Degradation Effects of Ionizing Radiation on Spacecraft Components and Biological Samples*

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The space environment is harsh, and understanding its effects is essential in creating systems that operate correctly despite the harsh conditions. The Space Survivability Testing (SST) chamber is a ground based system designed by the Material Physics group to simulate the space environment. This system was completed and refined in order to test electronics, commercial parts, and biological samples in a space-like environment. Systems tested in conjunction with this URCO project include radiation hardened wiring, components used on communication satellites, Commercial-Off-The-Shelf (COTS) electronics, radish seeds, and mouse muscle cells.

I. INTRODUCTION

Interactions with the space environment can cause unforeseen and detrimental effects to spacecraft, sensors, components and materials. These components potentially might not operate as designed, or in the extreme case, could fail altogether. Electronic and biological systems are particularly sensitive to radiation exposure [1] in space. Radiation effects can adversely affect electronics [2] by modifying materials' electrical and mechanical properties [3], and can modify the cell structure and lifetimes of living cells. These effects can be complex and difficult to accurately predict, thereby requiring extensive space [6,7] and ground-based [8-10] testing. Understanding how and why parts fail, or biological samples die can lead to better designs to combat this damage. The largest contributor to detrimental effects is often high energy electron, or β, radiation [4], which is prevalent in space, particularly in Low Earth Orbit (LEO) where most small-satellites are sent.

II. APPLICATIONS OF THE SPACE SURVIABILLITY TEST CHAMBER

A. COMMERCIAL OFF THE SHELF PARTS

Small satellites are typically short term missions (6-8 months) and are likely to use untested COTS parts in order to save money and development time; these COTS parts are not specifically designed to withstand radiation as are much more expensive radiation hardened parts. It is difficult and expensive to send anything into space, and therefore it is extremely important that components used on spacecraft can adequately handle radiation exposure. Testing for potential environmental-induced modifications is increasingly more important as small satellite programs evolve to have longer mission lifetime, extend to more harsh environments (such as polar, geosynchronous, or even lunar orbits), make more diverse and sensitive measurements, minimize shielding to reduce mass, and utilize more compact

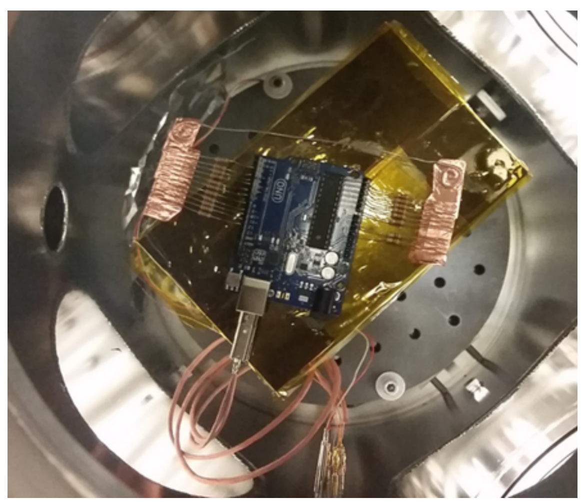

Figure 1 – Microcontroller inside the SST

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and sensitive electronics which often include COTS components. The most practical and economic approach to predicting and mitigating these harmful effects is to accurately simulate space environment effects through long-duration, well-characterized testing in an accessible, accelerated laboratory environment [6,8].

To test the viability of COTS components a microcontroller was placed in the SST [see Figure 1] with a dose rate of 1.0 krad/hr. An open source code was modified to diagnose the microcontroller *in-situ* and monitored for 'soft errors,' known as single-event upsets (SEU) and 'hard errors,' single-event effects (SEE). SEU's occur when radiation causes a charge disturbance large enough to alter the state of memory bits, but is minor enough that the system is still functional. SEE's occur when radiation strikes the components of the circuitry in a way that causes a change in the circuit operation and permanent damage.

The diagnostic software did not show any failures until complete system failure at 250 Gy total ionizing dose (TID) after approximately 10 days of radiation and vacuum exposure, this is similar to what is expected in medium-earth orbit (MEO). An error code indicated a mismatched memory byte was produced which made uploading the diagnostic software impossible, this was discovered during a system check at approximately a week of exposure but the actual time the error was created was unknown [18,19].

Overall the experiment showed that COTS parts are actually quite resistant to radiation and can function at an acceptable level for multiple days or even weeks in space. This would be acceptable for a trip to the moon, but would not work for long term missions in orbit.

