION
PP1(240),PP2(240),AJ1(240),AJ2(240),WT(240),PT(240)
             DIMENSION E(ieng),PHIE1(IENG),PHIE2(IENG),PHIE(ieng)
             DIMENSION PHIE3(IENG),PHIE4(IENG)
      C
             CHARACTER*80 LABEL
             DATA LABEL/' TESTING INSPEC.DAT'/
      C
      C DATA FOR PROTON ENERGY GRETER THEN 10. MeV.
      C

      C
            DO I=JJJ,JJJ
                  HRX(I)=I-1
            END DO
            DO j=1,IENG
             E(J)=float(j)-0.5

            END DO

      C     Get gamma
            OPEN(UNIT=666,FILE='GAMMA.DAT',STATUS='UNKNOWN')
            REWIND(666)
            READ(666,*) GAMMA
            CLOSE(666)

      C     Get E0
            OPEN(777,FILE='E0.DAT',STATUS='UNKNOWN')
            REWIND(777)
            READ(777,*) E0
            CLOSE(777)

      C     Loop for all Energy values
            DO LOOP=1 , 1500
                  PHIE(LOOP)= REAL(LOOP)**(-REAL(GAMMA))*2.71828183**
```

```
     -      (-REAL(LOOP)/REAL(E0))

            IF (PHIE(LOOP) .LT. 10.**(-17)) PHIE(LOOP) = 10.**(-
17)
      END DO

      OPEN(UNIT=15,FILE='INSPEC.DAT',STATUS='UNKNOWN')
      WRITE(15,760)LABEL
  760 FORMAT(A80)
      WRITE(15,*)IENG/5

C     WRITE ALL VALUES TO INSPEC.DAT

      WRITE(15,761)(E(I),PHIE(I)*3600,I=1,IENG,5)
  761 FORMAT(8E10.4)
      CLOSE(UNIT=15)
      RETURN
      end
```

Appendix D – The Normalization Code

This is an excel macro written in Visual Basic which normalizes a point based on its value of Gamma and E0. It finds out the value of Gamma and E0 based on the items position in a file (every file has the same format). Note that this function must be called from another macro that determines what to normalize the radiation level from.

```
Private Sub norm(NORMALIZEFROM As Integer)
'
' norm Macro
' Macro recorded 7/30/2004 by ANSER
'
'
' THIS FUNCTION TAKES IN AS INPUT NORMALIZEFROM. THEREFORE, IT ALREADY KNOWS WHAT
TO NORMALIZE FROM


    Dim GAMMA As Double 'this is gamma
    Dim E0 As Double 'this is E0
    Dim PHIE(1501) As Double 'this is the PHIE
    Dim PHIETOTAL As Double 'this is the total of all phie past normalizefrom

    Dim NEWRADIATION As Double




    'find based on cell location the Gamma and E0
    GAMMA = (ActiveCell.Column - 2#) / 2#
    E0 = (ActiveCell.row - 2#) * 10#


    'loop for all PHIE filling it based on function with E0 and gamma
    For E = 1 To 1500
      PHIE(E) = E ^ (-GAMMA) * 2.71828183 ^ (-E / E0)
    Next E

    'sum up all phie
    PHIETOTAL = 0
    For E = NORMALIZEFROM To 1500
        PHIETOTAL = PHIETOTAL + PHIE(E)
    Next E

    'now, renormalize the radiation
    NEWRADIATION = ActiveCell.Value 'set the new radiation to equal the old
radiation
    NEWRADIATION = NEWRADIATION / PHIETOTAL 'divide it by the total phie to
normalize it

    'place the renormalized radiation into the chart under the new chart
    ActiveCell.Offset(54, 0).Select
    ActiveCell.Value = NEWRADIATION

    'move the curser back up to where it started one column to
the right
    ActiveCell.Offset(-54, 1).Range("A1").Select
'
End Sub
```