COMPUTER SIMULATIONS OF RADIATION SHIELDING IN SPACE BY POLYMERIC MATERIALS

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Abstract

This research has included extensive analysis of the radiation shielding capabilities of various polymeric materials being developed for radiation shielding in manned space flight. Code validation was performed using NASA-Langley's GRNTRN deterministic ion code to make comparisons against experimental data recorded at Brookhaven National Laboratory. GRNTRN currently can only model one type of particle at one specific energy, but is being expanded to simulate the actual space radiation environment. Additional work has been conducted using NASA-Langley's HZETRN, which is their current generation space code. This code can simulate the actual space radiation environment, using both Galactic Cosmic Ray spectra and Solar Particle Event spectra. HZETRN was used to evaluate the shielding capabilities of various polymers.

Further work has been conducted in developing a new code using GEANT4. This new code is being used to make comparisons against NASA-Langley's HZETRN, which will hopefully increase the level of confidence in HZETRN's results.

Lastly, research has been conducted in producing polymeric panels using prepreg. These panels consist of many layers of carbon fibers surrounded by polymers with good radiation shielding properties. Hopefully, these panels will be good multi-functional materials, since they could lead to panels with good mechanical and radiation shielding properties.

Introduction

NASA has always had a major emphasis on developing technologies that can be used for manned space flight. This has been evidenced by the massive attention that was given to the first manned lunar landing in 1969. This excitement has continued to fuel the design of other manned projects such as the Space Shuttle and the future Crew Exploration Vehicle (CEV). Clearly, any sort of manned space flight requires extraordinary design considerations and extremely effective technology, because there are innumerable hazards associated with manned space flight. Among these, radiation damage is a very major concern[1].

The space radiation environment is potentially extremely hazardous. Radiation in space can consist of every known particle including all energetic ions[2]. This radiation can be grouped into three major categories. First, there is radiation of galactic origin referred to as Galactic Cosmic Rays or GCR. GCR is a relatively constant background level of radiation throughout the solar system. The GCR spectrum consists of a relatively large number of heavy ions in it, which is important for estimating radiation damage in biological systems, since these particles cause more damage than a proton of comparable energy. Next, radiation that originates from the acceleration of the solar plasma is referred to as Solar Energetic Particles, SEPs, or Solar Particle Events, SPEs. These SPEs consist almost entirely of protons with a very small number of helium nuclei mixed in. SPEs generally have particles of lower energy than GCR, but they can be extremely dangerous due to the shear number of particles associated with a typical SPE. SPEs can deliver lethal doses of radiation in an extremely short period of time, such as a few days[2]. Lastly, radiation particles can be trapped inside the confines of a geomagnetic field. Around Earth, the bands of trapped particles are referred to as the Van Allen Belts. The Van Allen Belts are a torus of trapped radiation, consisting mostly of protons and electrons centered on the earth's geomagnetic equator. There are two major belts in the Van Allen Belts. The inner belt reaches a maximum at approximately 3,600 km, while the outer belt reaches a very broad maximum at approximately 10,000 km. There is a minimum at around 7,000 km. The inner and outer belt can be potentially harmful to spacecraft leaving Low Earth Orbit (LEO) for interplanetary space. However, usually the passage time is relatively short and so the possibility for radiation damage is significantly reduced[2].

Previously, NASA has not been too concerned about GCR, since manned missions beyond the van

Allen belts were short. NASA was far more worried by SPEs, since they could be lethal in a short period of time and also because SPEs are far more unexpected than the GCR spectrum, which only slowly changes[2].

However, with the possibility of long-term deep space missions at hand, NASA must conquer the new challenge of protecting astronauts from the risks of GCR damage. GCR ions significantly increase the risk of cancer and NASA will not accept higher than a 3% risk of a fatal cancer over the lifetime of the astronaut[1]. Furthermore, NASA must prevent radiation sickness, which can have effects that compromise mission safety[1]. Also, adequate protection from GCR for a prolonged manned mission will most likely provide sufficient protection from a SPE unless the astronaut is engaging in Extravehicular Activity (EVA)[2].

