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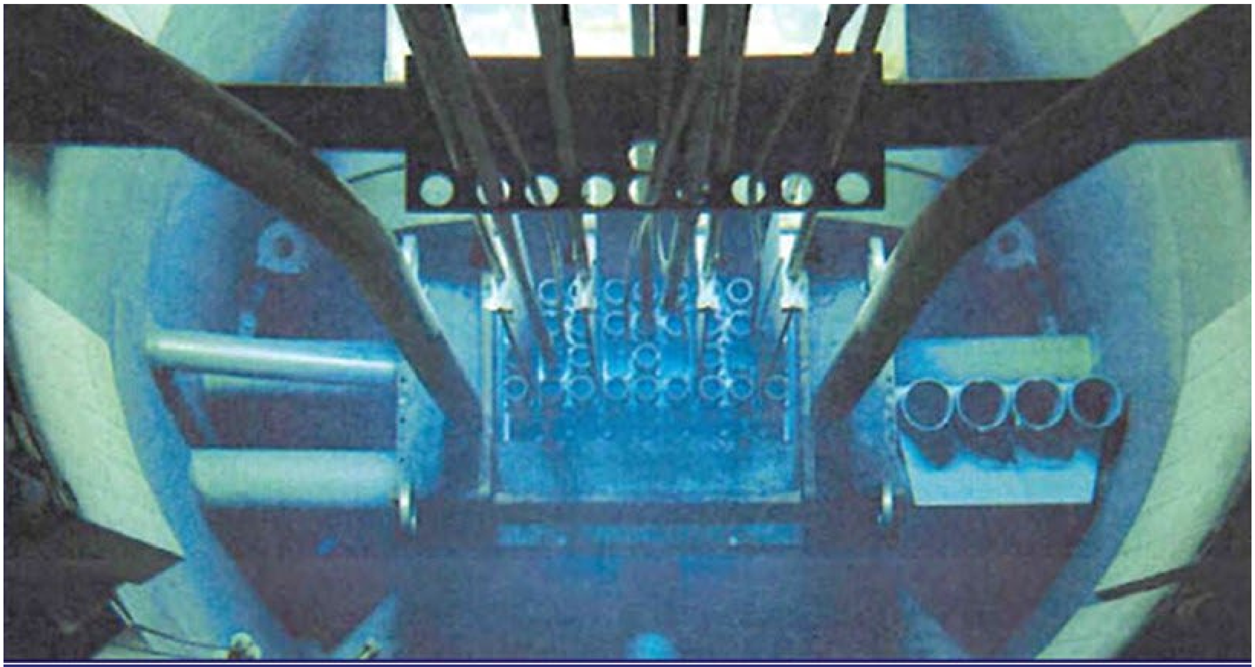

Safeguards by Design Projects Final Report-FY-22

University of Rhode Island

University of Texas- Austin

Philip Lafreniere
Christy Ruggiero

9/6/2022

LA-UR

Los Alamos NATIONAL LABORATORY

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List of Acronyms

CAD	Computer Aided Drawing
COVID-19	Coronavirus-2019
DOE	U. S. Department of Energy’s
FEA	Finite Element Analysis
HCD	Human Capital Development
IAEA	International Atomic Energy Agency
LANL	Los Alamos National Laboratory
MW	Mega-watt
NETL	Nuclear Engineering Teaching Laboratory
NEUP	Nuclear Engineering University Programs
NGSI	Next Generation Safeguards Initiative
NNSA	National Nuclear Security Administration
RINSC	Rhode Island Nuclear Science Center
ROUP	Remotely operated underwater platform
TRIGA	Training, Research, Isotopes, General Atomics (Research Reactor)
URI	University of Rhode Island
UT-A	University of Texas at Austin

Safeguards by Design Challenge Final Report- FY21

1. Project Summary

This University Engagement project challenged engineering students at universities, that do not have Bachelor degree programs in nuclear engineering but do have research reactors and some nuclear engineering coursework, to incorporate Safeguards by Design concepts into their Senior Capstone Design Project. This University Engagement project was part of the U. S. Department of Energy's (DOE) National Nuclear Security Administration (NNSA), Office of Defense Nuclear Nonproliferation, Office of International Nuclear Safeguards, Next Generation Safeguards Initiative (NGSI), Human Capital Development (HCD): University Engagement Program. This program exposed university students with Mechanical Engineering majors and Nuclear Engineering minors to the concepts of international nuclear safeguards.

In FY22, three teams at the University of Rhode Island and two teams at the University of Texas - Austin participated in researching, designing, building, and testing projects to support international nuclear safeguards measurements or verification. The projects involved engaging in activities at the university's research reactors. All the projects engaged students with prototyping a design and/or tool for application at the Universities' reactor. At the end of the course, most of the students expressed the experience was positive and they learned more about international nuclear safeguards and applying requirements than they had previously encountered.

This school year the projects were further complicated by the COVID-19 pandemic. Both universities had limited in classes on campus, still relying on Zoom classes, and limited direct student/professor interactions. Furthermore, Los Alamos National Laboratory (LANL) greatly restricted travel, therefore making it impossible to visit the students at the end of the semester for the review of their design projects. The final design and review meeting for the projects happened via meetings over the internet. Additionally, the teams did build and test some prototypes but could only do so in a limited capacity.

2. Merit to Human Capital Development (HCD)

These university challenges directly contributed to the HCD mission by introducing students from the broad engineering field to safeguards concepts and approaches as part of their engineering senior level design course. Unlike nuclear engineering or other safeguards-focusing majors, the students had no knowledge of safeguards, non-proliferation, or the International Atomic Energy Agency (IAEA) before initiating their projects. Using the Senior Capstone Project is a great venue for the students to get hands on experience incorporating safeguards needs into their designs and seeing how those needs interact with the engineering requirements that are more standard. The students not only learn about safeguards, but also learn that they can contribute to the safeguards mission. Nuclear safeguards can only reach its full potential in terms of cost and resource savings if all the different voices during the planning and construction phases of a facility are aware of the requirements and incorporate them in the design phases.

Some of these design concepts may eventually merit undergoing the patent process; and or sharing the designs for build and use at other research reactors.

3. FY22 University Engagements:

3.1 University of Rhode Island:

LANL and the University of Rhode Island (URI) are working three projects for the 2021-2022 school year. These projects go over two semesters, so the same team works on the projects for the entire school year. Each project team consists of four to five students. Additionally, the focus for the projects for this school year was using the Rhode Island Nuclear Science Center (RINSC), which houses a General Electric 2 mega-watt (MW), light water cooled, pool type reactor. See Figure 1.

