INTRODUCTION:

The nature of this Project Readiness Package (PRP) report is determine through experimentation and analysis whether a radiation barrier on the outer surface of the RIT SPEX Group's future CubeSat or the classical method of using radiation hardened components prove to be a better radiation protection system for the electrical components onboard the CubeSat. The selection will be made on the basis of minimized lead time and cost while maintaining the required radiation resistance for component functionality. This is only a subsystem of the overarching CubeSat build and the timeline for those items can be found in Table 4. The items found in this PRP are as follows: Functional Decomposition (Figure 3), Potential Concepts for testing, Customer Requirements and Objectives (Table 1), Engineering Requirements (Table 2), House of Quality (Table 3), Skills Checklist (Appendix A), Three-Week Plan(Appendix B), Work Breakdown (Table 5) and Required Resources Anticipated (Table 6).

ADMINISTRATIVE INFORMATION:

Project Name (tentative): Potential RIT SPEX CubeSat Radiation Protection System Testing

Project Number: R15301

Preferred Start/End Semester in Senior Design:

☐ Fall/Winter ☒ Fall/Spring ☐ Winter/Spring

Faculty Champion: Unknown

Other Support:

Name	Dept.	Email	Phone
Dr. Dorin Patru: Technical Advisor	EE	dxpeee@rit.edu	(585)-475-2388
Dr. Agamemnon Crassidis: Technical Advisor	ME	alceme@rit.edu	(585)-475-4730

Project "Guide": Unknown

Primary Customer:

Name	Dept.	Email
Anthony Hennig, Representing SPEX	ME	aih2400@rit.edu

Sponsors:

Name/Organization	Contact Info.	Type & Amount of Support Committed
RIT SPEX Group	aih2400@rit.edu	Fund raising and grant proposals for financial support. Note that this only happens once the SPEX team

		has reached this step in their design.
NASA ELaNa Program	(202)-358-1100	If accepted, this will cover the cost with launching, communicating and tracking of the CubeSat.
Sponsored Research Programs @ RIT	(585)-475-7983 research@rit.edu	Research funding once accepted as an MSD.

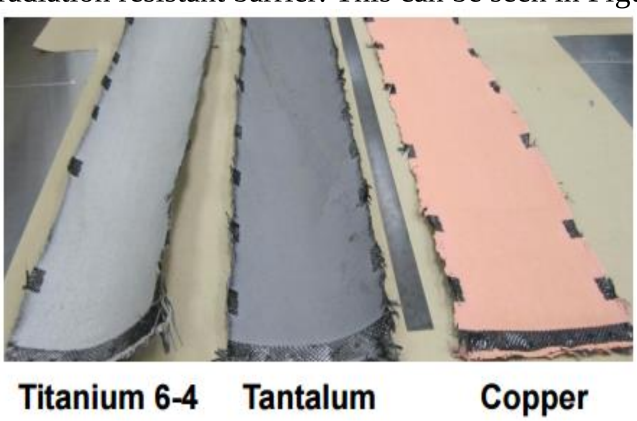
PROJECT OVERVIEW:

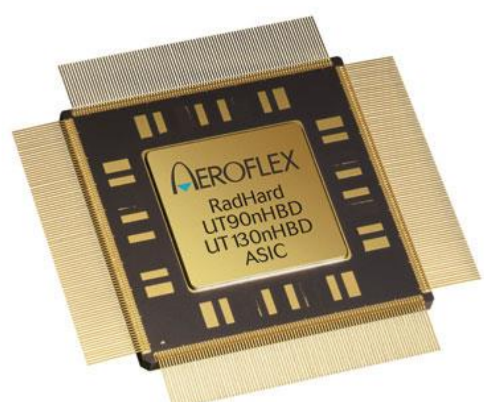
The nature of this PRP report is regarding the RIT SPEX team's selection of their future CubeSat's radiation protection system on the basis of lead time, cost and resistivity to ionizing particles. One of the many obstacles that they will be faced with is how to prevent radiation from turning their CubeSat into space debris. Radiation in its many forms can be very harsh and unforgiving to electrical components and its negative effects are only made all the more worse and likely to occur in space.

