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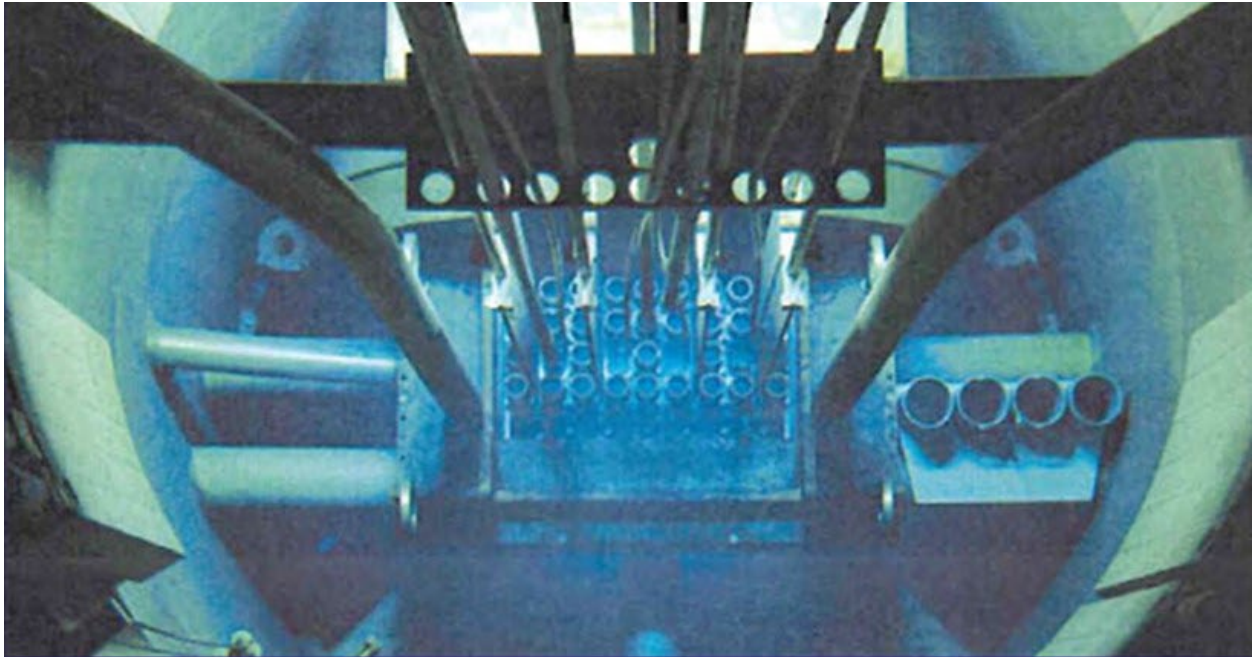
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Safeguards by Design Projects Final Report-FY-22

University of Rhode Island
University of Texas- Austin

**Philip Lafreniere
Christy Ruggiero**

9/6/2022
LA-UR

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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/>