Figure 1. Photographic showing Rhode Island Nuclear Science Center (RINSC) and the General Electric Research Reactor.[1]

Professors and Staff:

- Prof. Dr. Bahram Nassersharif: *Distinguished University Professor,* University of Rhode Island, Mechanical, Industrial and Systems Engineering Department

- Prof. Cameron Goodwin: *Adjunct Professor,* University of Rhode Island, Mechanical, Industrial and Systems Engineering Department, & Director, Rhode Island Nuclear Science Center

3.2 University of Texas-Austin:

LANL and the University of Texas-Austin (UT-A) worked one project for the fall 2021 and one project for the spring 2022 semester. Both project teams consisted of four students. Additionally, the focus for the project was using the research reactor at the Nuclear Engineering Teaching Laboratory (NETL) located on the J.J. Pickle Research Campus. The reactor is a 1 MW TRIGA (Training, Research, Isotopes, General Atomics) Mark II Research Reactor. These facilities are seen in Figure 2. As university's shut down other TRIGA reactors across the country, UT-A accepted fuel from the closing reactors. There is limited history on this fuel, so NETL has a safeguards need to identify the nuclear material content of the fuel.

[1] Rhode Island Nuclear Science Center, accessed August 18, 2020 here: http://www.rinsc.ri.gov/ and here: http://www.rinsc.ri.gov/education/

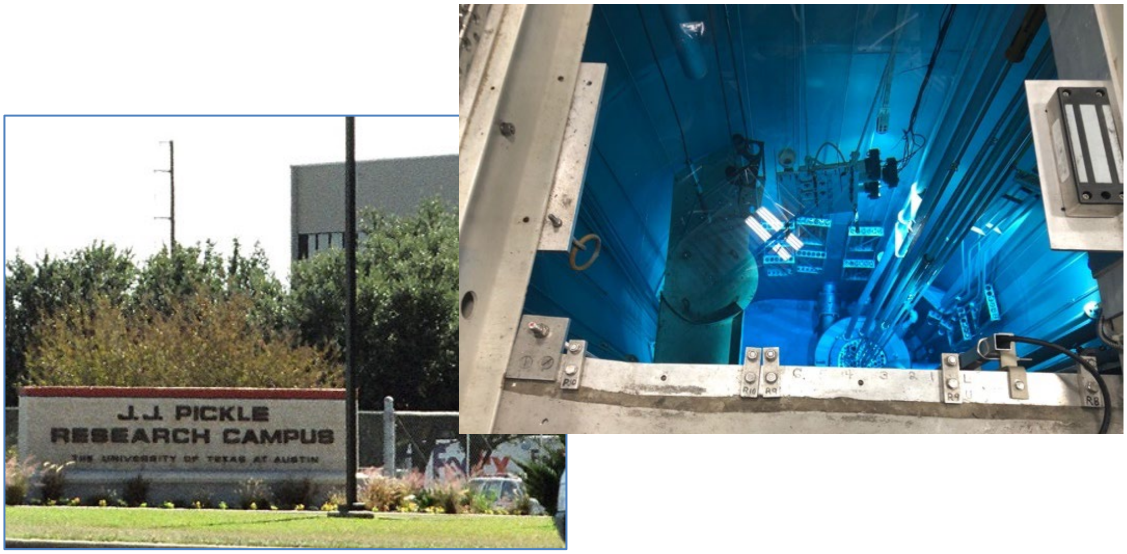

Figure 2. Photographic showing location of UT-A's Nuclear Engineering and Testing Laboratory (NETL) and the inside of the TRIGA Research Reactor.[2]

Professors and Staff:

- Prof. Richard Crawford: *Earl N. & Margaret Brasfield Endowed Faculty Fellowship in Engineering*, University of Texas at Austin, Walker Department of Mechanical Engineering

- Prof. William Charlton: *Director, Nuclear Engineering Teaching Laboratory (NETL)* and *John J. McKetta Energy Professor* in the Nuclear and Radiation Engineering Program, University of Texas at Austin, Department of Mechanical Engineering

- Jason Spivey: *Senior Design Projects Program Coordinator,* University of Texas at Austin, Walker Department of Mechanical Engineering

4. FY 22 Design Projects

In FY22 LANL completed 3 projects with student teams from URI and 2 projects with student teams from UT-A. See Table 1 for a complete list of FY22 projects. LANL has copy of all final reports, presentations, and brochures for student designs.

[2] Picture on left taken from: https://en.wikipedia.org/wiki/J._J._Pickle_Research_Campus

Table 1. List of University Engagement Projects for FY22

University	Project	Title	# Students
URI	1	Improved Underwater Rover for Fuel Inspection	5
URI	2	Improved Neutron Radiography Facility Design	4
URI	3	Radiation Detector Array for 3D Source Mapping	4
UT-A	4	Improved Calorimeter for Measuring Changes in Nuclear Fuel Content for Fuel in a TRIGA Reactor Pool – Fall Semester	4
UT-A	5	Improved Calorimeter for Measuring Changes in Nuclear Fuel Content for Fuel in a TRIGA Reactor Pool – Spring Semester	4
		Total Number of Students	19

4.1 University of Rhode Island Capstone Design Projects

4.1.1 Capstone Design Project 1: Improved Underwater Rover for Fuel Inspection

Design of an improved tethered gamma resistant single person Remote Operated Vehicle (ROV) for videography of nuclear fuel elements.

There are routine inspections of nuclear fuel elements at research reactors for safety and safeguards purposes. There are inspections of nuclear fuel assemblies at power reactors before core loading and after removal from core for refueling of the nuclear reactor. Currently at research reactors, operators inspect fuel elements manually by multiple operators. One operator removes the fuel element from the core, during shutdown, and raises the fuel element to approximately six feet underwater and a second operator takes photographs of the assembly from the pool side. There are several challenges that affect the photographing process; these challenges are optical distortion of the image by the presence of the water medium, surface disturbances caused by the pole holding the assembly, and the normal water circulation in the pool.

Operators would prefer to not have to raise the fuel assembly from its normal depth of approximately 30 feet under water, which would require the lowering of a camera to normal fuel depth and then photographing and video recordings at a relatively close distance to the fuel element. To accomplish this photography and videorecording would require designing a remotely operated underwater vehicle and camera to record the imagery.

The goal of this project is to improve on the design from the 2020-2021 Capstone Team. Then build, and test a underwater ROV to use photography and videography to support safeguards and nuclear material inventory taking of fuel at the RINSC reactor. The design has the following technical requirements.

- The ROV shall operate underwater to inspect nuclear fuel remotely in pool research reactors at approximate depths of approximately 30 feet and at least 6 feet away from the fuel element.

- The design shall meet international nuclear safeguards requirements and U.S. NRC safety regulations. This project shall build on the concept from the 2019/2020 school year project.

- The underwater rover design shall incorporate a camera with radiation protection (shielding) for still or video photography of fuel element in the pool research reactor to identify fuel element number and inspect fuel element for cracks or other damage.

- The underwater rover will be tethered to its operator and freely navigate the pool. Training for operation of the rover should take less than 2 hours.

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4.1.2 Capstone Design Project 2: Improved Neutron Radiography Facility

Design of an improved collimator for neutron imaging system for the Rhode Nuclear Science Center Reactor.

Neutron radiography is a useful tool for looking at used/spent/irradiated nuclear fuel. This device can find cracks in the fuel rod cladding, additionally with neutron radiography one can evaluate the nuclear material content of the fuel. Currently spent fuel content is a calculation based on reactor operation. Determining reactor operation time and conditions is challenging for research reactors because operators shut on and off reactor more frequently, move fuel around more frequently, and often flip fuel rods for improved performance. Measurements of actual nuclear material content in the fuel rod would support international nuclear safeguards and improve nuclear material accounting. The task for the students was to design a neutron radiography facility that could be part of the RINSC, for better fuel nuclear material accounting and photographic radiography for fuel inspection to look for defects in the fuel rod cladding.