Months or even years of research, funding and hard-work on a CubeSat can be wiped out in a mere matter of seconds from a belt of cosmic radiation or a solar flare if the CubeSat does not have a way of deflecting these ionizing particles. In order to prevent this from happening, satellite manufactures have used radiation hardened components as shown in Figure 2, in their satellites which are specially designed electrical components that have been treated with various material such as depleted boron, gallium nitride, and tantalum during the component's manufacturing process that imbue them to be more resistant to the harmful cosmic rays.

The down side is that radiation hardening each electrical component is a costly specialized process. And being such a specialized process serving to such a small niche means that it is not financially attractive for the companies performing these specialized processes to keep pre-made hardened components in stock due to the fact that technology comes in such a variety flavors and has such a short lifespan. This is what creates the long lead time which can put a sizable gap in the launch date of a satellite.

To combat this, the technology aspect needs to be taken out of the equation to make the solution more capable to withstand the test of time. One solution is to use the findings of Shields-1 which is a research team at NASA working on developing a radiation barrier that would encase the electrical components inside the satellite and prevent radiation damage during orbit. The radiation barrier's composition consists of layering of various metals and composites such as aluminum, copper, carbon fiber and titanium and then putting radiofrequency applied tantalum spray between the layers which would serve to create a radiation resistant barrier. This can be seen in Figure 1. [4]





Figures 1 and 2: *(1) Some of the layup materials that would be used in the barrier [4]. (2) An example of a radiation hardened electrical component [5].*

[1] "CubeSat Launch initiative (CSLI)." NASA, n.d. Web. 6 Feb. 2015.
[2] "What Is a Satellite?." NASA, n.d. Web. 6 Feb. 2015.
[3] P. M. Swartwout, "CubeSat Database," St. Louis University. [Online]. [Accessed 7 February 2015].
[4] "Shields-1, a CubeSat with a radiation shielding research payload". NASA, n.d. Web. 5 Mar. 2015.
[5] "Rad-hard Space Electronics Hit the Mainstream." - Military & Aerospace Electronics. N.p., n.d. Web. 04 May 2015.
[6] "Radiation Protection." Wikipedia. Wikimedia Foundation, n.d. Web. 16 May 2015.
<http://en.wikipedia.org/wiki/Radiation_protection#Shielding>.

DETAILED PROJECT DESCRIPTION:

Customer Requirements and Objectives:

Customer Requirement Number	General Category	Importance	Description
CR36	Technology	Critical	CubeSat's electrical components have a system to protect from effects of radiation in orbit.
CR37	Layout	Critical	Testing needs must be able to be completed at a MSD level.
CR38	Technology	Critical	Radiation protection system must be passive system.
CR39	Layout	Desirable	The radiation protection system cannot exceed the weight or size limitations of either a 1U CubeSat.
CR40	Technology	Critical	The system cannot interfere with other primary functions and systems.
CR41	Technology	Critical	Radiation hardened components must be able to function with the same performance as the non-hardened counterparts.
CR42	Layout	Important	The radiation barrier, if selected, must have a lead time less than or equal to the lead time for the radiation hardened components.
CR43	Funding	Important	Cost effective testing.

Table 1: *Customer Requirements and Objectives with associated level of importance. This is compared against Engineering Metrics (Table 2) in the HOQ as shown in Table 3.*

Functional Decomposition:

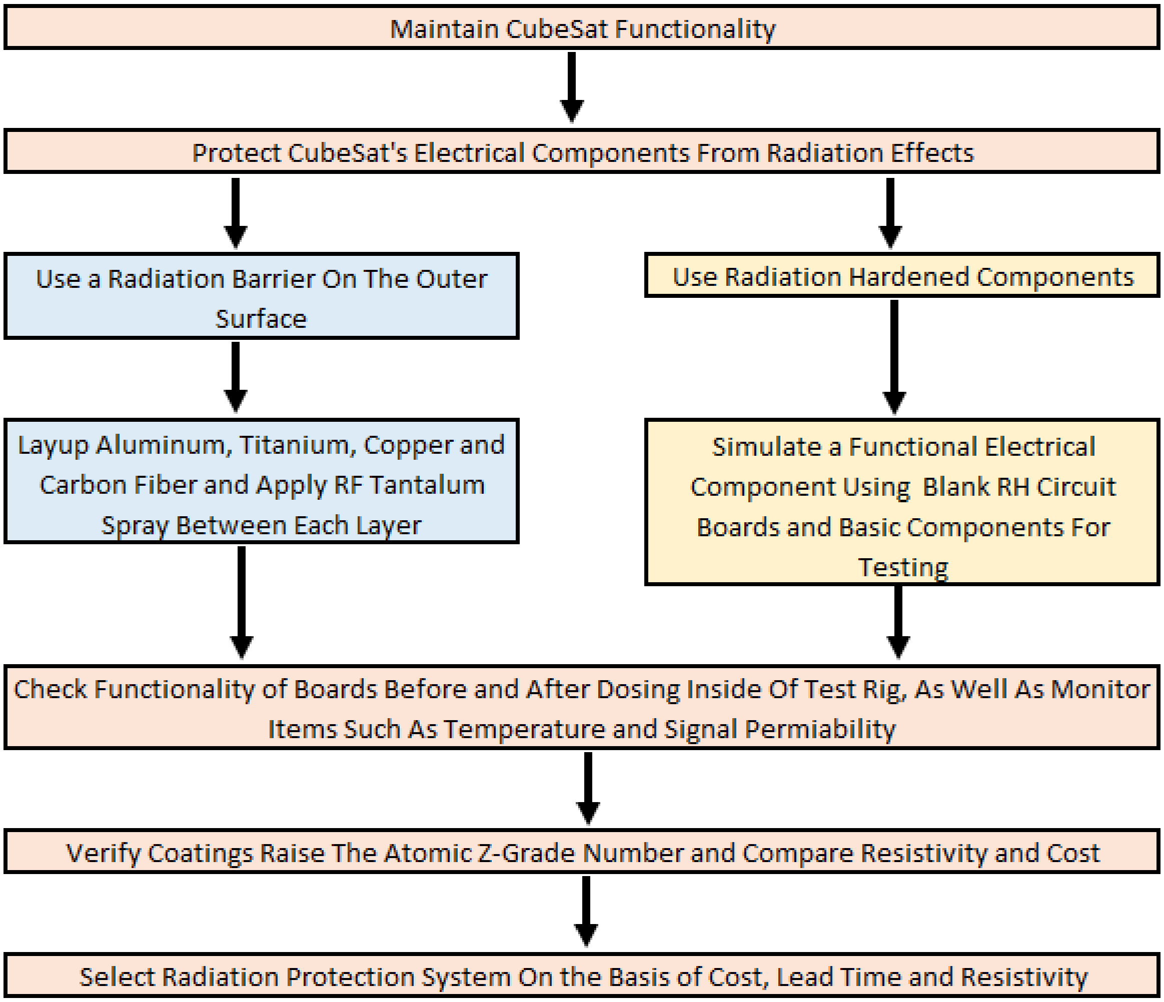


Figure 3: *Functional Decomposition diagram of the intended procedure for the CubeSat radiation protection system selection.*

Potential Concepts:

Since these concepts have both already been created, there are no potential concepts to list. However, there is a potential testing procedure that can be used to test these two ideas. First the MSD team will need to purchase both radiation hardened and non-hardened blank circuit boards and simple components which can be purchased in a shorter timeframe and more cost effectively than the full fletched CubeSat components. They will then create multiple boards with the same circuit design (to ensure a control sample and which will be tested for uniform functionality before and after being dosed by radiation. The highest dose of radiation that the boards can withstand while still functioning will act as the benchmark for the radiation barrier testing.

The non-hardened circuits will be places inside of a 1U sized cavity carved out of the side of a lead box. The opening of the cavity will then be covered with a cut out sample of the radiation barrier that is to be dosed with radiation. The lead box will ensure that the radiation that reaches the non-hardened board only passes through the barrier to minimize uncertainty in the results. Multiple trials will be run for each variation in the barrier sample to further validate. During this portion of testing the internal temperature of the cavity will be monitored with thermocouples as well as other parameters such as the ability to send a communication signal at the proper frequency through the barrier to align with customer and engineering requirements. After, the

costs, lead times and test results will all be compared and analyzed to be reported back to the SPEX team with the MSD team's recommendation for radiation protection system.

