RESEARCH REACTOR UTILIZATION AT THE UNIVERSITY OF UTAH FOR NUCLEAR EDUCATION, TRAINING AND SERVICES

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1. INTRODUCTION

Educated and trained human capital is one of the most important requirements for successful deployment of nuclear technology and nuclear power industry in the world. Highly skilled workers for a number of different jobs are required to have a basic understanding of the nuclear engineering field, nuclear science principles, nuclear policy and regulations, nuclear security and forensics. Nuclear science and engineering applications can be found not just in the power and health industries, but also in military, industrial, environmental and commercial programmes around the world. Developing the insight and awareness of basic science and engineering principles behind nuclear technologies will not only provide enhanced marketability for students graduating from nuclear engineering programs but also better prepare them for careers that incorporate an increased understanding of nuclear science and engineering. Industry, national laboratories, government agencies, nuclear power plants and associated facilities in the US, as well as universities are all facing a huge wave of retirees in addition to the renaissance of nuclear engineering and science that is bringing a new demand for long term, profitable nuclear engineering careers both as workers and as entrepreneurs. Although the standard nuclear engineers are expected to have a college degree in nuclear engineering, the 21st century, as we see it, projects a demand for different career profiles: more diversified and broad knowledge gained through dual degrees, such as a combination of a major in any relevant discipline and a minor in nuclear engineering, and also encouraging such students to complete at least a master’s degree in nuclear engineering or where possible complete the reactor operation training. Having hands-on experience and capabilities to apply classroom knowledge into practical meanings is becoming a crucial component of modern nuclear engineering curricula [1].

At the University of Utah Nuclear Engineering Program (UNEP) we are developing a comprehensive educational approach addressing all these aspects and thus preparing our students for the near and long term future, which will require a synergistic knowledge of many engineering disciplines combined with experiential knowledge. Our emerging strength is in experiential learning, as we bring our students to use our research reactor as an integral part of the nuclear engineering curriculum, helping therefore that all of our students build sufficient level of nuclear engineering literacy in order to be able to contribute productively to the nuclear engineering workforce or continue their education toward doctoral degrees. UNEP has positioned itself recently as a program of unique structure; as the program offers graduate degrees in nuclear engineering to students with Bachelor of Science degrees in engineering or science disciplines, as well as a nuclear engineering minor starting in the fall of 2010. Additionally, the training of a number of graduate and undergraduate students in the operation of the TRIGA research reactor and the opportunity to become NRC licensed trainees add to the uniqueness of the programme. With this mix we are educating a different profile of nuclear engineer: combined degrees in engineering or related science disciplines with nuclear engineering (either graduate degrees or combination with the minor degree), hands-on experience, exposure to research projects and TRIGA training.

The UUTR (University of Utah TRIGA Reactor), shown in Figure 1, has been established as a university wide facility to promote research, education and training, as well as various applications of nuclear engineering, radiation science and health physics, including service to industry and community. Recently, we are revitalizing the use of the UUTR for neutron activation analysis (NAA), increasing the use of the existing reactor vertical ports for material irradiations and tests of the response of various electronic devices exposed to high neutron fluence.

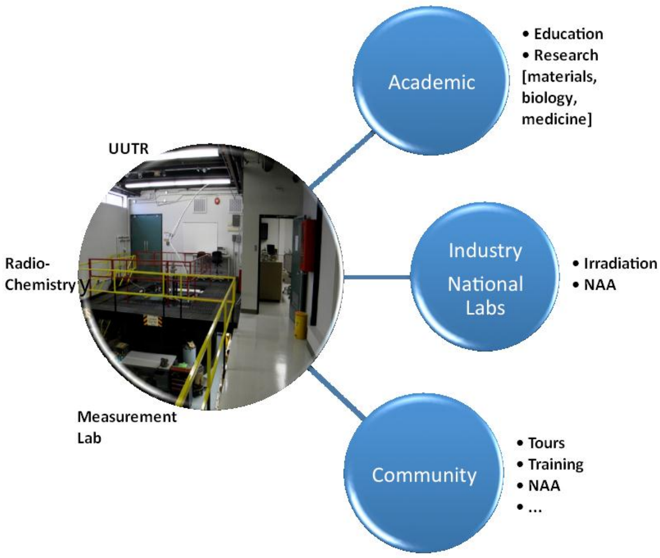

Fig. 1. University of Utah TRIGA (UUTR).