For the second URI project, the design team shall improve on the design from the 2020-2021 school year to be able to design a capability to do neutron radiography and neutron spectroscopy for nuclear material content of fuel. This project may only be a design project and not a build and test project if URI is unable to acquire the necessary hardware for the project. The design has the following technical requirements.

- The improved design of a neutron radiography facility for the Rhode Island Nuclear Science Center that could assist in meeting international nuclear safeguards requirements (inspection and elemental/isotopic analysis of fuel) and will meet NRC safety regulations. The design shall begin with the design from the previous year (2020-2021 school year).

- This design shall improve on previous designs in the areas of neutron beam device, radiation imaging, and conversion to visual band. The work will focus on the design, build, and testing of the collimator for use at the Rhode Island Nuclear Science Center (RINSC).

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4.1.3 Capstone Design Project 3: Radiation Detector Array for 3D Source Mapping

Design of an array of three gamma directors to detect radioactive source in three dimensions

The ability to locate sources of radioactivity has various safeguards and security applications. One is the ability to perform environmental sampling to detect sources at nuclear facilities. Second, the ability to locate sources would be usable at locations such as border inspection stations or port of entries to detect the transport of radioactive material for illicit reasons. The RINSC possesses detection tools that can aid in these applications and could be useful for locating sources within the facility.

For the third URI project the design team shall develop an apparatus and software for locating a radiation source in three dimensions utilizing three radiation detectors on the x, y, and z axes. The design has the following technical requirements.

- Locate radiation source within three dimensions within an accuracy of ±10% using an array of three gamma detectors applied to radiation source provided by the RINSC.
- Develop calculation software to process detector information automatically into a location of the source within a three-dimensional volume
- Comply with ALARA safety standards
- 1 atm operating conditions

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4.2 University of Texas at Austin Senior Design Project

4.2.1 Senior Design Project 1: Improved Calorimeter for Measuring Changes in Nuclear Fuel Content for Fuel in a TRIGA Reactor Pool – Fall Semester

Development of an improved design to use calorimetry measurements for measuring changes in irradiated nuclear fuel in a TRIGA reactor pool

It is critical to global security to ensure there is no diversion of nuclear materials from civilian nuclear facilities for military purposes. A system of safeguards can support verifying the completeness and correctness of a state's declaration of their nuclear materials and nuclear activities. Due to the highly variable and adaptable nature of research reactors, the verification of the nuclear material content of nuclear is challenging. For the University of Texas at Austin Nuclear Engineering Teaching Laboratory (NETL) reactor this issue is further complicated by the progeny of its fuel materials. All the fuel used by the NETL came from another research reactor facility, therefore the details of the irradiation profiles of the fuel is unknown. Thus, there is a larger than desirable uncertainty associated with the nuclear material content of the fuel used at the NETL.

Operators typically characterize nuclear fuels by the fuel burnup, irradiation time, cooling time, and initial ^{235}U enrichment. Burnup measures the energy produced by the fuel per unit mass of initial uranium. Knowledge of the characteristics listed above are useful in correlating nuclear material content of the used fuel (specifically ^{235}U and Pu mass).

The project focuses on using calorimetry to measure changes in irradiated nuclear fuel in a

TRIGA Research Reactor Pool. The technique of calorimetry assay of nuclear materials involves the measurement of the heat transfer rate released by nuclear fuel. In this project, the students are working with irradiated fuel. The project involves measuring accurately the heat transfer, and from this one can calculate the content of some isotopes present in the nuclear fuel. Therefore, the calorimetry technique can be useful in accounting for changes in the isotopic composition of fuel rods at research reactors.

The following are requirements for the design project.

- The research reactor fuel measurement system shall be able to measure the nuclear content of used nuclear fuel at the UT-A Nuclear Engineering Teaching Laboratory (NETL) TRIGA reactor. The system shall meet international nuclear safeguards requirements and U.S. NRC safety regulations.
- The research reactor fuel measurement system will design a calorimetry measurement capability for measuring irradiated fuel in the reactor pool. The Fall 2021 team shall build upon the work completed by the Spring 2021 team.
- The instrument capability shall undergo a demonstration of the calorimetry measurement system on a benchtop scale
- The team will also develop Computer Aided Drawing (CAD) files of the final design, thermal finite element analysis for simulated TRIGA fuel rod, and Bill of Materials

4.2.2 Senior Design Project 2: Using Calorimetry to Measure Changes in Irradiated Nuclear Fuel in a TRIGA Reactor Pool

Development of a capability to use calorimetry measurements for measuring changes in irradiated nuclear fuel in a TRIGA reactor pool

The spring senior design project continues the work with the same motivations as the fall design project to develop a calorimeter to measure irradiated nuclear fuel. Their developments are based off an assessment of the work performed during the course of Senior Design Project 1 in the fall semester. The work looked to make adjustments to the design of the fall semester, as well as do additional advanced finite element analysis and develop a full-scale prototype for making measurements on a single rod in the TRIGA reactor spent fuel pool.

The following are requirements for the design project:

- The research reactor fuel measurement system shall be able to measure the nuclear content of used nuclear fuel at the UT-A Nuclear Engineering Teaching Laboratory (NETL) TRIGA reactor. The system shall meet international nuclear safeguards requirements and U.S. NRC safety regulations.
- The research reactor fuel measurement system will design a calorimetry measurement capability for measuring irradiated fuel in the reactor pool. The Spring 2022 team shall build upon the work completed by the Fall 2021 team.
- The team will develop a mechanical stirring mechanism to ensure homogenous heat distribution for measurement of spent fuel rod heat emission.

- A prototype for measuring heat emission of a single fuel rod will be developed and tested
- The team will also develop CAD files of the improved final design based off prototype testing, thermal finite element analysis for simulated TRIGA fuel rod, and Bill of Materials

5. FY22 Project Teams and Final Deliverables

The Covid-19 pandemic greatly affected all the university teams. The teams had limited support in testing designs and making improvements to their design projects. The teams delivered their final presentations via the internet, either through Skype or WebEx. LANL made no visits in the fall and spring semesters to meet with university teams and support meeting the students for the final project review.

5.1 University of Rhode Island Capstone Design Projects

5.1.1 Capstone Design Project 1: Improved Underwater Rover for Fuel Inspection

The students designed, built and tested a remotely operated underwater drone for the visual inspection of spent fuel rods. The drone selected was a bottle type of design that was tested both for maneuverability and focal length underwater of the built-in camera to ensure the ability to inspect the serial numbers on fuel rods from distances of six feet. The team consisted of members Jacob Glantz, Felicity Griffin, Paulina Loredo, Emmett Nguyen, and Ryan Wisniewski. A photo of the team is seen in Figure 3. The final design constructed is seen in Figure 4. A replica of their final design poster in seen in Figure 5.