In the GCR spectrum, a large component of the damage is from ions of high charge and energy (HZE), for which unfortunately significant data are lacking on biological damage. Furthermore, there is not very high accuracy in the cross sections databases for HZE. All of the calculations performed by NASA use nuclear models that are checked by comparison with experiment. However, there are large systematic errors in the experiments, which limit the level of confidence in the models[2].

HZE ions passing through materials cause much more damage as they create a larger swath of damaged area. This can be seen in figure 1[2].

Figure 1 shows a path of equal energy ions with hydrogen on the far left and iron on the far right. The black represents areas that have been significantly affected or damaged by the ion passing through. As you can see, the thickness of the damage increases with increasing atomic charge. This shows that ions of equal energy do not necessarily impart the same amount of damage to a system, since it is heavily dependent on the atomic charge. It would take several hundred protons to equal the damage from one iron ion of the same energy. Furthermore, the thickness of the damaged area from an iron ion is sufficiently large that it could destroy the nucleus of a cell, which would constitute a lethal event for that cell. This exemplifies the difficulty in predicting biological damage, since one must be able to predict statistically where in the cell the damage is done. Destruction of the nucleus is fatal for the cell, but destruction of more peripheral components may not be so devastating. Due to the difficulty of modeling an exact biological system, NASA is most interested in limiting the dose equivalent in water.

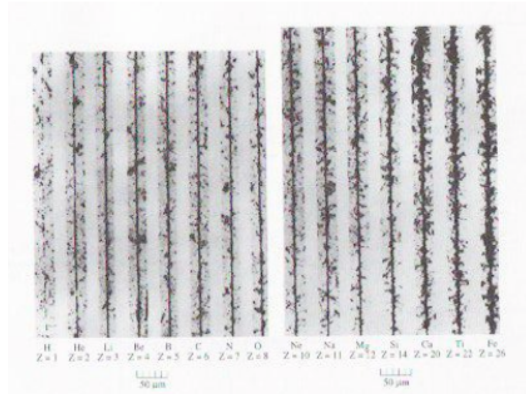


Figure 1. Ions Passing through Material

Water is used, since a typical cell is between 60% and 90% water by weight. Therefore, water can be considered a very crude biological approximation for radiation damage. To measure this biological damage, dose equivalent is used and is a measure of the biological damage from a dose of a certain type of radiation. Dose equivalent is obtained by multiplying the dose by a quality factor, which reflects the expected level of biological damage. Therefore, an iron HZE ion would have a much higher quality factor than a proton, which would show that the iron ion does far more biological damage[2].

It is also important to gain some understanding of what types of materials form effective shields against space radiation. The effectiveness of the radiation shielding material depends on the basic atomic and/or molecular cross sections and also the nuclear cross sections. The atomic and molecular cross sections depend on the density of electrons per unit volume, the electronic excitation energy, and also the tight binding corrections of the inner shell electrons[3]. The best absorbing materials, which make the most effective radiation shielding materials, have the highest electron density, the least electronic excitation energy, and the smallest tight binding corrections[3]. Therefore, liquid hydrogen is the best space radiation shielding material[3]. Of the three major factors, the single most important feature is the electron density. Therefore, hydrogen will always have the best shielding characteristics of any atom, since it has the highest electron density of any atom. This shows the importance of designing materials that have high hydrogen content. Also, one wishes to have some level of fragmentation of the HZE ions into smaller ions, which are easier to shield against and reduce the quality factor for that type of radiation. Therefore, it is advantageous to have a shielding material that causes some level of fragmentation of HZE ions to make them easier to handle without causing additional secondary particles through fragmentation of the shielding material nuclei[4]. Hydrogen again serves this purpose very well, since it cannot fragment into other nuclei. However, if one causes too much fragmentation, then it can be problematic, since there are vastly more particles that must be dealt with. In addition, due to the expense and difficulty in launching additional supplies into space, NASA seeks to develop materials that can effectively perform multiple purposes. Therefore, one would like to design materials that can be used for both radiation shielding and another purpose, such as structural components (good mechanical properties) or thermal shields.