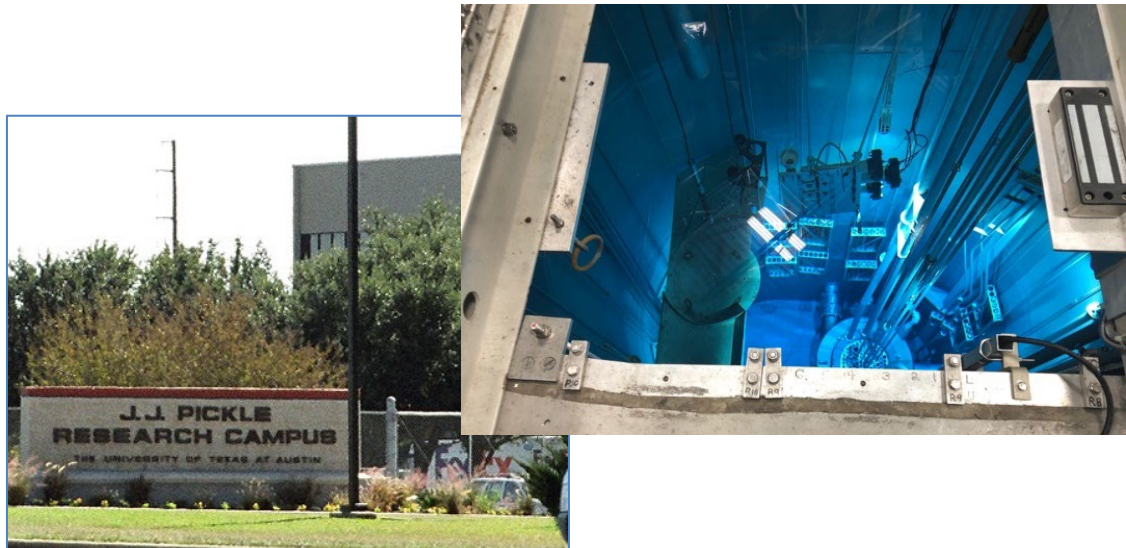


Figure 2. Photographic showing location of UT-A's Nuclear Engineering and Testing Laboratory (NETL) and the inside of the TRIGA Research Reactor.²

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.

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).

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

Design of an array of three gamma detectors 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 $\pm 10\%$ 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

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 Loreda, 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 is seen in Figure 5.



Figure 3. URI Student Team 1: Felicity Griffin, Ryan Wisniewski, Paulina Loreda, and Jacob Glantz (Not Pictured Emmett Nguyen)



Figure 4. URI Team 1 Final Design



Jacob Glantz
Research Engineer

Felicity Griffin
Nuclear Engineer

Paulina Loreda
Design Engineer

Emmett Nguyen
Electronics Engineer

Ryan Wisniewski
CAD and Fluids Engineer



**RHODY ROVS
TEAM 10**

Rhody ROV's Los Alamos National Laboratory



Summary

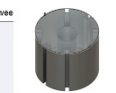
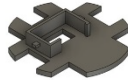
Team 10, the Rhody ROVs, was tasked with designing an underwater remotely operated vehicle (ROV) for the Rhode Island Nuclear Science Center (RINSC) to use in the inspection of fuel elements at the research nuclear reactor located at the University of Rhode Island (URI) Bay Campus in Narragansett, RI. This project

Design

The ROV was made to be bottom heavy, with lead shot placed inside of a donut shaped canister, to provide a steady upright camera view. The interior was designed to fit around the screws used to mount the other pieces while evenly distributing the weight of the lead. The camera mount sits on top of the donut, with space for an HDMI cable for live video. The camera is oriented to allow for rubber well nuts to be used for waterproofing on the side mounts, and to help the HDMI cables pass through. Clamps, and a cap with a silicone ring create an easy to replace waterproof seal, while reactor safe 3M 4200 marine epoxy was used for the remaining

Design Specifications

Basic Functions	Remote controlled movement, live camera feed
Special Features	Radiation resistance (able to withstand 400 Grays/hr), waterproof
Service Environment	6ft away from fuel elements in RINSC Reactor Pool
Operation Depth	Less than 30 ft
Size (dimensions)	1 cubic foot
Weight	Less than 20 pounds
Tethered Length	50-70 ft
Materials	-Aluminum -LE -AB
Life Cycle Target	At least 1 year
Maintenance Schedule and Location	On site
Reliability	Between 100% and 90%



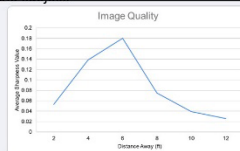
Introduction

The purpose of this project is to facilitate the safe and efficient inspection of fuel elements in a pool-type nuclear reactor by designing a tethered waterproof radiation resistant underwater drone. The fuel elements must be inspected periodically to ensure a safely functioning system. The current method is underdeveloped and therefore can be time consuming, inefficient and a potential safety

Testing

	Tests	Results
Camera	Image quality, battery life, and field of view. Ensure video is clear, battery is long lasting, and FOV is large enough.	Quality meets RINSC standards, battery life cycle is acceptable, and FOV measures 23.75" x 14.5", within the requirements.
Motor Functionality	Find minimum directional and rotational speeds, diveability, and hoverability.	Speeds were low enough for operators to accurately take videos, ROV successfully dove and surfaced in 14ft pool, and maintained hover at

The team performed testing to determine whether the ROV met the expectations of the design specifications. The ROV passed all of the tests with minor adjustments. The camera quality and battery life were deemed acceptable for use as required by RINSC. The motor functionality tests showed that the ROV will be able to accurately take videos as needed. The ROV stayed watertight after adjusting the fit of the bottom cap and while there was a little bit of drift, it did not deviate from the field of view, so it is negligible. The graph pictured shows sharpness values as calculated from MATLAB. As seen on the graph, the images were sharpest at a distance of 6 feet away, which is ideal since the camera was focused at a distance of 6 feet away from the subject.