This paper highlights the role of the UUTR in nuclear engineering education and curriculum innovation at the University of Utah, in training students for research reactor operating licenses and in increasing the use of the UUTR for commercial applications and applied research in various disciplines such as civil engineering, environmental engineering, electrical engineering, radiobiology and similar fields.

2. PRINCIPAL EXPERIMENTAL FEATURES OF THE UUTR FACILITY

The UUTR reactor has been licensed, administered, and operated by the University of Utah for education, research and reactor services since 1975. The reactor facility is located on the main campus of the University of Utah in Salt Lake City, Utah. The UUTR reactor is a standard design, nominal 100 kW (licensed for 100 kW but operated at 90 kW), natural convection cooled TRIGA® pool reactor with a graphite reflector providing accommodation for a few pool irradiation facilities. The reactor core is located near the bottom of a water filled aluminium tank. The UUTR utilizes solid fuel elements developed by General Atomics (GA), in which the zirconium-hydride moderator is homogeneously combined with enriched uranium. The unique feature of these fuel-moderator elements is the prompt temperature coefficient of reactivity, which gives the TRIGA® reactor its built-in safety by automatically limiting reactor power to a safe level in the event of a power excursion. The reactor core consists of a lattice of cylindrical, stainless steel clad, UZrH1.6 fuel-moderator elements (SS), and aluminum clad UZrH1.0 fuel-moderator elements.

The UUTR has been designed with multiple in-core irradiation facilities for a broad range of potential experimental activities consisting of a central cavity, the pneumatic transfer tube and individual fuel element locations. Principal experimental features of the UUTR facility include:

— A central irradiator;
— Three beam ports;
— Pneumatic tube irradiator;
— A fast neutron irradiator; and
— A thermal irradiator.

To date, beam tube irradiations have not been performed at UUTR. Regular experiments include the neutron activation analysis and irradiation of various material samples. In a typical year, NAA is performed on the order of up to 50 samples and irradiation of materials in the order of up to 300 samples. On average, 95% of all experiments involve the samples' irradiation in the fast neutron irradiator and thermal irradiator.

The Central Irradiation Facility (CIF) is located in the central fuel pin position of the UUTR. A special tube is constructed to accommodate transfer of samples into the central fuel pin position, the 'A' fuel ring. Because this facility is an in-core irradiator located at the center of the core, there are special restrictions on the reactivity of samples placed in this irradiator. This irradiator has two special features: (a) a sealed interior that holds heavy water and (b) a motor that rotates the sample holder to spatially average the neutron fluence in the assembly.

The Pneumatic Transfer System (PTS) is available at the UUTR facility. The PTS is installed within a 1.5 inch O. D. tube and is driven by the force of dry, compressed helium. The PTS has a slight curve in its tube in order to prevent direct streaming of neutrons from the core to the surface of the pool. The UUTR PTS is designed to quickly transfer individual specimens into and out of the reactor core. The specimens are placed in a small polyethylene holder, the "rabbit," which in turn is placed into the receiver. It travels through aluminium and PVC tubing to the terminus at the reactor core centerline, and returns along the same path to the receiver. Directional gas flow moves the "rabbit" between receiver and terminus. A compressed gas system supplies helium to the system, and a set solenoid valve directs flow.

The Fast Neutron Irradiation Facility (FNIF) is designed to provide sample exposure to neutrons with minimal moderation. The entire device has two pieces, a stand and a sample holder. All structures were fabricated from Al-5052, which is a material compatible with the TRIGA reactor system. The irradiator consists of the outer box and the inner box. The outer box is loaded with lead bricks and sealed by bolting the inner box to the outer box with aluminium bolts. Graphite gasket material, "Grafoil," was used on the contact surfaces. Grafoil is radiation resistant and has been proven in high radiation applications at other reactor facilities. The irradiator is loaded with standard lead shielding bricks on one side. This side is placed next to the core face for additional gamma shielding. Also, thermal neutron absorbers may be placed in any position to decrease sample exposure to thermal neutrons. The irradiator is about 500 pounds sub-buoyant.