Figure 3. URI Student Team 1: Felicity Griffin, Ryan Wisniewski, Paulina Loredo, and Jacob Glants (Not Pitcured Emmett Nugyen)

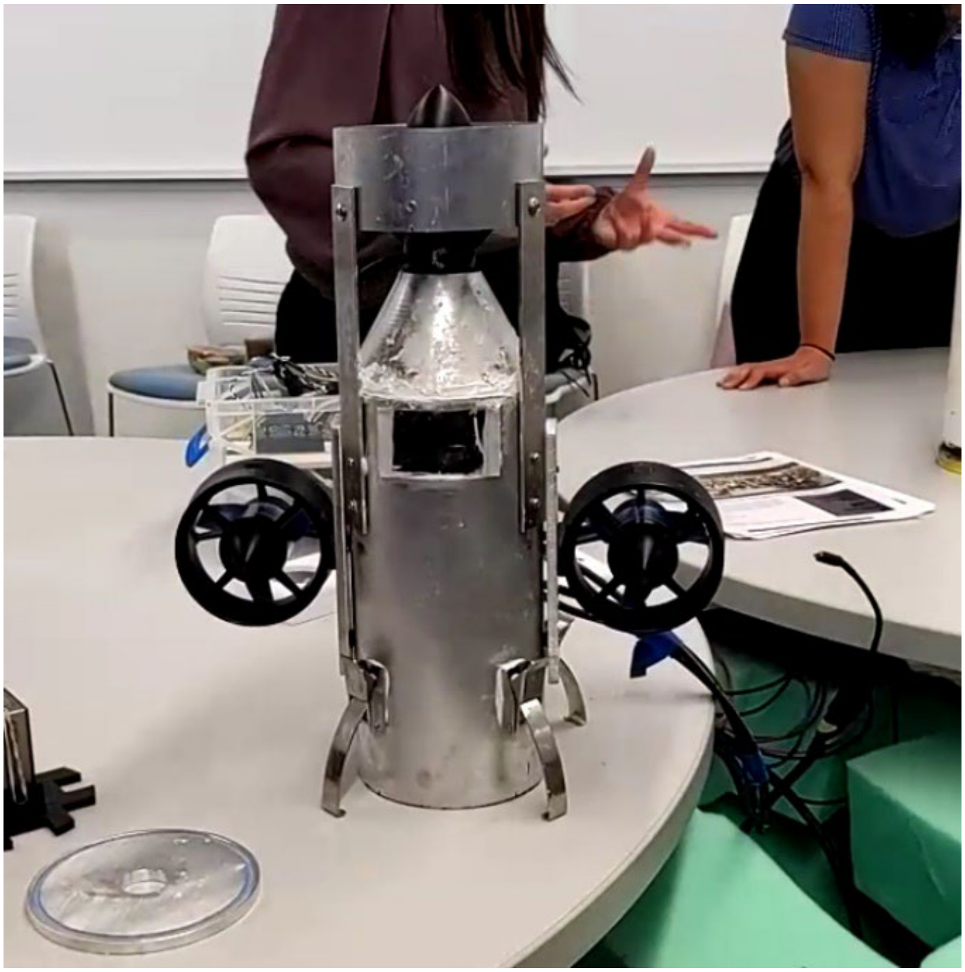


Figure 4. URI Team 1 Final Design

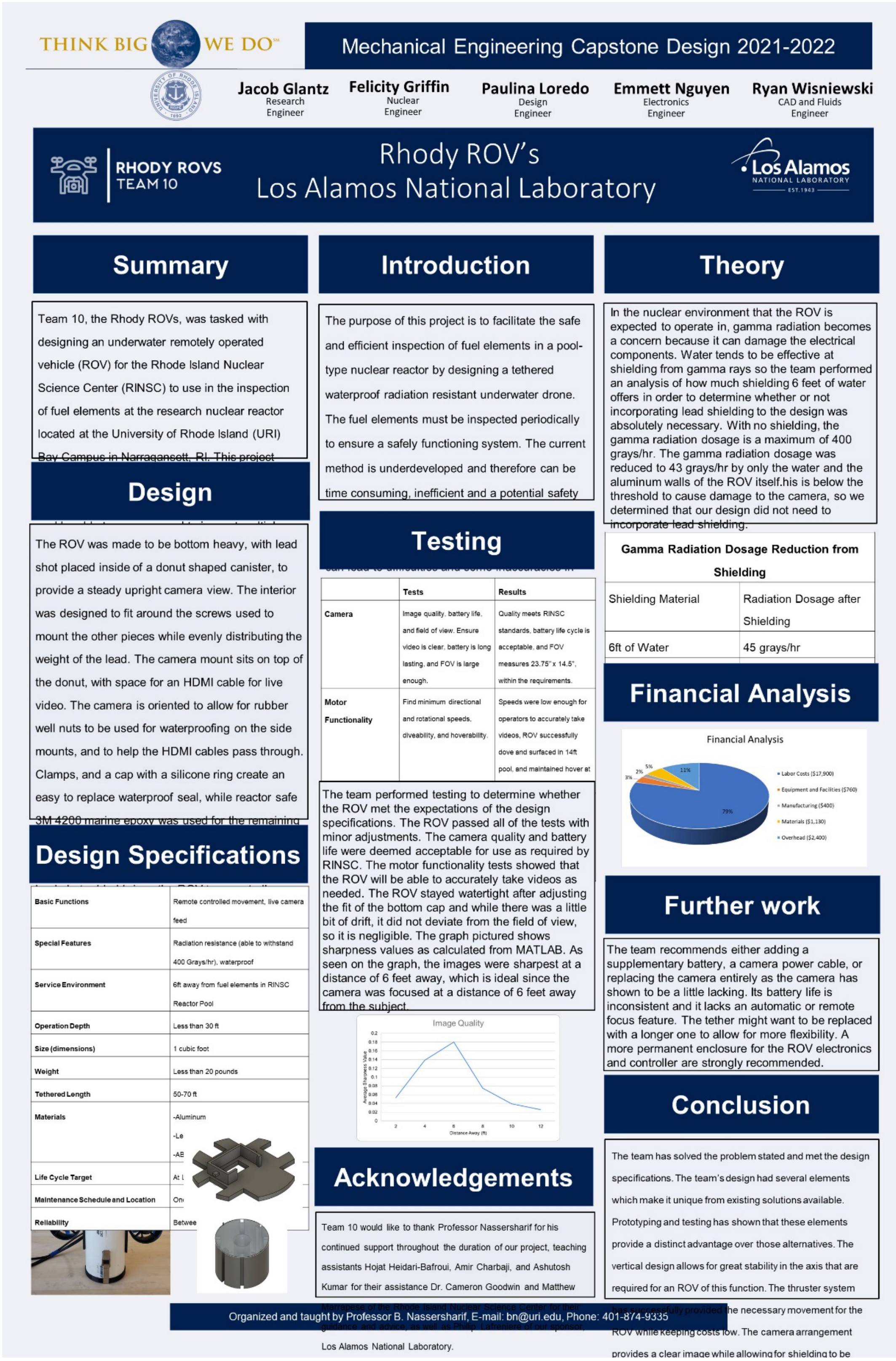


Figure 5. URI Team 1 replica of final poster.