Acknowledgements

Team 10 would like to thank Professor Nassersharif for his continued support throughout the duration of our project, teaching assistants Hojat Heidari-Bafroui, Amir Charbaji, and Ashutosh Kumar for their assistance Dr. Cameron Goodwin and Matthew

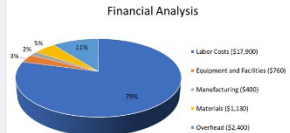
Theory

In the nuclear environment that the ROV is expected to operate in, gamma radiation becomes a concern because it can damage the electrical components. Water tends to be effective at shielding from gamma rays so the team performed an analysis of how much shielding 6 feet of water offers in order to determine whether or not incorporating lead shielding to the design was absolutely necessary. With no shielding, the gamma radiation dosage is a maximum of 400 grays/hr. The gamma radiation dosage was reduced to 43 grays/hr by only the water and the aluminum walls of the ROV itself. This is below the threshold to cause damage to the camera, so we determined that our design did not need to incorporate lead shielding.

Gamma Radiation Dosage Reduction from Shielding

Shielding Material	Radiation Dosage after Shielding
6ft of Water	45 grays/hr

Financial Analysis



Further work

The team recommends either adding a supplementary battery, a camera power cable, or replacing the camera entirely as the camera has shown to be a little lacking. Its battery life is inconsistent and it lacks an automatic or remote focus feature. The tether might want to be replaced with a longer one to allow for more flexibility. A more permanent enclosure for the ROV electronics and controller are strongly recommended.

Conclusion

The team has solved the problem stated and met the design specifications. The team's design had several elements which make it unique from existing solutions available. Prototyping and testing has shown that these elements provide a distinct advantage over those alternatives. The vertical design allows for great stability in the axis that are required for an ROV of this function. The thruster system

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

Los Alamos National Laboratory.

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.