3. UUTR AS INTEGRAL PART OF NUCLEAR ENGINEERING CURRICULUM

In the years of nuclear renaissance all nuclear engineering programmes in the US recognize a need for a modernized curriculum in strengthening nuclear science and engineering disciplinary depth. At UNEP we are focused in helping students learn how to extend their range of skills and develop habits of mind and subject matter knowledge. Our education infrastructure has been recently revised to incorporate experiential learning tools as an integral part of ongoing courses to achieve that all students attending the nuclear engineering programme build a sufficient level of nuclear engineering literacy in order to be able to contribute productively to the nuclear engineering workforce or continue their education toward doctoral degrees. The current curriculum was reviewed from the aspect of common teaching competencies in relation to common teaching modes, emphasizing knowledge of subject matter. The main focus was to incorporate the use of UUTR into the curriculum at all levels of classes.

Web-based interactive course modules integrated with the extensive experimental practices using the UUTR, enhanced learning and interest in reactor physics and radiation transport classes reflect in full the nowadays multidisciplinary dimension of these important nuclear engineering topics. In addition, visualization of reactor physics and radiation transport phenomena are found to be interesting and inspirational ways ensuring students' broader understanding. Core courses at UNEP now take the following practices: theory is presented in class, students then practice the presented concepts using web-based interactive tools as an introduction to a next step in using more complex approaches such as running nuclear engineering codes, using the library of codes installed and available at UNEP, then analyze the data and finally perform well designed and planned experiments at the UUTR to benchmark some of the simulation and modelling results.

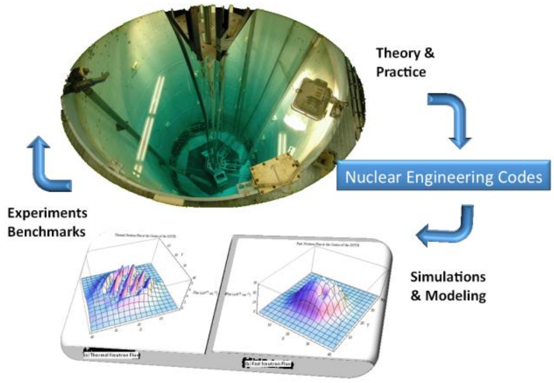

Fig. 2. UUTR as part of curriculum.

In addition, the UNEP curriculum includes two consecutive classes regarding preparation of students, both undergraduate and graduate, for a reactor operating license. Classes include a review of reactor physics; specifics of research reactors and UUTR physics, thermal-hydraulics, control, instrumentation, accident analysis, radiation and radiation doses, fuel management and burnup, a review of the experiments that could and could not be performed at the facility; a review of nuclear policy and regulation and training in operating the UUTR. Every year the NRC representatives hold the final exam for a UUTR operating license. This training programme is developed to incorporate the instructional requirements necessary to provide qualified personnel to operate and maintain the facility in a safe manner in all modes of operation, and is in compliance with the facility license, including all technical specifications and applicable regulations. The UUTR training program is periodically evaluated and revised as appropriate to reflect industry experience as well as changes to the facility, procedures, regulations, and quality assurance requirements. Our training programme is periodically reviewed by licensee management for its effectiveness [2]. In recent years, the UUTR training programme usually has on average five students a year.

4. RESEARCH AND DEVELOPMENT INVOLVING UUTR

Starting in 2009, research and development using the UUTR has been significantly expanded. The UUTR with associated facilities, also called the "U Station" in terms of research and development, is made available nationally for various types of experimental studies, as well as in creating the experiments suitable for evaluation and benchmarking of the numerical codes pertaining to reactor physics, radiation damage and radiation transport.

The extensive collaboration with many departments at the University itself, as shown in Figure 3, has increased the yearly usage of UUTR runs and expanded the scope of experiments promoting new research at UNEP. The University of Utah departments and programmes that are benefiting directly from the research opportunity and equipment available at the program and the UUTR itself are the Departments for Civil and Environmental Engineering, Chemical Engineering, Mechanical Engineering, Metallurgy, Archaeology and the Radiobiology Division at the University of Utah School of Medicine. In the last year, a strong collaboration has been developed with the Scientific Computing and Imaging Institute at the University of Utah in advancing the research effort at the UNEP pertaining to reactor simulations and analysis. The strong nuclear engineering modelling, simulation and computational research program at the UNEP together with the advancements in data streaming and visualizations developed by the Scientific Computing and Imaging Institute at the University of Utah culminated in joint development of reactor data visualizations on iPhone/iPods/iPads.

