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Nuclear Criticality Safety Pipeline Course with Hands-On Experimental Training at Lawrence Livermore's Inherently Safe Subcritical Assembly Training Center

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Nuclear Criticality Safety Pipeline Course with Hands-On Experimental Training at Lawrence Livermore's Inherently Safe Subcritical Assembly Training Center

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1. INTRODUCTION

The Nuclear Criticality Safety Divisions at Lawrence Livermore National Laboratory (LLNL) and Los Alamos National Laboratory (LANL) have partnered with Prof. Massimiliano Fratoni of the University of California Berkeley to offer a semester long course on nuclear criticality safety. This course is part of a larger pipeline project among many of the Department of Energy (DOE) laboratories designed to stimulate student interest in the field of criticality safety. The course focuses on teaching the fundamentals of criticality safety, familiarity with national and consensus standards, and preparing criticality safety evaluations. Students also receive hands-on experience with special nuclear material by performing experiments with the Inherently Safe Subcritical Assembly (ISSA) at LLNL [1]. Guest lectures are taught remotely and in-person by criticality safety engineers at LLNL and LANL, giving students an opportunity to interact with professionals in the field. The students complete a semester long project involving developing and writing a criticality safety evaluation.

As universities tend to focus heavily on nuclear power and advanced nuclear reactor design, this course gives students a better understanding and perspective of what criticality safety entails. The goal of this pipeline course is to introduce students to criticality safety as another available field for nuclear engineers. It is also a way for criticality safety programs to identify talented students who have the interest and aptitude to work in criticality safety for hire upon graduation. LLNL and LANL have both hosted past students as summer students, participated in students graduate projects, and hired students as criticality safety engineers. This has provided a unique opportunity for criticality safety programs to spot young talent with better retention outcomes.

2. COURSE STRUCTURE AND CONTENT

The structure of the pipeline course is to provide students with the knowledge and resources to perform criticality safety work at actual national laboratories and gain experience through hands-on experiments related to criticality safety. In addition, students have the opportunity to learn how to use various Monte Carlo radiation transport codes to perform criticality calculations. The course is only offered during the fall semester for undergraduate and graduate students with an average of 18 students per class. Students are paired in groups of three to four and assigned a semester long project to perform a criticality safety evaluation. LLNL and LANL act as operations personnel and mentor the students by fielding questions and defining the process inputs needed to perform the operation. Students learn how to navigate the process of developing a criticality safety evaluation, construct computational models with radiation transport codes, and familiarize themselves with industry accepted handbook data. Additionally, the Nuclear Criticality Safety Division at LLNL hosts the students at the ISSA training center to perform hands-on experiments and see how criticality safety controls are applied in real operations. At the end of the semester, each group presents their criticality safety evaluation and associated criticality safety controls.

2.1. Criticality Safety Evaluation Project

LLNL and LANL each provide three to four project options each semester for the students to pick from to perform their criticality safety evaluations. The topics are real life examples of operations currently performed, or future operations to be performed at each of the laboratories. Many of the projects relate to operations performed in a plutonium production facility. However, there are many options related to research and development opportunities to highlight the vast array of work criticality safety engineers perform. Some examples of past projects include additive manufacturing of uranium metal, ISSA experiments with heavy water, ^{233}U experiments with composite shielding, carbon aerosol capture of uranium metal, plutonium dissolution, plutonium precipitation, and plutonium oxide storage. The students are expected to use accepted handbook data or radiation transport codes to establish their basis for the operation remaining subcritical. Figure 1 shows computational models from previous projects constructed by the students.