Engineering Requirements:

ER No.	Function	Engineering Requirements	Units	Marginal Value	Ideal Value	Test to Verify Performance
ER1	Passage of signal through radiation barrier	Radiation barrier does not affect the signal frequency required for communications.	[MHz]	3	435	In the test rig, transmit a comm. signal through to see that it is received.
ER2	Cost analysis and system selection	Radiation protection system selected minimizes cost (and by extension, lead time) the most while maintaining equal or better protection.	[Y/N]	Y	Y	The lead time and cost are the items that are sought to be minimized but not at the expense of performance so a cost analysis taking into account the cost of having lead time will be conducted.
ER3	Weight added from barrier	Weight addition stays within CubeSat weight limitations for its size.	[kg]	<1.33	<1.20	1U CubeSat's must be under 1.33 kg
ER4	Barrier construction	Apply various thickness layers of radio frequency tantalum to aluminum, copper, titanium or carbon fiber.	[mm]	TBD	TBD	This is one of the deliverables for the PRP
ER5	Barrier dimensions	Make sure that the barrier does not push the CubeSat over its size requirements so to be compatible with NASA's requirements	[cm^3]	20	10	Ensure CubeSat can fit in at least a 2U CubeSat size (20cm^3)
ER6	Validation trials	Multiple trials must be able to be conducted for the testing of the radiation barrier using various layup material combinations and thicknesses.	[Trials per Variation]	3	5	Multiple trials must be run to ensure validity of test results.
ER7	Insulating effects of radiation barrier	Ensure radiation barrier does not affect the proper margin between avionics maximum temperature and operational temperature.	[Δ°C]	15	10	Place a thermocouple in the test rig to monitor temperature changes that occur during operation.
ER8	Functionality without needing controls or inputs	Radiation hardened components works without requiring any additional inputs.	[Y/N]	N	Y	Ensure that the radiation hardened components function without needing additional wire channels, greater power input, etc.

ER9	Radiation Protection	Ensure that the selected radiation protection system functions and protects electrical components.	[Y/N]	Y	Y	Compare RH circuit boards against non-RH circuit boards behind RB and check for functionality before and after dosing.
ER10	Compatibility with solar panels/array	Ensure functionality of solar panels on the surface of the CubeSat via their power output.	[Y/N]	N	Y	Make sure surface of radiation barrier can be mounted upon, if not switch to deployable solar arrays.

Table 2: *Engineering Requirements as deemed important by the engineer which should be kept in mind when any type of analysis or design is being carried out.*

House of Quality:

			Engineering Metrics										Customer Perception				
	Customer Requirements	Customer Weights	Radiation barrier does not effect the signal frequency required for comms.	Radiation protection system selected minimizes cost (and by extension, lead time) the most while maintaining equal or better protection.	Weight addition stays within CubeSat weight limitations for its size.	Apply various thickness layers of radio frequency tantalum to aluminum, copper, titanium or carbon fiber.	Make sure that the barrier does not push the CubeSat over its size requirements so to be compatible with NASA's requirements	Multiple trials must be able to be conducted for the testing of the radiation barrier using various layup material combinations and thicknesses.	Ensure radiation barrier does not effect the proper margin between avionics maximum temperature and operational temperature.	Radiation hardened components works without requiring any additional inputs.	Ensure that the selected radiaiton protection system functions and protects electrical components.	Ensure functionality of solar panels on the surface of the CubeSat via their power output.	1 Worse	2	3	4	5 Better
CR36	CubeSat's electrical componets have a system to protect from effects of	5							5		5	5					
CR37	Testing needs must be able to be completed at a MSD level.	5				5		3									
CR38	Radiation protection system must be passive system.	5								3							
CR39	The radiation protection system can not exceed the weight or size limitations of either a 1U CubeSat.	2			4		2										
CR40	The system cannot interfer with other primary functions and systems.	5	5						5			5					
CR41	Radiation hardened components must be able to function with the same performance as the non-hardened counterparts.	5						3			5						
CR42	The radiation barrier, if selected based on pricing, must have a lead time <= time for the RH components	3		3													
CR43	Cost effective testing.	4		4		5											
	Technical Targets (Specifications)		435	Yes	1.2	TBD	10	5	15	Yes	Yes	Yes	A: Shields-1 CubeSat #1 B: MicroMas #2 C: Cornel University - Violet NanoSat				
	Units		[MHz]	[Yes/No]	[kg]	[mm]	[cm^3]	[Trials per Variation]	[Δ°C]	[Yes/No]	[Yes/No]	[Yes/No]					
	Technical Benchmarking	Better 5															
		4															
		3															
		2															
		Worse 1															
		Raw score	25	25	8	45	4	30	50	15	50	50					
		Relative Weight	8%	8%	3%	15%	1%	10%	17%	5%	17%	17%					