Currently, NASA uses aluminum for radiation shielding[4]. This material is marginally effective at radiation shielding, since it has a low electron density. Therefore, researchers have been looking for other materials, which have higher hydrogen content than aluminum, to use as radiation shielding materials. Polymers have been a natural area of interest, due to the possibility of creating very good multi-functional materials. Polyethylene is often used along with aluminum as benchmarks for making comparisons about the radiation shielding effectiveness of a new material. Polyethylene is of particular interest because it inherently has the highest hydrogen content possible in a polymer. Furthermore, polyethylene does not contain any large nuclei, which is important because the absence of large nuclei dramatically reduces the risk of the shielding material fragmenting from a collision with a radiation ion. That is beneficial, because it reduces the number of particles that must be dealt with by an effective radiation shield[5]. Unfortunately, polyethylene does not possess particularly good thermal and mechanical properties, and so it is difficult to use it in the harsh space environment.

GRNTRN and HZETRN

There are several different types of codes, which the radiation shielding group at NASA-Langley have developed, in order to evaluate the shielding properties of different materials. There are two very distinct types of codes that have been developed. First, there is a lab code, which is capable of mimicking experimental setups, and simulates a beam of one type of particle with a very narrow energy distribution passing through shielding material. The other type is a space code, which simulates the actual space radiation environment, including all the different types of particles at their correct energy distribution.

GRNTRN is the current generation Lab Code, which is named for the Green's functions that it uses. GRNTRN takes one type of projectile at one energy and impacts it with the shielding material. The shielding material can currently only have one layer. Unfortunately, it is not yet possible to simulate a shielding material with multiple layers stacked on top of each other by using GRNTRN.

The most important output from the lab code is the energy deposited graph. Energy deposited refers to the amount of energy deposited in the silicon detectors by whatever particles come out the backside of the target. These particles can be primary, which are the same particles that were accelerated down the beam line, or they can be secondary, which are particles that were produced during physical interactions with the shielding material. The energy deposited is crucial information, because it is the closest data to the raw experimental data, which is recorded at a nuclear accelerator facility. Therefore, one can use the energy deposited graphs to make comparisons with experiment in an attempt to validate the math, physics, and code. Eventually, the math and physics in the lab code will form the next generation space code, which takes an actual spectrum of particles at realistic space energies. The space code simulates the space radiation environment as closely as possible. However, at the moment, the space code relies on HZETRN, which is an older model and more limited than GRNTRN.

Results of the Lab Code

As mentioned earlier, the lab code takes one type of projectile particle at one specific energy and impacts it on a target or shielding material. There can be a very small spread in the energy of the projectile to more closely imitate the experiments. It has also been configured to mimic the experimental setup by attenuating through the detectors, which would be present in the experimental setup. This is needed, because there are detectors and triggers, which the particles must pass through before hitting the shielding material in experiments. This, however, does not constitute a multiple layer code, because it does not allow nuclear fragmentation to occur in any of the detectors or trigger. This is a valid assumption, because the experimentalists will run a "target out run," which is essentially a background scan of the setup with everything except the target present. They can then subtract out any fragmentation that occurs in the detectors or trigger. Therefore, the experiment only measures the nuclear fragmentation in the actual target or shielding material.

GRNTRN predicts the energy deposited in the silicon detectors following a 5 g/cm^2 UDABDA1 target with a 1 GeV/nucleon iron-56 projectile as shown in figure 2.