B. SPACE GRADE ELECTRONIC COMPONENTS

In comparison to the run of the mill electronics that were tested before, some space grade and radiation hardened electronics were also tested [see Figure 2]. High performance RF communications cabling underwent accelerated testing involving more than 3 months inside the SST chamber, and receiving a ~250 krad TID that would be experienced on a full multi-year mission. *In-situ* permittivity characterization was performed to understand the long-term cumulative effects of β-radiation on cable properties, particularly frequency response and power loss. Electrostatic discharge was monitored and characterized using custom video and current monitoring software.

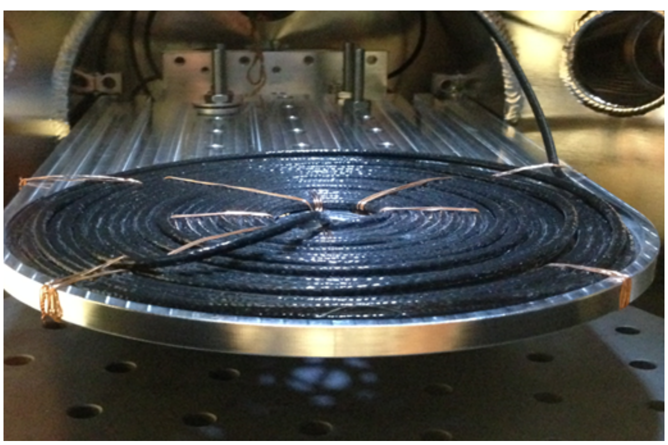

Figure 2 – Space grade cable inside the SST

The results were resoundingly unexciting, almost nothing happened during the 104 days of testing. Although there were over 1000 oscilloscope events, the pulse rate was constant and did not change if the radiation was present or not. It is expected that the pulses were just noise that was being picked up. In addition, observed arc events were very small and contained <1 nJ of energy which is of no risk to damage the cables. In addition, these arcs were not observed on the oscilloscope and could not be correlated to the cause.

One of the biggest reasons between the difference in the results between COTS parts and space-grade parts was due to the fact that we tested a full Arduino microcontroller for the COTS test. This is a highly complex and sensitive piece of electronics, whereas the space-grade cable was simply a cable and not complex or sensitive at all.

C. TELECOMMUNICATIONS SATELLITE COMPONENTS

High frequency RF antenna dielectric components used on telecommunications satellites were tested in orbital conditions. Electrostatic discharge events induced by β-radiation were monitored and characterized using both video and current monitoring to identify the frequency, location, and magnitude of discharges. Effect of temperature (~10 ˚C to 60 ˚C) on discharge characteristics was tested over full orbital cycles of several days.

Arcs were measured on the antennas, but had energies lower than the threshold for concern. The energy in each arc was around 2 nJ at a rate of about 5 arcs/hr. This, expanded over a 15 year mission left an total energy deposition of ~1 mJ which was acceptable and would not affect antenna performance during the 15 year lifetime.

D. BIOLOGICAL SAMPLES

For biological tests, another custom piece of equipment had to be designed. The biological test chamber is an aluminum 'box' designed to maintain a controlled atmosphere inside, but still allow for irradiation of the samples [see Figure 3]. This chamber has an aluminum window that allows for 250 keV – 2.5 MeV radiation energies from the Sr^{90} source to penetrate to the inside of the chamber. The cavity inside the chamber can be customized to accommodate a variety of samples and the temperature of the whole chamber can be controlled [20,21]. Two types of biological samples have been tested, mouse muscle cells and radish seeds.

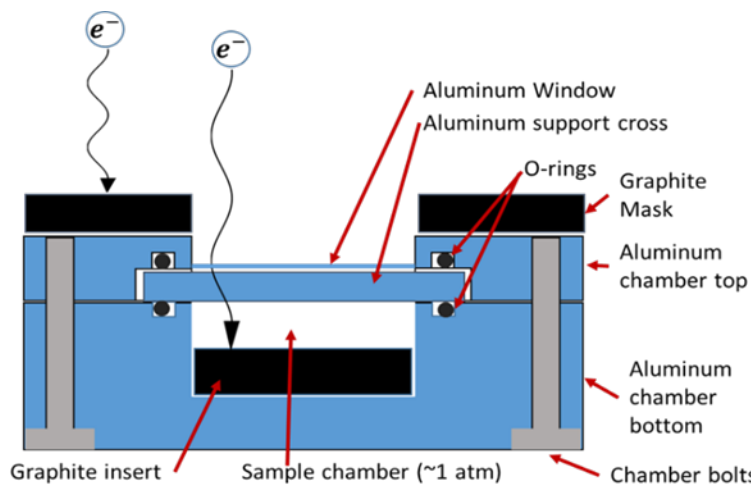

Figure 3 – Diagram of the Biological Test Chamber

In-Vitro tests of muscle cells irradiated in the SST and biological test chamber have been studied. Effects of radiation on muscle cells will progress work in cardiovascular disease and degenerative tissue risks from space irradiation experienced by astronauts. Muscle cells were examined after different doses of radiation and compared to a non-irradiated sample [see Figure 4]. Initial studies show significant damage to muscle cells after irradiation.