Table 3: *House of Quality which compares the levels of importance of the Customer Requirements against the Engineering Requirements shown in the tables above. From the Customer Requirements, an item listed as 'Critical' was rated as 5 for customer weight, whereas items listed as 'Important' and 'Desirable' where given a customer weight range of 3 to 4 and 1 to 2, respectively.*

Project Deliverables:

The final outcome of this project is show with definitive proof which radiation protection system is better in the categories of cost, build time, and effective resistance to radiation. This will be shown through trial testing of both systems under controlled and replicated environmental conditions of the potential exposure they will endure in operation. The proof will be shown by the faults that the other system has such as cracking in the barrier or a nonfunctional RH circuit board

at a radiation dosage that can be withstand by the barrier or vice versa. If both prove equally effective at providing the required resistance the system will be chosen on a cost and time analysis. A test rig for mounting each system at the radiation lab will likely be required to be made since this is a specialize project. If the radiation barrier is found to be more effective, optimal layer thickness of each material is to be shown through test trials.

Budget Estimate:

The budget will mainly be weighed down by the cost to layup the radiation barrier as it requires specialized materials that need to be assembled in a controlled environment. The radiation hardened circuit boards are also items that require special ordering where cost varies based on the component hardened (i.e.: a RH processor costs more than RH memory). A conservative cost estimate would be between $10,000 and $50,000 however the MSD team will need spec out the materials they need through testing so this range is malleable.

However, by using the testing procedure as outlined in the Potential Concepts section, the cost of this project can be greatly reduced to an estimate under $10,000 depending on radiation facility use costs.

Intellectual Property (IP) Considerations:

Building upon the research being conducted through NASA’s research team working on the Shields-1 CubeSat design may require special permission in order to use some of the published information so that there is not a legal bind that might be encountered during testing.

Other Information:

This project has a lot of cost associated with it. As such, it will be of the utmost importance that all analysis is done up front before purchasing any of the more expensive equipment as well as ensuring a time slot at the listed test facilities. Otherwise, this project has a good chance of costing much more than anticipated.

Timeline of Project With Respect To the Full CubeSat:

This project is likely to require two iterations before its maiden test in space, as such breaking the testing up into manageable chunks and in a way that can be easily picked up by the next MSD team will be crucial. Determining an ending milestones will be based on the acquiring of materials, funding and test facilities usage as these are the lengthiest processes which serve to slow testing. The completion of the radiation protection system and its alignment with the other associated CubeSat systems is as shown below in Table 4.

Academic Year	**Team A**	**Team B**
2015 - 2016	Structure	-
2016 - 2017	Solar Arrays	Attitude Control
2017 - 2018	Communication	Radiation Protection
2018 - 2019	Avionics	-
2019-2020	Vibration Mitigation	-

Table 4: *Table of proposed timeline for all the PRPs related to developing a CubeSat.*

WORK BREAKDOWN:

Discipline	How Many?	Anticipated Skills Needed
EE	1	EE1: Circuit building, testing (and knowledge of the accompanying test equipment), debugging, and the general knowhow of the functionality of various circuit boards will be required. They will need to be able to test the functionality of the circuit board system after it has been dosed with radiation to determine whether the tested radiation protection system passes or fails. They will also need knowledge of the potential circuit boards required to go into the CubeSat and be able to spec. out cost efficient solutions for both non radiation hardened and radiation hardened circuitry which will be tested.
ME	3	ME1: Needs advanced knowledge of composite materials and the ability to use spectrometry devices for post specimen analysis. They will use information gathered from trial testing and compare it to potential cracking, splitting, heat damage, etc. that may have occurred due to radiation-caused damage to draw conclusions about the effectiveness of the method used for that layup. ME2: In charge of creating a test rig that can test both methods equally in amount of exposure and location of exposure. They will need knowledge of heat transfer through radiation in order to determine the size and location of the exposure site as well as GD&T and basic machining knowledge to build the test bench. Responsible for the radiation exposure calculations and analysis through use of MATLAB, LabVIEW, ANSYS, etc. ME3: Will be in charge of analyzing the layup process of the radiation barrier and will be the main leads in physically building the actual barrier. Knowledge of materials and their radioactive sensitive properties will be required.
ISE	1	ISE1: Will act as the team leader in scheduling, main customer interface, purchasing and will be the contact who reaches out and maintains relations with the required facilities which will be used during build and testing of the systems.