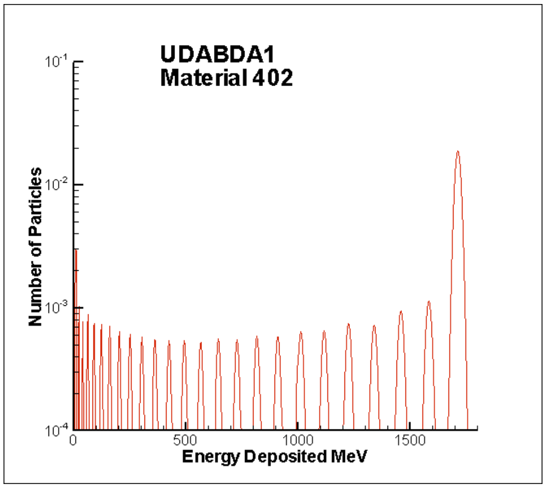


Figure 2. GRNTRN Output

This graph contains some important information. The furthest right peak corresponds to the primary ion, which is Iron (Z=26). The peak one to the left of the primary is Manganese (Z=25). This pattern continues all the way to the leftmost peak, which is Hydrogen (Z=1). Obviously, this is important because it tells the relative number of particles and predicts the amount of fragmentation, which is likely to occur. Fragmentation occurs when the primary particle, which is the incident particle, is split into multiple smaller, secondary particles. Secondly, this graph also shows some of the odd-even effect, which is a well understood phenomenon in nuclear physics. The odd-even effect is most visible with particles having a nuclear charge in the teens. Also, the graph shows that hydrogen and helium are produced at a much higher rate than other fragments. Furthermore, one can see why some fragmentation is good, since it must produce smaller particles, which will deposit less energy in the internal environment of the spacecraft, which consequently reduces the radiation dose that astronauts and electronics in the spacecraft receive. However, the problem with fragmentation is that it produces many more particles and so it can be potentially more dangerous, since one increases the number of particles that interact with the internal spacecraft environment.

Results from the Space Code

The space code is different from the lab code, since it uses many different types of projectiles at an actual distribution of energies as seen in space. This is obviously quite useful, because it enables one to model the space radiation environment using a computer simulation. The most common type of output from the space code is a dose depth curve. Dose depth curves plot dose equivalent versus depth in the shielding material. Dose equivalent is a biologically weighted measure of radiation exposure or dose. Furthermore, the dose depth curves are produced for both a GCR and SPE spectrum. The solar particle events have many fewer heavy particles, which are more dangerous than lighter particles, but the shear number of particles in a SPE can make these events extraordinarily dangerous to manned space missions.

In order to produce these data points, the space code uses the HZETRN transport code. This code is significantly older and less mathematically advanced than GRNTRN, which the lab code uses, but it is still fairly accurate for the very broad distribution of energies that the GCR and SPE spectra have. GRNTRN (Lab Code) is more accurate, and it can deal with a spectrum of particles that has little or no spread in energy. GRNTRN makes its predictions using the Green's functions, whereas HZETRN uses many more mathematical approximations and assumptions.

Dose depth curves are very convenient plots, because they are some of the most easily understood. All that the curve shows is how much radiation exposure, measured in dose equivalent, there is for a given depth with a certain shielding material. Therefore, if the dose equivalent (y-axis) is lower for one shielding material at a given depth than it is for another shielding material at the same depth, then the first material is a better radiation shield than the second material. So, the better shielding materials appear lower on the graph. This is useful, since it allows researchers to assess whether or not two different materials are significantly different from a radiation shielding point of view. Furthermore, since HZETRN simulates the actual space radiation environment, one can draw rather broad conclusions about the effectiveness of a shielding material, whereas one must be far more careful with GRNTRN, because that code only shows that a material is a better shield for one type of particle at one energy. However, that situation is not representative of space and can produce misleading results if one examines the shielding properties of materials using GRNTRN with an uncommon projectile at an uncommon energy. Therefore, one cannot say that GRNTRN will definitively identify the best shielding material.

Figure 3 is the calculated GCR dose depth curve for the materials that Dr. Robert Orwoll had tested at Brookhaven. It also includes polyethylene and aluminum since those have been two standard benchmarks for making comparisons about the effectiveness of radiation shielding materials. Polyethylene is considered a very good shield, since it has the highest hydrogen content possible in a polymer, whereas aluminum is not a good shielding material, due to its low electron density. The materials from top to bottom are Aluminum, Ultem, Polysulfone, PMDABDA1, UDABDA1, UDABDA2, BPBPA, Noryl 731, and Polyethylene.