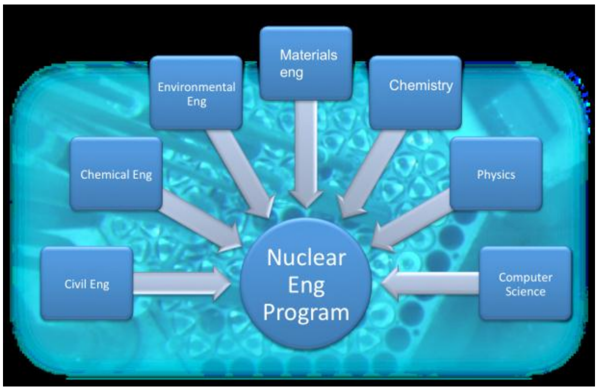

Fig. 3. Nuclear engineering program wide collaboration.

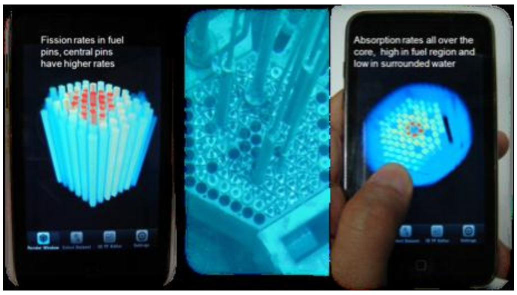

Fig. 4. Reactor data visualizations on iPhones/iPods.

Main research utilizing the UUTR is currently focused upon:

— Advanced computational modeling and simulation of reactor processes, reactor core and reactor systems using advanced computational platforms and developing series of benchmark experiments for validation and uncertainty quantifications of such new modeling tools;
— Experiments for radiation hardening of the electronic components tested for their durability and strength;
— Experimental studies of radiation effects on the Nano Electro-Mechanical Switch devices for their durability and accuracy;
— Dose reconstruction methodologies development for internal and external dose evaluation for epidemiological uses;
— Elemental analysis of various environmental samples;
— Elemental analysis of concrete for improving its composition toward low-activation grade concrete;
— Radiation experimental studies of various materials for their responses to radiation fields;
— Development of measurement techniques for nuclear material detections; and
— Nuclear forensics.

In addition, the UUTR facility can be used for experiments of interest in studying various cell lines contributing to and advancing research in boron or gadolinium neutron capture therapies, neutron therapies or in studying the effects of mixed radiation fields.

5. CURRENT SCOPE OF SERVICES BASED ON UUTR CAPABILITIES

Two main services that are provided to industry, national labs, the US Air Force, and other entities, and are based on the usage of UUTR are NAA, [3] and correlated studies, and irradiation of samples to examine their durability and integrity. The main limitations of the UUTR are its lack of horizontal beam ports. All irradiation facilities are therefore limited to vertical ports that determine the size and the type of samples applicable to each of irradiation facility.

5.1. Environmental sample studies using NAA

Fig. 5. NAA of the Great Salt Lake.

Environmental pollution studies require highly sensitive analytical techniques capable of accurately determining trace elements, mainly heavy metals, in various environmental samples. Salt Lake City is built around beautiful Great Slat Lake, Figure 5, which is the largest natural lake west of the Mississippi River. At the current level the Great Salt Lake is ~75 miles long, ~35 miles wide, and is 923 ft (281 m) deep at its deepest point. Great Salt Lake’s salinity is highly variable and depends on the lake's level. It ranges from 5 to 27%, which is too high to allow for aquatic life. Several types of algae are present that support the life of brine shrimp and brine flies. Great Salt Lake's waters are slightly enriched in potassium and depleted in calcium. A few years ago, US Geological Survey and US Fish & Wildlife researchers recorded the highest reading of mercury ever to be found in water in the US. A number of wetland soils samples near the Great Salt Lake were analyzed, and fourteen different elements have been identified, among them, Ba, Dy, I, Mg, Mn, Eu, Al, As, Br, Sm and La. More studies are on the way.

5.2. Characterization of additives in tobacco using NAA

Several American tobacco products were examined by NAA at the UUTR to study possible additives. The products studied were found to have the following elements: V, Mg, Mn, Na, Cl, K, Br and Al, as shown in Figure 6. Many of these elements, like K and Mg, are commonly found in plant life. Br is most likely a component of the alkaloids found in nicotine. V and Al could possibly be contamination from metal surfaces or the tobacco cutting and shredding devices used in the growing and preparation of the cigarettes. More tobacco products have already been selected and are planned to be analyzed and compared for the content of additives.