5.1.2 Capstone Design Project 2: Improved Neutron Radiography Facility

The students designed and built a collimator for neutron radiography to be deployed and fitted at the research reactor at URI. This was a continuation of FY 21 work. The collimator developed and constructed was a parallel collimator design consisting of a series of aluminum shells with boron carbide powder and concrete being alternatively packed into annular discs and being spread through the collimator. The team consisted of members Matthew Cabral, Giorgios Bovis, Ashwin Narayan, and Ryan Barker. The team members with their final constructed collimator are seen in Figure 6. A replica of their final poster is seen in Figure 7.

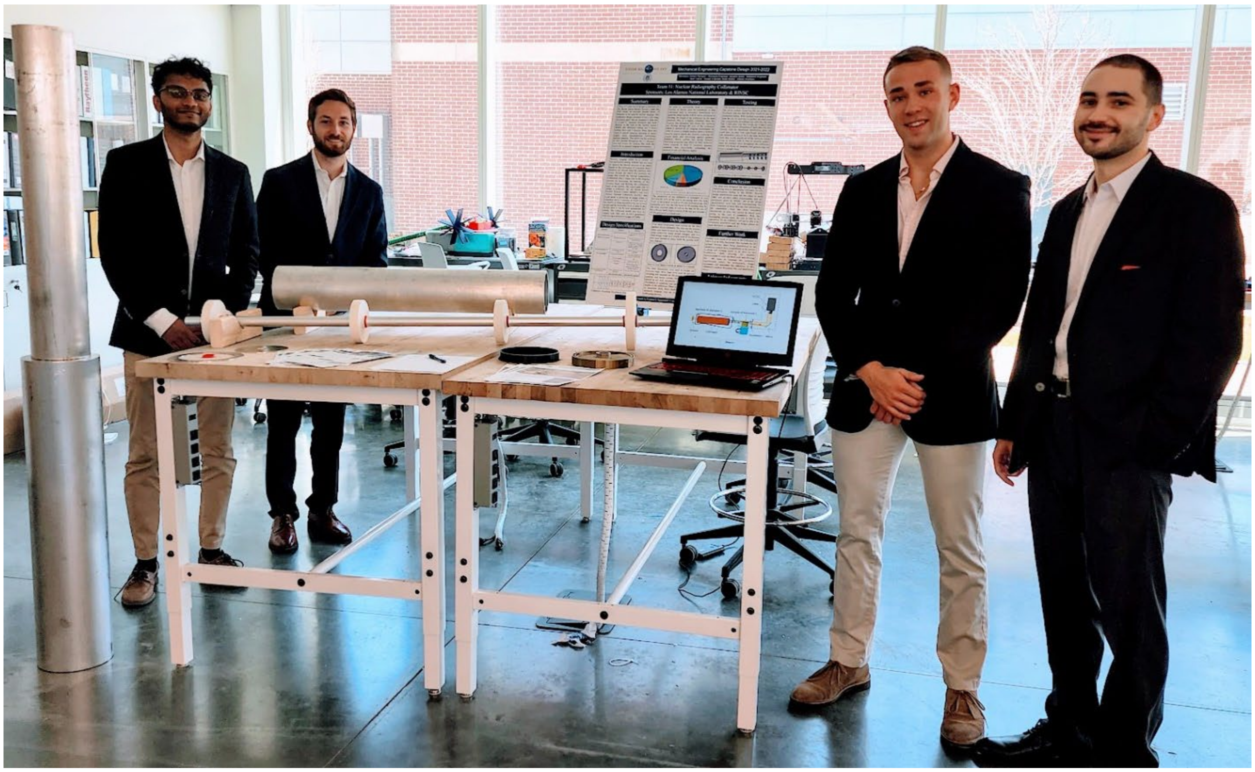


Figure 6. URI Student Team 2 Members with Collimator for Nuclear Radiography Facility: Ashwin Narayan, Ryan Barker, Matthew Carbral, and Giorgios Bovis,

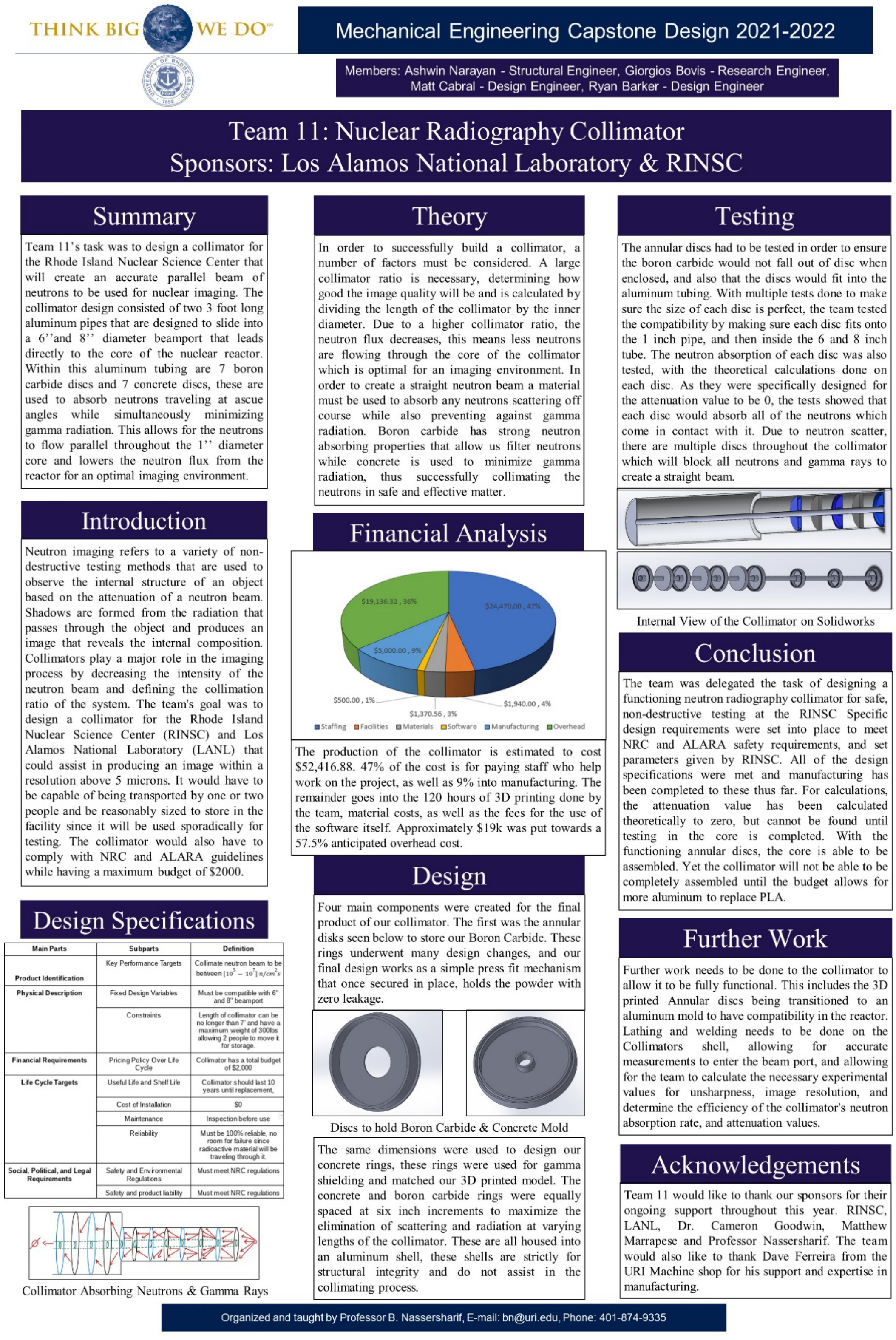


Figure 7. URI Team 2 replica of final poster.