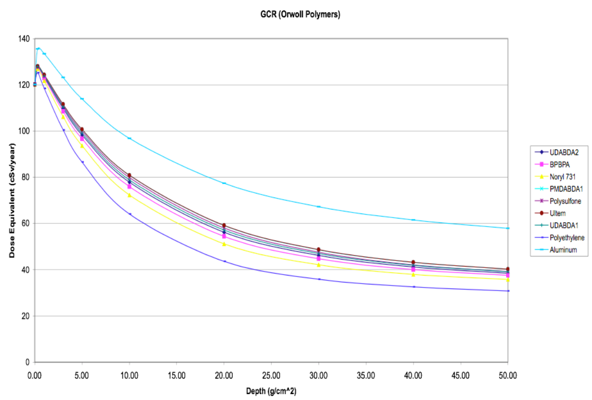


Figure 3. GCR Dose Depth Curve

Figure 4 is for the same materials, after being exposed to a SPE spectrum. The materials are in the same relative order.

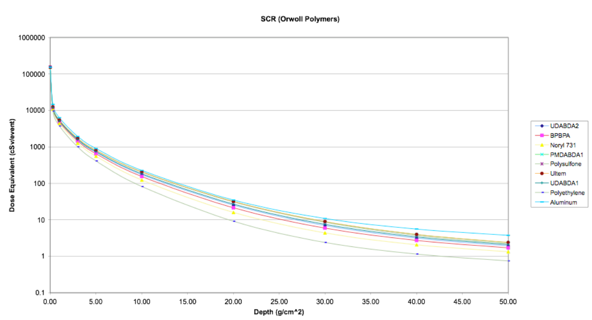


Figure 4. SPE Dose Depth Curve

Clearly, Polyethylene is the best shielding material for both GCR and SPE. Aluminum is the worst shield in both cases. The second best shielding material for both the GCR and SPE spectra is Noryl 731, a commercial polymer. Noryl 731 is noticeably better than any of the other polymers. However, of the materials designed by Dr. Orwoll, BPBPA is the best shield for both GCR and SPE.

On the GCR graph, one can see that a little bit of shielding material (approximately 0.5 g/cm^2) actually increases the Dose Equivalent above the level of no shielding material. This is due to the nuclear fragmentation. When the projectile fragments, there are at least two particles produced. Therefore, two or more particles must be dealt with instead of one, and so the result can be a more dangerous situation than if one had no shielding material. So, nuclear fragmentation is good, since it results in the formation of lighter particles, which are easier to slow and also since they are less damaging biologically; but it is bad, since there are more particles to slow after fragmentation. This is a complicated set of tradeoffs to find the best shielding material with a thickness that adequately protects astronauts and equipment but can still actually be launched into space.

On the SPE dose depth curve, the dose equivalent falls off extremely fast as a function of depth (dose equivalent is plotted on a logarithmic scale). This demonstrates that SPE are almost entirely protons, which are easier to shield against. However, the values of dose equivalent are still extremely high at low depths, since there are huge numbers of particles associated with the SPE. One needs approximately 10 g/cm^2 of shielding to reduce the dose equivalent down to the level of no shielding material for the GCR background. That shows the dangers associated with SPEs quite well.

GEANT4

GEANT4 is a software package, which contains the tools necessary to model the passage of particles through matter[6]. GEANT4 is capable of modeling any particle passing through any matter in any geometry. GEANT4 can be configured to control all aspects of the simulation from generation of the primary particles to recording the data being studied. At the core of GEANT, there is C++ code, which simulates a large number of physical models that are capable of handling a wide energy range.