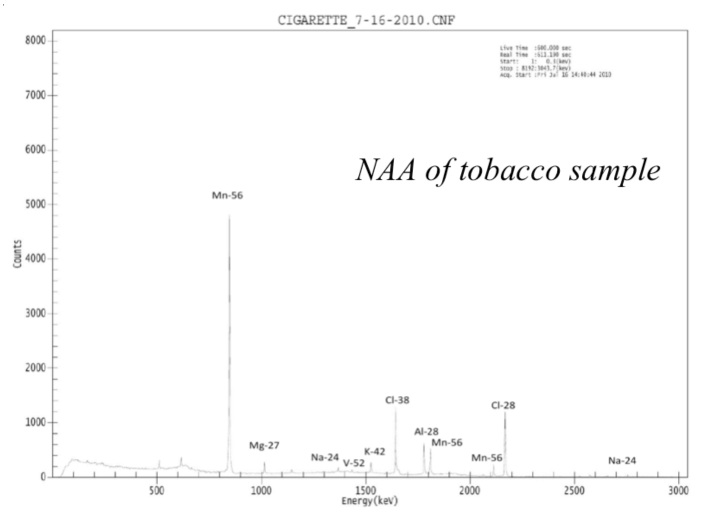

Fig. 6. Post-NAA Gamma Spectrum of Tobacco Sample, [4]

5.3. NAA based studies of bleaching agents in wooden chopsticks

In addition to the soil samples and tobacco products, imported Chinese chopsticks have recently been analyzed to determine what bleaching agents are used to give the chopstick a lighter appearance. Many bleaching agents can have detrimental biological effects if consumed. It was found that barium sulphate was used to give the chopsticks a lighter appearance. Barium is very abundant in China, making it an easy and economical substance for wood bleaching.

5.4. Electronics and other devices and materials irradiation for durability and strength

The FINF at the UUTR (see description of UUTR irradiation facilities in Section 2) is a very unique facility providing low gamma poisoning with a relatively high neutron flux ($\sim 10^{12}$ $cm^{-2}s^{-1}$). This facility has been used for years to perform experiments on the durability and strength of electronic devices and study the effects of high neutron fluxes on various materials.

6. FINAL REMARKS AND CONCLUSIONS

The University of Utah has recognized a sudden demand for nuclear energy in the US and worldwide that marked a new era in nuclear engineering and nuclear power development, which we often call the nuclear renaissance. The University of Utah has also recognized that the nuclear renaissance requires increased knowledge in nuclear science and technology. Nuclear scientists and engineers play a vital role in the development and implementation of current and future nuclear power reactors, additional research is necessary in the fields of health physics and radiochemistry to understand the health effects of radiation and nuclear activities, and the generation and application of radiopharmaceuticals is becoming a fast growing market. Nuclear science and engineering applications can be found not just in the power and health industries, but in military, industrial, environmental and commercial programmes around the world. Developing the insight and awareness of the basic science and engineering principles behind nuclear technologies will not only provide enhanced marketability for students graduating from the University of Utah, but also better prepare them for further studies in nuclear engineering graduate programs or careers that incorporate an increased understanding of nuclear science and engineering. To achieve these goals, we recently revised the educational curriculum to include the use of UUTR as a part of all core courses at the undergraduate and graduate levels. In addition, to foster further interest in nuclear engineering and science disciplines related to research and power reactors and applications of nuclear engineering to other fields, we have created two consecutive courses pertaining to reactor operation. Students who complete successfully these courses are eligible for a final exam performed by the US Nuclear Regulatory Commission to obtain a license to operate the UUTR. All graduate students and undergraduate students who are involved in ongoing research in the programme are included in service activities. They become part of the teams performing the real world samples measurements and data analysis, and are involved in completion of the reports for clients.

Beginning in 2009, the research and development using the UUTR have been significantly expanded. The UUTR with associated facilities, also called the “U Station” in terms of research and development, has been made available nationally for various types of experimental studies, as well as in creating the experiments suitable for evaluation and benchmarking of the numerical codes pertaining to reactor physics, radiation damage and radiation transport. This also increased our visibility in performing service studies, mainly through providing time at UUTR for irradiation of various samples and small electronic devices to test their durability and integrity when exposed to high neutron fluence and in analyzing the elemental compositions of various samples based on NAA.

7. REFERENCES

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