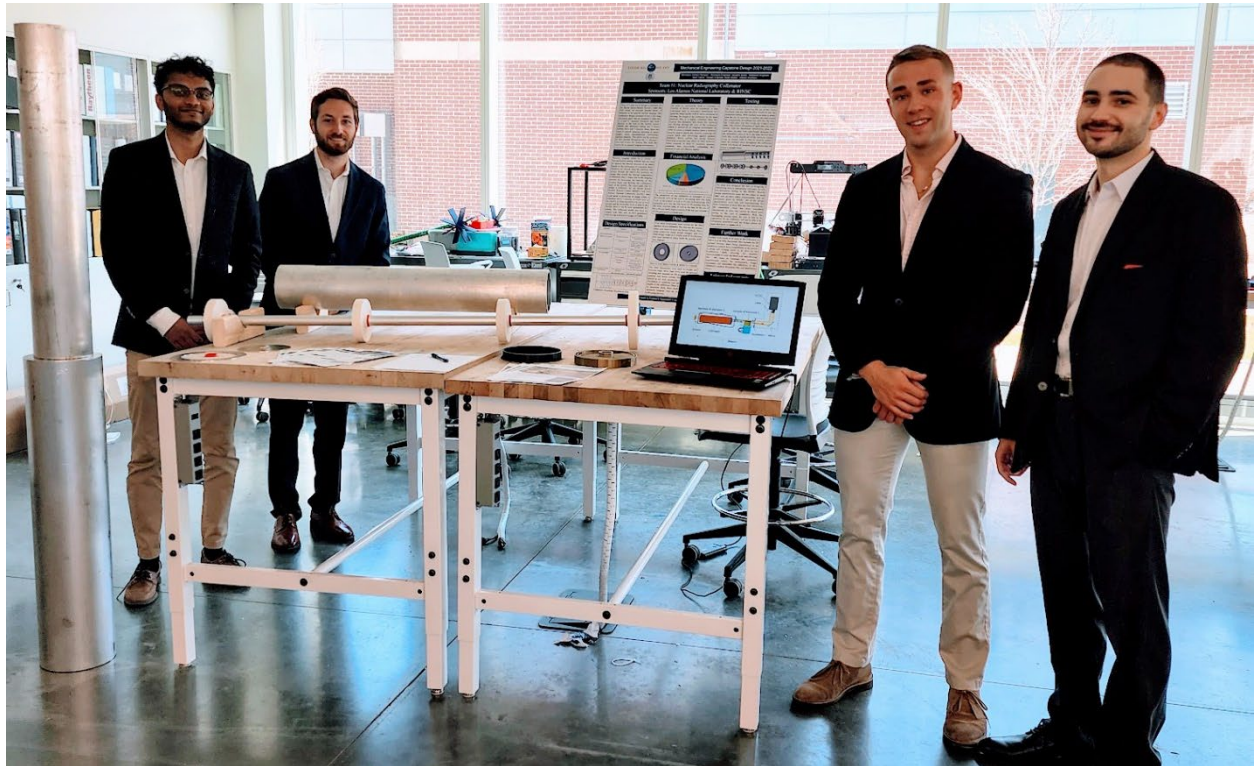


Figure 6. URI Student Team 2 Members with Collimator for Nuclear Radiography Facility: Ashwin Narayan, Ryan Barker, Matthew Carbral, and Giorgios Bovis,



Team 11: Nuclear Radiography Collimator Sponsors: Los Alamos National Laboratory & RINSC

Summary

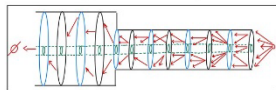
Team 11's task was to design a collimator for the Rhode Island Nuclear Science Center that will create an accurate parallel beam of neutrons to be used for nuclear imaging. The collimator design consisted of two 3 foot long aluminum pipes that are designed to slide into a 6" and 8" diameter beamport that leads directly to the core of the nuclear reactor. Within this aluminum tubing are 7 boron carbide discs and 7 concrete discs, these are used to absorb neutrons traveling at acute angles while simultaneously minimizing gamma radiation. This allows for the neutrons to flow parallel throughout the 1" diameter core and lowers the neutron flux from the reactor for an optimal imaging environment.

Introduction

Neutron imaging refers to a variety of non-destructive testing methods that are used to observe the internal structure of an object based on the attenuation of a neutron beam. Shadows are formed from the radiation that passes through the object and produces an image that reveals the internal composition. Collimators play a major role in the imaging process by decreasing the intensity of the neutron beam and defining the collimation ratio of the system. The team's goal was to design a collimator for the Rhode Island Nuclear Science Center (RINSC) and Los Alamos National Laboratory (LANL) that could assist in producing an image within a resolution above 5 microns. It would have to be capable of being transported by one or two people and be reasonably sized to store in the facility since it will be used sporadically for testing. The collimator would also have to comply with NRC and ALARA guidelines while having a maximum budget of \$2000.

Design Specifications

Main Parts	Subparts	Definition
Product Identification	Key Performance Targets	Collimate neutron beam to be between $(10^3 - 10^4) \text{ n/cm}^2 \cdot \text{s}$
	Fixed Design Variables	Must be compatible with 6" and 8" beamport
Physical Description	Constraints	Length of collimator can be no longer than 7' and have a maximum weight of 500lbs allowing 2 people to move it for storage.
	Pricing Policy Over Life Cycle	Collimator has a total budget of \$2,000
Financial Requirements	Useful Life and Shelf Life	Collimator should last 10 years until replacement.
Life Cycle Targets	Cost of Installation	\$0
	Maintenance	Inspection before use
	Reliability	Must be 100% reliable, no room for failure since radioactive material will be traveling through it.
Social, Political, and Legal Requirements	Safety and Environmental Regulations	Must meet NRC regulations
	Safety and product liability	Must meet NRC regulations

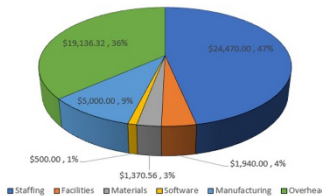


Collimator Absorbing Neutrons & Gamma Rays

Theory

In order to successfully build a collimator, a number of factors must be considered. A large collimator ratio is necessary, determining how good the image quality will be and is calculated by dividing the length of the collimator by the inner diameter. Due to a higher collimator ratio, the neutron flux decreases, this means less neutrons are flowing through the core of the collimator which is optimal for an imaging environment. In order to create a straight neutron beam a material must be used to absorb any neutrons scattering off course while also preventing against gamma radiation. Boron carbide has strong neutron absorbing properties that allow us filter neutrons while concrete is used to minimize gamma radiation, thus successfully collimating the neutrons in safe and effective matter.