5.1.3 Capstone Design Project 3: Radiation Detector Array for 3D Source Mapping

The students developed and built a multi-detector array for mapping a radiation source in 3-dimensions. The design project consisted of two components of development, the physical detector array setup and the processing program to calculate the location of the source with its associated error.

The final design involved three detectors placed on adjustable tripods to provide position data along with counting data to the post-processing programs. The exact position of the detector is determined using a laser measurement system allowing for extremely precise measurements to perform the triangulation calculation in the processing program. The processing program built in MATLAB was able to both calculate the position and plot it in 3-dimensions. The intended use of the program and detector system is a deployable source locating system that can be applied to both safeguards and orphan source applications.

The team consisted of members: Jacqueline Schings, Michael Peters, Carlos Casanova, and Cameron Lavoie. A photography of the team is provided in Figure 8. As part of the project, an ANS transaction paper was developed and submitted to the 2022 Winter ANS Conference. A photo of the completed design is seen in Figure 9. A replica of their final poster is seen in Figure 10.

Figure 8. URI Student Team 3 Members Radiation Detector Array for 3D Source Mapping: Cameron Lavoie, Carlos Casanova, Jacqueline Schings, and Michael Peters

Figure 9. URI Team 3 Final Detector Array Apparatus Design

THINK BIG WE DO

Mechanical Engineering Capstone Design 2021-2022

Carlos Casanova
CAD & Survey Engineer

Cameron Lavoie
Marketing Engineer

Michael Peters
Analytics Engineer

Jacqueline Schings
Project Manager

Los Alamos NATIONAL LABORATORY

Team 12: Radfinder

RADFINDER

Summary

Team 12 was tasked with creating an array composed of three gamma-ray detectors, provided by the university, to detect gamma radiation in two dimensions. It was determined the array could be used instead to determine a radiological source's position in three dimensions. A methodology and MATLAB script was developed to accurately determine the positions of gamma-ray emissive sources.

Introduction

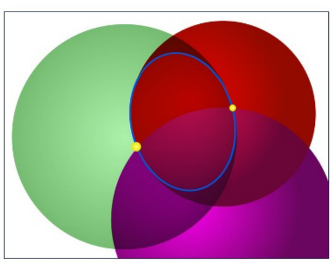
The team was tasked with determining the position of a radioactive gamma source in two dimensions using three gamma detectors. However, after additional consideration, it was realized that it was possible to locate the source in three dimensions. With nuclear non-proliferation as the team's primary focus, the team set out to create an array that could cut down on the radiation exposure to personnel searching for a radioactive source. To achieve this, the team developed a triangulation algorithm that could accurately and reliably calculate the position of the source using the data collected from the provided detectors in counts per second (CPS) and the positions of the detectors in an X, Y, Z coordinate system. After running various trials, it was observed that the array was always able to accurately determine the position of the radioactive source to +/- 10% of the target volume, which was approximately 25 cubic ft. Additionally, it was also found that only one detector was needed to calculate the position of the source provided four measurements are taken at unique locations. Our team was constrained by design specifications which acted as design and testing guidelines.

Manufacturing Cost	Less than $500
Accuracy / Precision	+/- 10% of target volume
Market Demand Anticipated	100 to 1000 units a year
Intended Use	Nuclear Non-Proliferation
Use conditions	-15 F to 115 F, and 1 Atm.

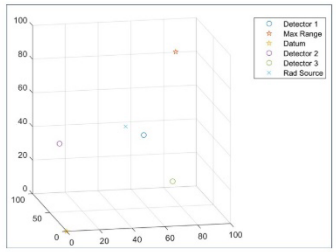
Subset of Design Specifications

Theory / Method

The design utilizes the principles of triangulation. This theory is best shown in GPS (Global Positioning Systems) and is alternatively known as trilateration. To successfully implement this array, a survey control device is required. The team decided to use the Leica DISTO S910 for this purpose. By knowing the intensity of the radiation field as measured in CPS by the detectors the team can determine the relative difference between the magnitude of the radii from each detector to the source. Knowing the origins of these spheres (otherwise known as the locations of the sensing crystals) and using spherical equations allows the team to determine two possible source positions. A second set of readings eliminate the false position. If the readings of the detectors get low enough to be less than 150% of the background radiation, the array must be made smaller. The intensity of the radiation source determines the overall size of the array. To take this important factor into consideration the team decided the design requires mobility and adjustability. This is reflected in the midscale design where the team uses tripods for maximum adjustability and adaptability.



Three spheres overlapped, the two yellow dots represent the potential source locations



MATLAB Plot Showing Position of Source and Detectors in 3 Dimensions

Design

The team's design required the manufacturing of 3D printed adapters that could clip and hold securely the gamma detector wands. These 3D printed adapters went through multiple iterations, all these iterations can be seen in the photo below. These adapters have a tapped ¼ in-20 screw hole in the base of the adapter on the bottom. This is used to attach the adapters to the tripods that we use in the midscale design. The left two iterations were different in their tolerancing. The difference between the black adapter and the gray adapter is a ½ mm tolerance. The adapter was designed with ergonomics in mind, it is easy to grip the front or the rear end of the adapter and push down to easily disconnect the adapter from the detector. To account for the needed adjustability of the array a purchase request for four Amazon Basic tripods was placed. These tripods have different height adjustments, and the tops can swivel in azimuth and altitudinal directions. They also have a ¼ in-20 screw on the top, which mates with the tapped hole on the adapter. The price to manufacture the adapters and to purchase the tripods was ~$500. The detector adapters have been made mistake proof as the detectors can snap in regardless of the direction of the adapter. The triangulation software was refined many times throughout the design project. Mathematica was the first software we utilized to solve the spherical equations but due to a lack of functionality a transition to MATLAB occurred. After the conversion to MATLAB the solutions were more accurate. The MATLAB script was made more user friendly using a graphical user interface (GUI). The results were also easier to visualize as the team created a three-dimensional plot of the detector sensing crystals with the position of the radioactive source so the operators would be better equipped at finding a source in the field.

The different iterations of the detector adapter design in order from oldest (left) to newest (right)

Testing

During the year, dozens of different tests were conducted. The team tested to see the actual viewing angle of the detectors and determined it to be a 270-degree wide angle where the readings of the detectors are above 85% of the highest value measured. The detector adapter's thread was also strength tested and rated at a factor of safety greater than three. The team also found that the source was consistently found within +/- 10% of the target volume. The MATLAB script was revised, and the team performed the midscale array design test utilizing a Leica DISTO S910. This device was used to verify a coordinate system in AutoCAD so the team was better able to extract coordinates for input into the MATLAB script. The team conducted testing comparing the calibration of the Canberra detectors to a calibrated Ludlum detector to correct error in the data because the detectors could not be calibrated and achieve the highest precision and accuracy possible. To the top right is a photograph of our midscale design testing setup.