GEANT4 is a Monte Carlo code. That means that the code generates one primary incident particle and transports that particle through the user-defined geometry. GEANT4 tracks all of the interactions that that single primary particle has. It then records all of the data that the user has specified to be recorded. Next, GEANT repeats the process all over again. GEANT will continue repeating the same setup until the user specifies that sufficient statistics have been achieved. Therefore, there can in theory be very few assumptions, either mathematical or physical, being made. However, one must run the code many times before the statistics of the data are adequate. Therefore, Monte Carlo codes have an advantage over deterministic codes, because they can make fewer assumptions. However, GEANT4 has the very large disadvantage that it takes far longer to run the code before the statistics are adequate. This becomes especially problematic for the GCR spectrum at large depths of shielding material. The heavy ions in the GCR spectrum, such as iron-56, have a high frequency of fragmentation as they pass through the shielding material. However, there are so many different possibilities for the products of the fragmentation of a heavy ion, that it takes a huge number of primary particles before there are sufficiently good statistics for any given individual fragmentation process. Therefore, one sometimes has to input a tremendously large number of primary particles while using GEANT4. This is very different from HZETRN and GRNTRN, which have taken all of these different processes into account with their mathematical approach to the problem. Therefore, HZETRN and GRNTRN are capable of producing data in far less time than GEANT.

A major goal of this research was to develop a code, which could be used to make comparisons with HZETRN using GEANT4. The goal is to duplicate HZETRN's results using GEANT. This would provide a huge amount of confidence in HZETRN, which is difficult to experimentally verify, if GEANT produced very similar results. GEANT and HZETRN work in such inherently different ways that it is very unlikely that they are both wrong in the same way. Therefore, similar results would strongly imply that both codes are probably quite accurate.

Work on this project did produce a code, which is capable of replicating the trends that HZETRN predicts for SPEs. Unfortunately, due to time constraints, the code based on GEANT has not been developed to the extent necessary to compare directly with HZETRN and to make comparisons about GCR. The work with HZETRN predicts dose equivalent, which is a derived radiation unit that provides a biological weighting of the risk of the specific type of radiation. However, it is more difficult to calculate the quality factor necessary to scale dose into dose equivalent. Therefore, the code using GEANT currently is only capable of producing results in terms of dose. Hopefully, another later project may continue work on this code and provide a more direct comparison with HZETRN.

The code based on GEANT has the following geometry configuration. First, the incident beam is generated along the x-axis. This beam can be of a single energy or of an energy distribution. However, the beam of primary particles can only be of a single type of particle. Therefore, to generate the a multi-ion spectrum, the code must be run multiple times with a different beam using the different ions in the spectrum. This problem does not exist for SPEs, since those consist almost entirely of protons. All other ions are so uncommon, that it is safe to ignore them. Furthermore, for making comparisons against HZETRN, HZETRN only considers protons in SPEs[7].

After the primary particles are generated and traveling along the x-axis with their specified energy distribution, they will impact the shielding material. The user can specify any type of material as the shielding material. Furthermore, the user can specify the thickness of the shielding material. The particles will pass through the material and any interactions that occur are recorded. Furthermore, all the particles will be tracked including fragmented particles from both the primary particle (or even a secondary particle from a secondary particle of the primary ion) and the shielding material. This is one other difference between HZETRN and GEANT. HZETRN does not consider and track particles that occur from fragmenting nuclei within the shielding material[8]. These particles interact with the shielding material until they either are stopped in the shielding material or they pass completely through it. Those particles that do not stop in the shielding material pass through it into water. The water is 1 g/cm^2 or 1 cm deep. Those particles will also continue to interact with the water until they are either stopped or pass completely through it. However, the radiation dose in the water is what is of interest. This dose is taken in water, because water can be used as a crude approximation of a biological system such as an astronaut, since all living cells are mostly water. 1 cm of thickness for the water was chosen after consultation with Dr. Steve Blattnig at NASA-Langley[7]. He believed that 1 cm of water would be the best comparison to make with HZETRN, which also measures the radiation dose in water.

Next, the primary particles are generated with the correct energy distribution for the King Spectrum from the August 1972 SPE. These particles are transported into the shielding material and continue to pass through the water tank if they have sufficient energy. The code will then record the energy deposited in the water, which can be converted into a dose by dividing by the mass of the water.