Financial Analysis



The production of the collimator is estimated to cost \$52,416.88. 47% of the cost is for paying staff who help work on the project, as well as 9% into manufacturing. The remainder goes into the 120 hours of 3D printing done by the team, material costs, as well as the fees for the use of the software itself. Approximately \$19k was put towards a 57.5% anticipated overhead cost.

Design

Four main components were created for the final product of our collimator. The first was the annular disks seen below to store our Boron Carbide. These rings underwent many design changes, and our final design works as a simple press fit mechanism that once secured in place, holds the powder with zero leakage.

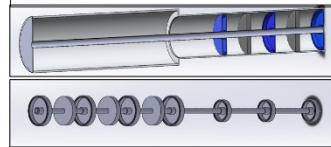


Discs to hold Boron Carbide & Concrete Mold

The same dimensions were used to design our concrete rings, these rings were used for gamma shielding and matched our 3D printed model. The concrete and boron carbide rings were equally spaced at six inch increments to maximize the elimination of scattering and radiation at varying lengths of the collimator. These are all housed into an aluminum shell, these shells are strictly for structural integrity and do not assist in the collimating process.

Testing

The annular discs had to be tested in order to ensure the boron carbide would not fall out of disc when enclosed, and also that the discs would fit into the aluminum tubing. With multiple tests done to make sure the size of each disc is perfect, the team tested the compatibility by making sure each disc fits onto the 1 inch pipe, and then inside the 6 and 8 inch tube. The neutron absorption of each disc was also tested, with the theoretical calculations done on each disc. As they were specifically designed for the attenuation value to be 0, the tests showed that each disc would absorb all of the neutrons which come in contact with it. Due to neutron scatter, there are multiple discs throughout the collimator which will block all neutrons and gamma rays to create a straight beam.



Internal View of the Collimator on Solidworks

Conclusion

The team was delegated the task of designing a functioning neutron radiography collimator for safe, non-destructive testing at the RINSC Specific design requirements were set into place to meet NRC and ALARA safety requirements, and set parameters given by RINSC. All of the design specifications were met and manufacturing has been completed to these thus far. For calculations, the attenuation value has been calculated theoretically to zero, but cannot be found until testing in the core is completed. With the functioning annular discs, the core is able to be assembled. Yet the collimator will not be able to be completely assembled until the budget allows for more aluminum to replace PLA.

Further Work

Further work needs to be done to the collimator to allow it to be fully functional. This includes the 3D printed Annular discs being transitioned to an aluminum mold to have compatibility in the reactor. Lathing and welding needs to be done on the Collimators shell, allowing for accurate measurements to enter the beam port, and allowing for the team to calculate the necessary experimental values for unsharpness, image resolution, and determine the efficiency of the collimator's neutron absorption rate, and attenuation values.

Acknowledgements

Team 11 would like to thank our sponsors for their ongoing support throughout this year. RINSC, LANL, Dr. Cameron Goodwin, Matthew Marrapese and Professor Nassersharif. The team would also like to thank Dave Ferreira from the URI Machine shop for his support and expertise in manufacturing.

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



Carlos Casanova
CAD & Survey
Engineer

Cameron Lavoie
Marketing Engineer

Michael Peters
Analytics Engineer

Jacqueline Schings
Project Manager



Team 12: 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

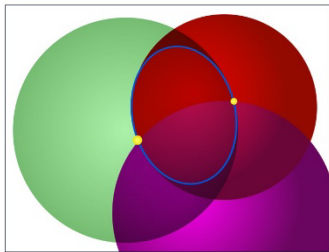
The team was tasked with determining the position of a radioactive gamma source in two dimensions using three gamma detectors. However, after additional consideration, it was realized that it was possible to locate the source in three dimensions. With nuclear non-proliferation as the team's primary focus, 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 $\pm 10\%$ 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	$\pm 10\%$ 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.

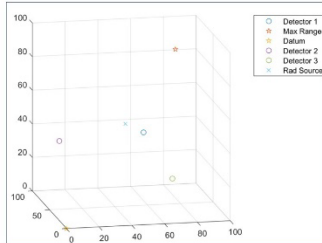
Subset of Design Specifications

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 $\frac{1}{4}$ 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 $\frac{1}{2}$ 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 $\frac{1}{4}$ 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 $\pm 10\%$ 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 $\pm 10\%$ 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 Heidarbafroui 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.

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), Choongao Lee. These members are pictured in Figure 12.