Financial Analysis

Manufacturing Cost	~$500
Price	~$18406
Estimated Retail Cost	~$19906
Energy Cost (Operation)	~$50-100 per 8-hour operation
Detectors with analyzers	$9906
Total Cost as of 4/20/2022	$25496.80
Overhead as of 4/20/2022	$8286.13

Estimated costs

Conclusion

The team created an array that is expandable, ergonomic, while keeping it as simple as possible with a graphical user interface. The research and design conducted during our design project could be used and implemented in future projects in nuclear non-proliferation and orphan source detection systems with a possibility for additional applications. The triangulation software and the theory can utilize any gamma detector which outputs a count rate. The design is successful at determining the location of an unknown radiological source within +/- 10% of the adjustable target volume, and it can perform this function in three dimensions, with one, two, or three detectors. By those metrics, the team considers this design project to be a success.

Photograph of Midscale Array

Further Work

The design still has experiments that need to be conducted. The team conducted the midscale testing to minimize scattering, future work would include conducting testing to determine the effects of higher levels of scattering in different environments. The team also would have liked to time a third party assembling and disassembling of the array using the team's assembly manual. The team would like to make the location of the source update in real time using an updated analysis program in MATLAB, which was not possible since the team did not have access to the detectors' computer interface program. As a team, we have recently learned that placing the detector stands too close to each other relative to the radiation source can cause the result to be inaccurate. Future experiments to assess the minimum variation in detector positions to attain accurate position readings from the array software are needed.

Acknowledgements

The team would like to thank Professor Nassersharif and Teaching Assistants Hojat Heidaribafroui and Ashutosh Kumar. We would also like to acknowledge our sponsor Dr. Philip Lafreniere of LANL for helping and consulting with the team. The team would also like to thank Dr. Cameron Goodwin and the many cooperative staff members from the RINSC for providing us laboratory space.

Organized and taught by Professor B. Nassersharif, E-mail: bn@uri.edu, Phone: 401-874-9335

April 29th, 2022

Figure 10. URI Team 3 Replica Final Poster

5.2 University of Texas at Austin Senior Design Project

5.2.1 Improved Calorimeter for Measuring Changes in Nuclear Fuel Content for Fuel in a TRIGA Reactor Pool – – Fall 2021

The Nuclear Engineering Teaching Laboratory (NETL) at The University of Texas at Austin hosts a General Atomics TRIGA Mark-II Reactor. NETL's uses the reactor for a variety of research that involves radiation or isotope production. The NETL must adhere to some basic safeguards and security codes to protect the facility and the surrounding community. A safeguard in place is the accounting of all nuclear materials in a facility, ensuring that none of it is diverted by ill-intentioned actors. The project aimed to help NETL with its security goals.

The students designed and prototyped a calorimeter to measure the power released by the fuel rods that are taken out of the TRIGA reactor. This measurement can be useful to the staff at NETL, since there are relations between the power released by a fuel rod and the isotopic composition of it. This means that NETL could have an accurate picture of how much nuclear material resides in their fuel rods.

The team's prototype design was a calorimeter that could assess a single fuel rod. After performing a Pugh assessment of possible design and assessing the previous Spring 2021 semester's design, the team settled on pursuing the development of both transient method and copper rod method calorimeters. To improve on the previous semester's design, the Fall 2021 design team applied vacuum insulation to their design rather than a foam insulation.

The team developed CAD drawings of the full fuel rod design and performed finite element analysis (FEA) to assess the safety and temperature change of the design under the conditions of a normal TRIGA fuel rod and to ensure that the water present in the measurement chamber of the calorimeter would not start to boil rendering the measurements inconclusive. The FEA analysis determined that the transient design would be able to make adequate measurements assuming there is at least an hour of time in the calorimeter before taking the measurement to ensure linear heat generation. The FEA analysis of the copper rod method determined that, for a 100 W rod, the copper rod method would be insufficient in removing heat from the measurement chamber of the calorimeter given the size constraints of the calorimeter apparatus. A figure of the model for the transient FEA analysis is seen in Figure 11.

The team performed benchtop scale experiments as a proof concept. Utilizing a YETI brand coffee mug with a 3d printed lid with orifices for insertion of thermocouples and a copper rod and an aquarium heater as a heat source, experiments were performed in a swimming pool. The experiments demonstrated that vacuum insulation would be effective for a calorimeter design, but challenges arise when determining placement of thermocouples as well as calibration of the apparatus. These are potential areas of improvement for the next semesters design team if they decide to build on their design.

The Fall 2021 design team consisted of members Salvador Chavarria, Parker Dentino, John Ketterer (Team Leader), Choonggao Lee. These members are pictured in Figure 12.

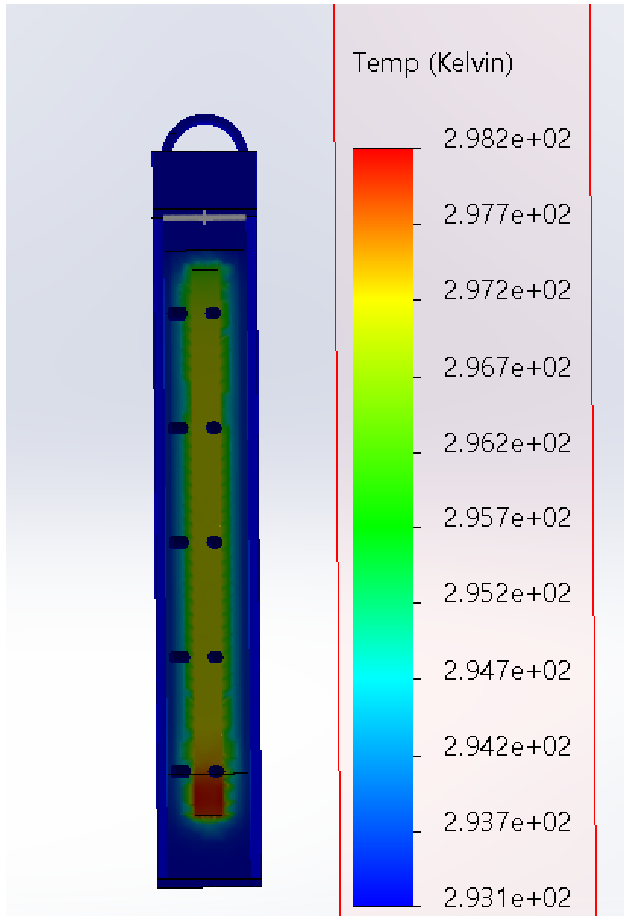


Figure 11- FEA analysis of Transient design for full fuel rod

Figure 12- (LEFT) John Ketter, Choonggao Lee, and Parker Dentino (L-R) with Copper Rod at UTexas machine shop (RIGHT) Salvador Chavarria and Choonggao Lee (L-R) setting up benchtop experiment on calorimeter

5.2.2 Senior Design Project 2: Continuation of Design of Calorimeter for Measuring Fuel Composition Changes in a TRIGA Reactor Pool, Spring 2022 Semester

The spring semester senior design project expanded on the work of the fall semester team. They reassessed the fall team's design and interacted with the team at NETL. After doing so, they determined to continue with the transient design suggested by the fall team as well as their suggestion to integrate a stirring mechanism. They however found after assessing the fall teams FEA analysis, that the simulations needed to be reperformed due to assumptions regarding radiative heating. In addition, after discussing with NETL, they recognized that a vacuum insulation for the calorimeter would be impractical and decided on foam insulation instead. They also learned the need to develop a tethered lid for the calorimeter design.