A dose depth curve was produced for the King Spectrum and shown in figure 5. The order of materials from top to bottom are Aluminum, UDABDA1, Noryl 731, Polyethylene, and Liquid Hydrogen.

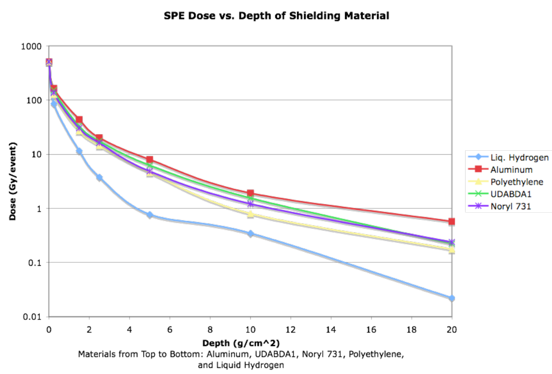


Figure 5. GEANT4 SPE Dose Depth Curve

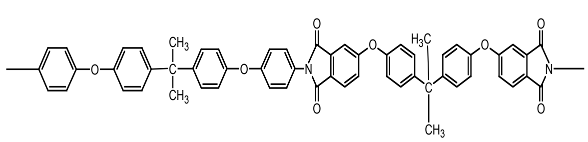
Figure 5 shows the same general shape and order of materials as HZETRN does. It also confirms that SPE spectrum are relatively easier to protect from since the dose falls off so rapidly. However, they are incredibly dangerous, because they start from such a massive level of dose. With no shielding, it would be impossible for a human to have survived being in deep space with the King Spectrum occurring. It is also important to note that this graph is also good confirmation of HZETRN, because it also replicates the same order of shielding materials as well as the same shape as HZETRN's dose depth curve.

A future project could include updating this GEANT4 based code to include GCR calculation as well as dose equivalent calculations.

Panel Construction

Another component of this project was an attempt to make polymeric panels that would have good radiation shielding properties as well as strong mechanical properties and good thermal properties.

Last year, Hillary Huttenhower made prepreg using UDABDA1 ($C_{58}H_{42}O_8N_2$). UDABDA1 is a polyimide polymer with the following structure:



Prepreg is a roll of carbon fibers coated in the specified polymer. Hillary Huttenhower was able to make the UDABDA1 prepreg in conjunction with Bert Cano at NASA-Langley Research Center.

This project has involved several attempts to make solid panels from the UDABDA1 prepreg. First, the prepreg must be cut into the shape and size of the panel that one wishes to make. Due to some relatively poor quality areas of the prepreg, it was decided that a 1.5 inch square panel would be the best option, because unfortunately, large areas of the prepreg were lacking significant coating of polymer. Therefore, it would be useless to attempt and make panels out of those sections of the prepreg lacking a polymer coat, since the panels would not be solidly filled with polymer.

After deciding on a 1.5 inch square panel, it was decided that a 10-ply panel would be the best thickness to start with first. This thickness is optimal, because it is not so thick that it takes a long time to cure[9]. So 10 1.5 inch squares of prepreg were prepared using blades at NASA-Langley. These 10 layers were then stacked on top of each other so that the carbon fibers were all running in the same direction (unidirectional). Then on the top and bottom of the 10 layers, there were several layers of nylon and fiberglass placed there to protect the prepreg from damage during the cure cycle. This collection of prepreg and fabric was then placed into a mold provided by NASA-Langley that is designed to fit into their equipment for the cure cycle.

Then, the mold was placed into an oven capable of applying pressure to the mold for the cure cycle. The cure cycle consists of a programmed set of changes in temperature, pressure, and vacuum. It should be noted that the pressure is applied by hydraulically pressing the loose top of the mold down into the bottom, while a slight vacuum is maintained by a pump and is used to remove any excess solvent gas from the oven.