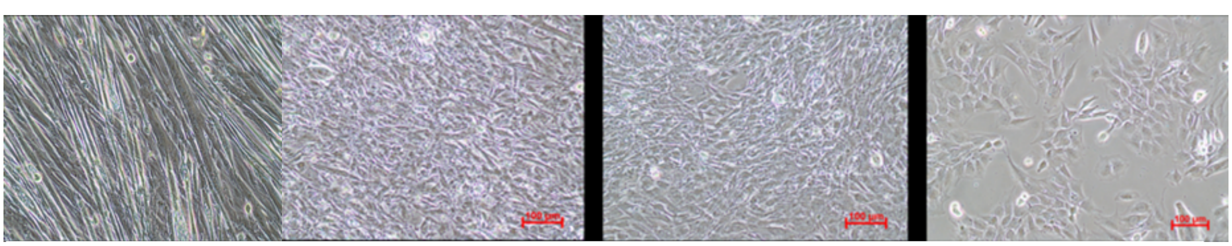

Figure 4 – Figure 8. Mouse muscle cells before irradiation (far left), and after irradiation (Left) 10 Gy, (Middle): 20 Gy, (Right): 50 Gy)

Radish seeds flown on the Russian BION-M1 missino were observed by Logan High School students to have faster germination rates than control, ground based radish seeds. Alterations to radish seed performance were hypothesized to be a result of radiation exposure during flight or vibrations during launch and reentry. A paint shaker was used to simulate launch vibration and seeds were tested in the SST to test if radiation was the cause of this change in germination rate. There were statistically significant increase in germination rate for both the space-exposed and vibration-exposed seeds, with the space-exposed seeds had the fastest germination rate [20]. Examination of the seed coats under an electron microscope [see Figure 5] showed enhanced production of surface proteins which are related to defense of the embryo from soil pathogens during seed germination. These proteins may also weaken the seed surface, allowing for faster water uptake and subsequent emergence of the plant embryo [21].

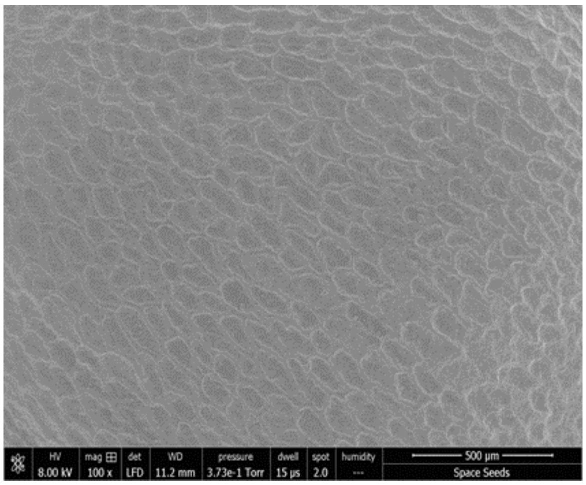

Figure 5 – Electron Microscope Image of radish seed (space-exposed) inside the SST chamber.

III. FUTURE WORK

The work completed during this URCO research has assisted in the development of myriad of possibilities for future work. Future work which has already been initiated include:

- Further communication satellite component testing, antennas and thermal coatings.
- Spacecraft materials testing
- Radiation induced conductivity of materials.
- Electronics used at the Space Dynamics Lab & Space Flight Industries
- Equipment to be flown on a Terrier Malamute rocket to test hybrid thruster designs developed at USU.

IV. IMPACT STATEMENT

This URCO grant allowed me to study and work on some incredible projects which could have some far reaching impacts in the space research community. It turned out to be a very diverse project, which led to international and multigenerational collaboration and has gotten significant attention from industry professionals. I was able to present on various portions and topics of this research two times, first at the American Physical Society Four Corners conference where I was awarded with an "Outstanding Undergraduate Presentation" distinction, and presented again at a Utah NASA Space Grant Consortium meeting. A third opportunity to present on Utah's Capitol Hill was cancelled due to weather. The experience and knowledge I gained was a fantastic addition to my senior design project in engineering, and married the engineering and physics realms (both of my majors). The experience, resume fodder, and networking gained during my research has opened many doors for my future.

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