FEA analysis was performed to assess the design with a 100 W heat generation from the surface of a simulated fuel with a set convection coefficient on the external surface of the design. In performing the simulations, the team was able to decide on an increased outer diameter, polyurethane insulation thickness, and determining the length of heat retention. In addition, FEA analysis was performed to determine the effect of stirring. These simulations determined that for a stirrer design at the bottom of the calorimeter, the majority of the mixing of fluid and reduction of temperature gradient was at the bottom and middle of the calorimeter with little effect at the top.

The team also developed and built a prototype design. This involved two significant considerations. The first was the lid. A 3-d printed threaded lid tethered to the calorimeters was developed. This lid was developed with three different tops with three different keys. The decided design was a Phillips-Head top with 3d-printed key to be manually operated from above the spent fuel pool at a depth of four feet. This design was tested and adjusted to ensure a water-tight seal.

The second major design consideration was the stirrer. Due to the presence and proximity of radiation from the spent fuel rods, a mechanical design with a power source outside the spent fuel pool was selected instead of a magnetic stirrer design or a mechanical stirred with the power source attached to the bottom of the calorimeter. The stirrer is placed below a mesh that the fuel rod is set atop to ensure mixing without the rod actually touching the impeller of the stirrer. Hydrofoil impeller blades were selected as they provide for the mixing of low viscosity liquids.

The off the shelf prototype was constructed, however there were issues with getting the impeller motor to work and did not have a power source for the cartridge heater that would be involved with prototype testing. Due to time constraints at the end of the semester, experimental testing of the prototype could not be performed. Photos of the prototype body and lid are seen in Figure 13. This team consisted of members Alice Harvey, Aaron Ferguson, Brian Gensheimer, and Tayler Jasek.

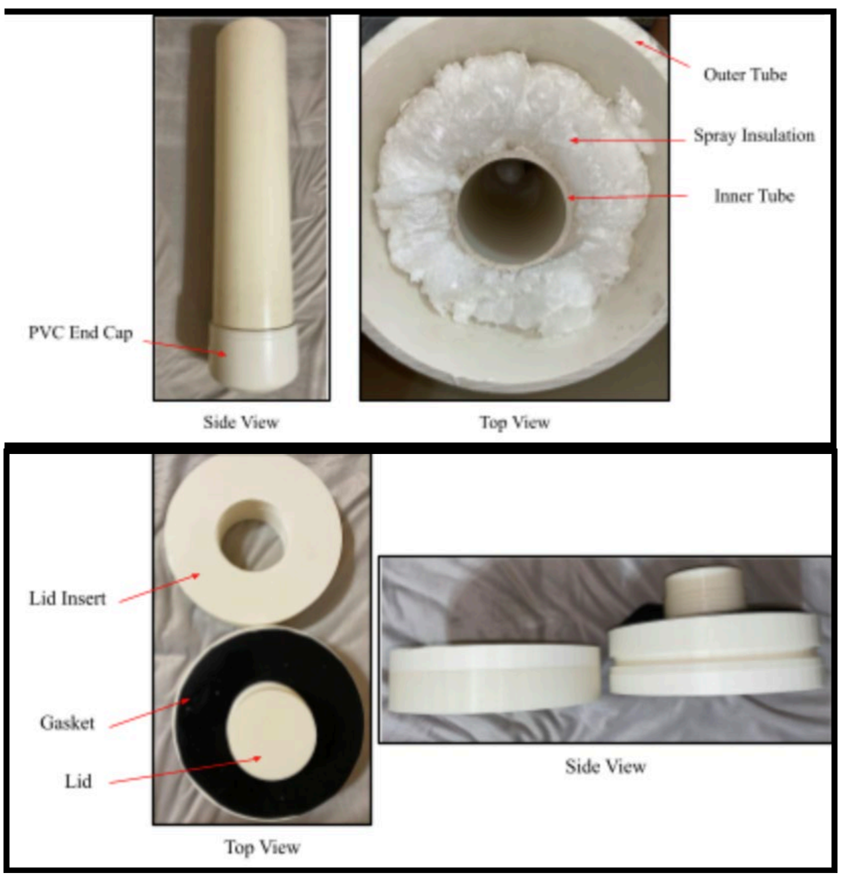


Figure 13. UTA Spring Semester Prototype Calorimeter Design Constructed

6. FY21 Additional Interactions and Outcomes

6.1 University of Rhode Island

6.1.1 LANL Presentations with URI

Carolynn Scherer presented the student projects with Professor Nassersharif on September 14, 2021; this presentation also covered the application of the 3 Capstone Projects to international nuclear safeguards. Philip Lafreniere met with all the students on the 3 design teams, reviewed their projects, helped with direction and guidance during the school year. These interactions were via Zoom and Webex.

6.1.2 URI Fall Semester

Philip attended the Proof-of-Concept reviews at URI on December 7, 2021 via Zoom.

6.1.3 URI Spring Semester

Philip attended the final presentations for the student work on April 15, 2022. All presentations at URI were via Zoom. Philip also was able to use Webex to attend the URI design showcase virtually on April 29, 2022.

6.2 University of Texas – Austin

6.2.1 UT-A Fall Semester

LANL met with the UT-A fall students and attended the final presentation on November 15, 2021. The meeting was via Zoom. There was a special WebEx event where the students had a chance to interact with LANL's Dr. Mark Croce, an expert in calorimetry and application to nuclear material measurements; additionally, he also covered microcalorimetry.

6.2.2 UT-A Spring Semester

LANL met with UT-A spring semester students regularly during the semester. There was a special WebEx events where the students had a chance to interact with LANL's Dr. Mark Croce, an expert in calorimetry and application to nuclear material measurements; additionally, he also covered microcalorimetry. Philip attended the final student presentation on April 21, 2022 via zoom.

7. FY23 University Engagement

In FY23, the university engagement and HCD will take a different approach than sponsoring a traditional capstone project. Instead, we will transition to engagement through instruction of a one-day tabletop exercise led by Y-12 to expose students to safeguards by design concepts. A representative will lead the exercise in person. As part of this project, the learning objectives, lecture modules, and tabletop exercise will be developed with the goal being that the Universities engaged with themselves will be able to takeover the tabletop exercise themselves after 2-3 years. As part of this proposal are Texas A&M University, University of California at Berkely, University of Michigan, University of Texas at Austin, and the University of Rhode Island.

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