The cure cycle for the first panel attempted is the following:

1. Ramp the temperature to 305°F at 12°F/min.

2. Reduce the pressure in the oven to 30 mm Hg below atmospheric pressure.

3. Apply 3 psi of pressure to the mold.

4. After reaching 305°F, hold the settings for 2 hours.

5. Then, ramp the temperature up to 605°F at 12°F/min.

6. Increase the pressure to 100 psi.

7. After reaching 605°F, hold the settings for 2 hours.

8. Cool the oven down to room temperature and release pressure and vacuum.

The purpose of raising the temperature to 305°F for two hours is to dry any excess solvent from the prepreg before the actual production of the panel starts. This is important, because excess solvent can prevent the polymer from filling in the gaps of the panel very well. Then, the increase in temperature to 605°F with a large amount of pressure allows the polymer to start flowing and filling in all the gaps between the carbon fibers.

Using this cure cycle, a panel was produced that weighed 11.9 grams, which was 0.7 grams less than the original 12.6 grams. This was not a large loss in weight, which implied that either the prepreg had already lost most of its solvent or the prepreg was not well coated in polymer[9]. The panel was 0.060 inches thick, which corresponds to 0.006 inches/ply. That is very close to the ideal thickness per ply[9].

Next, the panel was tested using an ultrasound (c scan). This test is capable of showing how well the polymer filled in the gaps between the carbon fibers during the cure cycle. Ideally, there should be no gaps anywhere in the panel, so that the polymer perfectly coats the carbon fibers and fills any space between them. Unfortunately, the ultrasound test did not show this. Figure 6 shows the result of the ultrasound test.

The white in the diagram shows areas where the panel has been completely filled in by polymer. Those are areas, where the panel formed like it should have. The black areas are areas where the panel is barely filled in at all. In other words, the black areas

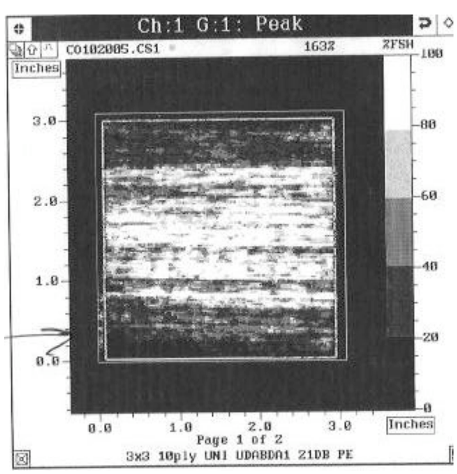


Figure 6. Ultrasound Test of the Panel

represent regions where the panel is almost exclusively carbon fibers. This test shows that only 25.64% of the panel appears as white and approximately 60% of the panel is unsatisfactorily filled in. Therefore, this panel was not properly made.

There are two possibilities for why the panel was not properly made. First, the cure cycle for the panel could have been off. There may not have been sufficient pressure or temperature applied during the cure cycle. The second possibility is that the prepreg is defective for several possible reasons. First, the viscosity of the polymer coat for the prepreg may have been too high. This would mean that the polymer would not flow as easily during the cure cycle of the panel and would produce a result similar to this. The other possibility is that there simply was not a sufficient amount of polymer coated onto the prepreg, while making the prepreg.

Unfortunately, Bert Cano believes that the problem is that there is not sufficient polymer on the prepreg. Currently, there is additional synthesis work being conducted to make more polymer so that another batch of prepreg can be used to make more prepreg that will hopefully have better success in making a structurally strong panel.

Conclusion

In conclusion, there are still many unresolved technical problems associated with prolonged manned space flight beyond the van Allen belts. This research illustrates the difficulty of providing firm answers to many questions, because there are still so many unsolved questions. However, this project has attempted to answer a very limited number of these questions, so that future manned space flight will have less risk of radiation related illnesses.

Acknowledgments

I would like to thank Dr. Robert Orwoll in particular for his constant willingness to provide any type of help and advise in completing this research. In addition, I would like to thank Dr. Steve Blattnig and Dr. Steve Walker for their help in understanding HZETRN and GRNTRN. Lastly, I would like to thank Bert Cano for his assistance in making the polymeric panel.

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