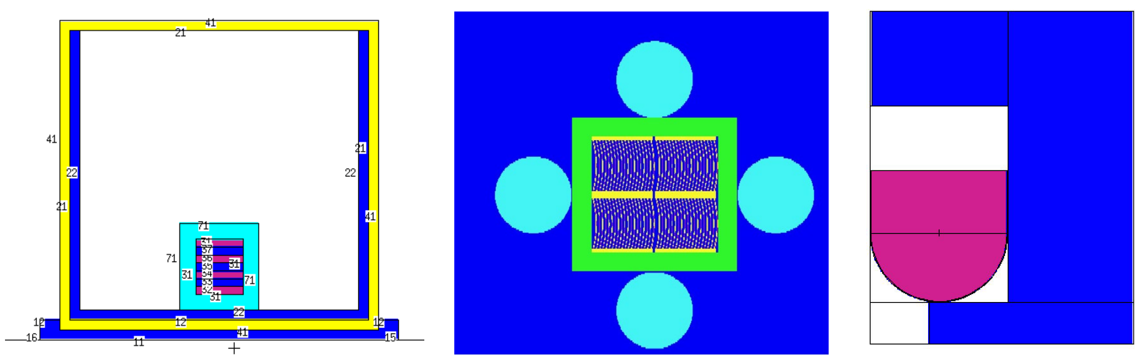

Figure 1. Computational Models Constructed by Students as Part of their Criticality Safety Evaluation Projects. Left: ^{233}U metal blocks with composite shielding; Center: ISSA assembly with heavy water; Right: Industrial mixer for performing solidification.

2.2. Hands-On Experiments with the Inherently Safe Subcritical Assembly

Two days during the semester, students travel to LLNL's Inherently Safe Subcritical Assembly (ISSA) training center designed to illustrate criticality safety and reactor physics concepts through hands-on experimental training. Students use a workbook to perform various experiments demonstrating the effects mass, spacing, water height, and moderation has on neutron multiplication [2-3]. ISSA consists of nine shortened Materials Test Reactor (MTR) type Omega West Reactor (OWR) "live" fuel assemblies made of highly enriched uranium ranging from 220 grams to 232 grams ^{235}U and a corresponding set of nine all-aluminum "mock" fuel assemblies [1]. Up to nine fuel assemblies can be placed in a lattice support structure and immersed in water in a tank. Four ^{3}He detectors are placed in tube wells and placed at any desired location within the ISSA tank. Neutron count rates may be measured using the inherent neutron source present in the fuel due to spontaneous fission of uranium isotopes and (α, n) reactions or by using an external ^{252}Cf or AmBe source placed within a central tube beneath the core.

Under the supervision of qualified LLNL criticality safety engineers, students are able to handle the ISSA fuel assemblies (Figure 2). For some students, this is their first experience with special nuclear material or with material at a quantity that can be made critical. The student workbook provides a number of well-defined steps allowing the students to add fuel assemblies one-by-one into the core. Upon each addition, students measure the count rate at different locations in the core and calculate the system's multiplication. The multiplication is then used to predict the number fuel assemblies needed to make the ISSA system critical with 1/M plots. Students are also exposed to other concepts used to perform approach-to-critical experiments like the half-way rule and three-quarter rule.

Figure 1. Students and Instructors Performing Hands-On Experimental Training with the ISSA Assembly at LLNL.

ISSA has many training capabilities for neutron multiplication and reactor physics experiments. In the future, we would like to broaden the available experiments to the Berkeley students or other students who would like to use the facility. Other experiments that have been performed with ISSA include neutron noise measurements with analysis methods including Rossi-α, Feynman Variance-to-Mean, and Cohn alpha, neutron multiplicity in passive interrogation mode, differential die-away with non-multiplying systems, and delayed neutron reinterrogation techniques with an external pulse neutron generator.

2.3. Hiring of Students from the Pipeline Course

Working at a national laboratory can be illustrious for many people, but the high cost of living in California for LLNL makes hiring and retention difficult. This pipeline course allows laboratories like LLNL to make connections and relationships to students at local colleges, who may want to stay in the area. Since starting this course in the fall of 2018, both LLNL and LANL have been able to hire students into the criticality safety field with some experience in criticality safety and with radiation transport codes. LLNL has hired one student from this Berkely course as a summer student, and later a full-time employee. LANL has hired three students from this Berkely course as full-time employees. Additionally, four students who took the Berkely course have found jobs in the field of criticality safety at other DOE laboratories. This demonstrates that by having a pipeline course, the desired outcome of hiring talented individuals with a better outcome for retention is achieved.

3. CONCLUSIONS

In partnership with the University of California Berkeley, a course on nuclear criticality safety has been established allowing students to interact with industry personal as well as gain useful experience. This course has led to at least six students pursuing full time employment in the nuclear criticality safety field and shown a higher rate of retention. Additionally, the use of LLN's ISSA training center allows students to gain valuable hands-on experience with special nuclear material. With the many training capabilities of ISSA, there is room to expand the experiments to be performed by students as well as support hosting other courses for university and industry personnel.

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