Table 5: *Anticipated required tasks and responsibilities for each team member.*

OTHER RESOURCES ANTICIPATED:

Category	Description	Resource Available?
Faculty		☐
	SPEX Advisors: Dr. Patru, Dr. Barbosu, Jennifer Connelly, Dr. Crassidis	☒
	ME, ISE, and EE faculty experience may be needed to ensure safe testing.	☒

	Faculty from the material science department, chemistry and physic department may be required in order to gain insight on the radiation barrier layup process.	☒
	Cornell University Radiation Test Lab faculty who will be needed to safely run the equipment for testing.	☐
Environment		☐
	Machine Shop and potentially Brinkman Lab	☒
	Cornell University Radiation Test Lab, ISE will need to outreach to get access and explain test.	☐
	MSD Design Center to present potential concepts and breakthroughs.	☒
	EE Senior Design Lab used as the assembly location for the EE to create the boards for testing.	☒
Equipment		☐
	Lathes, 3-axis mills, drill press, calipers, etc.	☒
	3D printer (potential use if the material can withstand radiation effects with deformation)	☒
	Radiation PPE as well as radiation badges and a Geiger counter.	☐
	Circuit board power source, meters, and other test circuit test equipment	☒
	Computers with software licenses for Cadence, MATLAB, LabVIEW and ANSYS	☒
	Soldering tools	☒
	Plasma spray chamber or sending in the components to a facility (NASA LaRC Facility) that has one.	☐
Materials		☐
	Lead for test rig for barrier	☐
	Radiation hardened circuit boards that can be modified and tested, as well as non-RH boards for baseline testing.	☐
	Carbon fiber, aluminum, copper, and titanium sheets for radiation barrier build.	☐
	Radiofrequency applied tantalum	☐
	Wiring and solder	☒
Other	**N/A**	☐

Table 6: *Anticipated required resources for project.*

APPENDIX A:

Skills Checklist

Project Name: Potential RIT SPEX CubeSat
Radiation Protection System Testing

Checklist
Completed by: Brendan Parke

For each discipline, indicate which skills or knowledge will be needed by students working on the associated project, and ***rank the skills in order of importance*** *(1=highest priority). You may use the same number multiple times to indicate equal rank.*

Mechanical Engineering: Three Students

	3D CAD		Aerodynamics
3	MATLAB programming		CFD
5	Machining (basic)		Biomaterials
	Stress analysis (2D)		Vibrations
	Statics/dynamic analysis (2D)		Combustion engines
	Thermodynamics	1	GD&T (geometic dimensioning & tolerancing)
	Fluid dynamics (CV)		Linear controls
3	LabView (data acquisition, etc.)	5	Composites
	Statistics		DFM
			Robotics (motion control)
	FEA	4	Other: Radiological Physics Concepts.
5	Heat transfer	4	Other: Spectrometry
	Modeling of electromechanical & fluid systems		Other:
4	Fatigue & static failure criteria (DME)		Other:
	Specifying machine elements		

Reviewed by (ME faculty): **N/A**

Industrial & Systems Engineering: One Student

	Statistical analysis of data – regression		Shop floor IE – methods, time study
	Materials science		Programming (C++)
	Materials processing – machining lab		
3	Facilities planning – layout, material handling		DOE
	Production systems design – lean, process improvement	4	Systems design – product/process design
	Ergonomics – interface of people & equipment (procedures, training, maintenance)		Data analysis, data mining
	Math modeling – linear programming), simulation		Manufacturing engr.
5	Project management		DFx -- Manuf., environment, sustainability

	Engineering economy – ROI		Other:
	Quality tools – SPC		Other:
5	Production control – scheduling		Other:

Reviewed by (ISE faculty): **N/A**

Electrical Engineering: One Student

	Circuit design: AC/DC converters, regulators, amplifier ckts, analog filter design, FPGA Logic design, sensor bias/support circuitry		Digital filter design and implementation, DSP
	Power systems: selection, analysis, power budget determination		Microcontroller selection/application
	System analysis: frequency analysis (Fourier, Laplace), stability, PID controllers, modulation schemes, VCO's & mixers, ADC selection	3	Wireless protocol, component selection
5	Circuit build, test, debug (scopes, DMM, function generators)		Antenna selection (simple design)
5	Board layout		Communication system front end design
	MATLAB		Algorithm design/simulation
	PSpice		Embedded software design/ implementation
	Programming: C, Assembly		Other:
	Electromagnetics (shielding, interference)		Other:
			Other:

Reviewed by (EE faculty): **N/A**

Computer Engineering: None

	Digital design (including HDL and FPGA)		Wireless networks
	Software for microcontrollers (including Linux and Windows)		Robotics (guidance, navigation, vision, machine learning, and control)
	Device programming: Assembly language, C		Concurrent and embedded software
	Programming: Java, C++		Embedded and real-time systems
	Analog design		Digital image processing
	Networking and network protocols		Computer vision
	Scientific computing (including C and MATLAB)		Network security
	Signal processing		Other:
	Interfacing transducers and actuators to microcontrollers		Other:
			Other:

Reviewed by (CE faculty): **N/A**

Chemical Engineering: None

☐	Energy and material balances on chemical systems	☐	Electrochemistry
☐	Fluid dynamics and Heat transfer	☐	Inorganic chemistry
☐	Thermodynamics (traditional and chemical)	☐	Environmental science and sustainability
☐	Mass transfer and separation process design: distillation, multistage absorption and stripping, batch and fixed-bed adsorption, liquid-liquid extraction, crystallization, membrane separations.	☐	Advanced material science, polymer science
☐	Chemical reactor design: chemical kinetics, equilibrium, and catalysts.	☐	Surface tension and interfacial phenomena
☐	Engineering lab skills: rheology (in Newtonian and non-Newtonian systems), pressure, temperature, concentration. Pilot lab systems; delivery system assembly including pumps, valves and pressure sensors.	☐	
☐	MATLAB and EXCEL: solve complex chemical engineering mathematics problems	☐	
☐	Advanced chemistry knowledge: general, physical, and organic	☐	
☐	Micro- and nano-scale phenomena and process design	☐	
☐	Basic chemistry-based material science	☐	
☐	Basic engineering economics	☐	Other:
☐	Basic Process Control	☐	Other:
☐		☐	Other:

Reviewed by (ChemE faculty): **N/A**

APPENDIX B:

Purposed Three-Week Plan and Work-Breakdown:

Task No.	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1	Introductions and initial discussions for possible radiation protection solutions with SPEX	2 days	Tue 9/1/17	Wed 9/2/17	-	Group
2	Establish materials needed for radiation shield stack up.	3 days	Thu 9/3/17	Mon 9/7/17	1	Mechanical Engineer #3 and Industrial Engineer #1
3	Reach out to local laboratories and universities such as Cornell and MIT that have the ability to test using high levels radiation.	5 days	Thu 9/3/17	Wed 9/9/17	1	Mechanical Engineer #2 and Mechanical Engineer #3

4	Price out radiation hardened and non-hardened circuity and materials for layup from vendors. Begin design of test rig.	3 days	Thu 9/10/17	Mon 9/14/17	3	Mechanical Engineer #1 and Mechanical Engineer #2 and Industrial Engineer #1
5	Present findings to SPEX Group to receive funding for parts and materials.	1 day	Tue 9/15/17	Tue 9/15/17	4	Mechanical Engineer #1 and Mechanical Engineer #3 and Industrial Engineer #1
6	Milestone #1: Background Research Complete	0 days	Tue 9/15/17	Tue 9/15/17	-	
7	Purchase R.H. circuitry and price out materials for test rig for barrier testing.	1 day	Wed 9/16/17	Wed 9/16/17	5	Electrical Engineer #1
8	Layup the radiation shielding at a lab and preform preliminary spectrometry on a cross section of the layer for comparison	2 days	Wed 9/16/17	Mon 9/21/17	5	Mechanical Engineer #2 and Mechanical Engineer #3
9	Discuss possible tests and exposure levels of each type of radiation that will be dosed to both the barrier and radiation hardened components.	2 days	Tue 9/22/17	Wed 9/23/17	8	Group
10	Milestone #2: Begin Component Testing	0 days	Wed 9/23/17	Wed 9/23/17	-	
11	Next Steps: Compare Results; Test new layups vs. different tests; cost analysis	0 days	Wed 9/23/17	Wed 9/23/17	-	