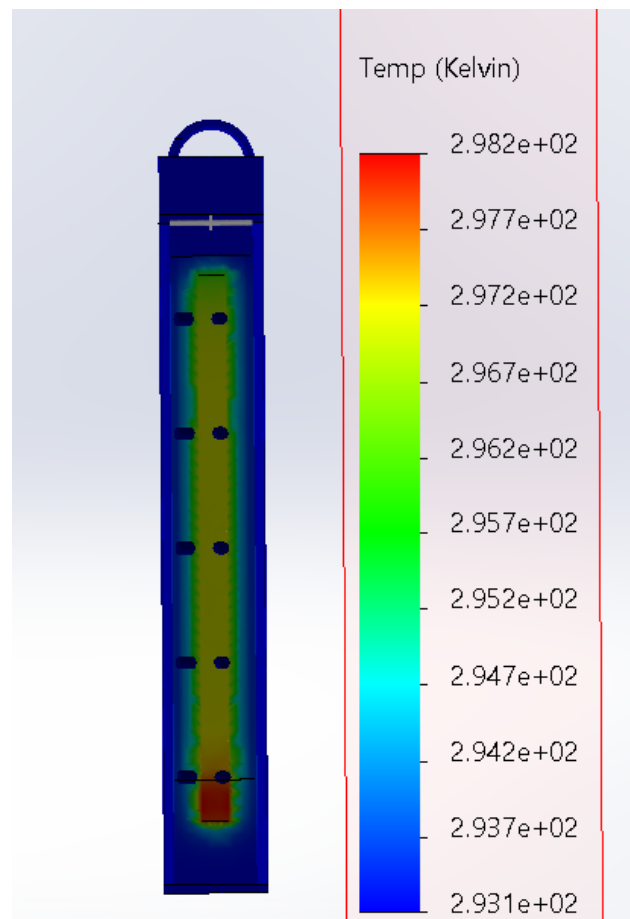


Figure 11- FEA analysis of Transient design for full fuel rod



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.

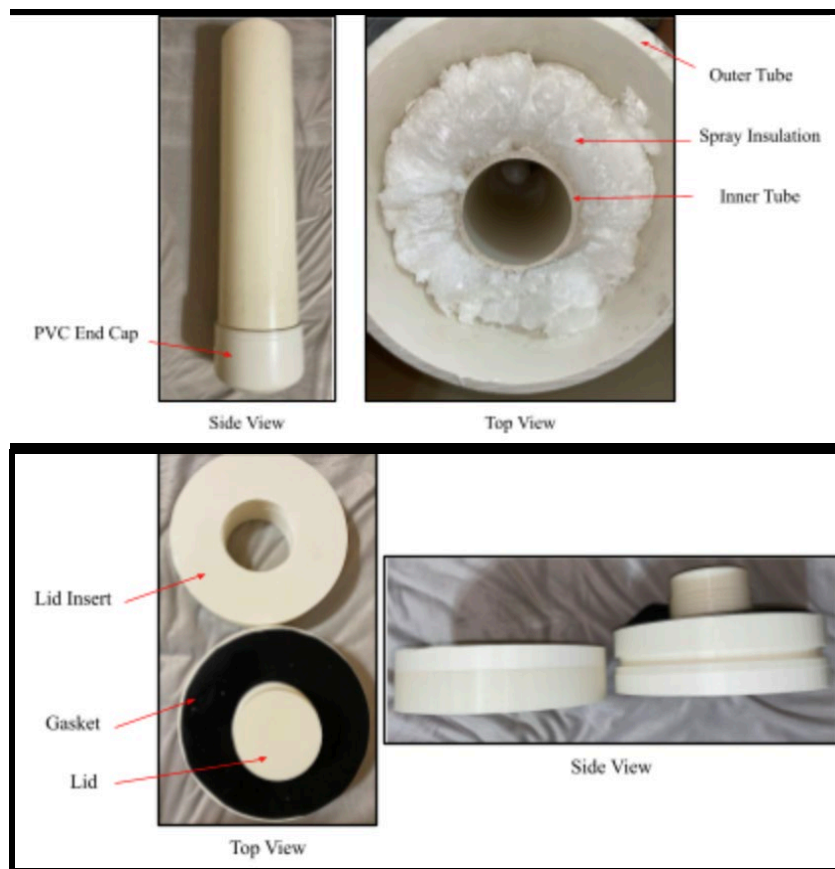


Figure 13. UTA Spring Semester Prototype Calorimeter Design Constructed

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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