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Educating Next Generation Nuclear Criticality Safety Engineers at the Idaho National Laboratory

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EDUCATING NEXT GENERATION NUCLEAR CRITICALITY SAFETY ENGINEERS AT THE IDAHO NATIONAL LABORATORY

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ABSTRACT

One of the challenges in educating our next generation of nuclear safety engineers is the limitation of opportunities to receive significant experience or hands-on training prior to graduation. Such training is generally restricted to on-the-job-training before this new engineering workforce can adequately provide assessment of nuclear systems and establish safety guidelines. Participation in the International Criticality Safety Benchmark Evaluation Project (ICSBEP) and the International Reactor Physics Experiment Evaluation Project (IRPhEP) can provide students and young professionals the opportunity to gain experience and enhance critical engineering skills. The ICSBEP and IRPhEP publish annual handbooks that contain evaluations of experiments along with summarized experimental data and peer-reviewed benchmark specifications to support the validation of neutronics codes, nuclear cross-section data, and the validation of reactor designs. Participation in the benchmark process not only benefits those who use these Handbooks within the international community, but provides the individual with opportunities for professional development, networking with an international community of experts, and valuable experience to be used in future employment. Traditionally students have participated in benchmarking activities via internships at national laboratories, universities, or companies involved with the ICSBEP and IRPhEP programs. Additional programs have been developed to facilitate the nuclear education of students while participating in the benchmark projects. These programs include coordination with the Center for Space Nuclear Research (CSNR) Next Degree Program, the Collaboration with the Department of Energy Idaho Operations Office to train nuclear and criticality safety engineers with student evaluations as the basis for their Master's thesis in nuclear engineering.

Key Words: Benchmark, Education, ICSBEP, IRPhEP, Training

1 INTRODUCTION

One of the challenges in today's new workforce of nuclear criticality and reactor physics safety is the limitation of opportunities to receive significant experience or hands-on training prior to graduation from a college or university. Such challenges hinder an individual's capability to provide assessment of nuclear systems, establish safety guidelines, and adhere to regulations and protocols. Typically such training is restricted to on-the-job training before this new engineering workforce can adequately perform their select occupational duties. Participation in the International Criticality Safety Benchmark Evaluation Project (ICSBEP) [1] and the International Reactor Physics Experiment Evaluation Project (IRPhEP) [2] can provide students and young professionals with the opportunity to gain experience and enhance critical engineering skills.

Both the ICSBEP and IRPhEP publish annual handbooks [3, 4] that contain peer-reviewed experimental data and benchmark specifications to support the validation of neutronics codes, nuclear cross-section data [1], and the validation of reactor designs [2]. Established benchmark procedures [5] require the engineer to investigate the background, methods, and results of the experiment being evaluated. Often experiments were performed with the intention to provide data for safety assessments and may have later been used to development criticality safety standards. Additional research and engineering judgment are necessary when an evaluator must assess incomplete, conflicting, or misleading experimental information. Members of the ICSBEP and IRPhEP community, as well as other laboratory or institutional personnel, provide their expertise throughout the process of developing a thorough benchmark evaluation. The young engineer also develops and analyzes computational models of the experiment to assess uncertainties in the benchmark experiment and provide benchmark model specifications with example results. Students typically develop a strong familiarity with either MCNP5 [6] or KENO [7] Monte Carlo neutronics codes as a part of their benchmark analysis. Each benchmark undergoes a thorough international peer-review process. Participation in the ICSBEP and IRPhEP benchmark evaluation process provides the individual with opportunities for professional development, networking with an international community of experts, and valuable experience to be utilized in their future employment [8].

2 EDUCATIONAL OPPORTUNITIES

The traditional avenue for student participation in benchmarking activities has been through internships at national laboratories or sponsored projects at universities or companies participating with the ICSBEP and IRPhEP. A summary of student contributions from 1995 to 2009 was previously published [8], with student participation via various U.S., Slovenian, Russian, or British nuclear facilities or laboratories. Typically interns participate for 10 weeks during the summer and then complete their benchmark and the review process while studying at their respective university. While it is possible to completely evaluate and document a well-defined experiment during the course of a summer, some students find it difficult to track down information (especially laboratory-sequestered notebook data) in a short time period or to complete their evaluation when the necessary time conflicts with their studies and graduate work. Therefore, additional avenues for student involvement in benchmarking are being established at the Idaho National Laboratory (INL) to provide them with adaptable means for professional development and participation in benchmark evaluations.

2.1 Master's Thesis Work and Student Projects

The comprehensive requirements and extensive peer-review of benchmark evaluations provide a rigorous structure for Master's work. Student evaluations are being used as the basis for Master's thesis topics in nuclear engineering programs. Experienced participants in ICSBEP and IRPhEP serve as mentors and committee members to support benchmark development, facilitate training and networking, and ultimately promote graduation of more experienced young nuclear professionals. Participation in a benchmark evaluation can also represent significant work as an undergraduate thesis or independent study project, as well as an excellent project for a team of senior undergraduate students. Students are encouraged to present a summary of their efforts at a professional meeting or submit their work for publication in a journal.

2.2 Center for Space Nuclear Research Next Degree Program

The Center for Space Nuclear Research (CSNR) was established at the INL with the mission to address the numerous challenges and opportunities relevant to the promotion of space nuclear research and education and the enablement of space nuclear applications. It is operated by the Universities Space Research Association (USRA) and its activities are overseen by a Science Council comprised of various representatives from academic and professional entities with space nuclear experience [9]. The CSNR has established a Next Degree Program that allows students to work part-time through the CSNR as subcontractors on sponsored projects while they finish their graduate studies. The Next Degree Program offers increased opportunities for training, research, and education while paying the students competitive salaries for the experience and education they have already obtained. Students either transfer to a local Idaho university to take their coursework or finish their degrees remotely through their university of origin [10]. The ICSBEP and IRPhEP have had a few students participate via this program as they transition into the professional workplace. Students typically work part-time during the school year and full-time during the summer at the INL, allowing for increased involvement with laboratory activities both within and outside their research scope. Funding is allotted for some student travel for participation in benchmark and other professional meetings.

Students participating in the CSNR Next Degree Program have the advantage of coordinating with other individuals interested in space nuclear activities, providing a broader understanding of nuclear applications and stimulating professional and academic discussions. Next Degree students can also serve as mentors for the CSNR summer fellows. Each summer a team of approximately 15 undergraduate and graduate students participate in various space-nuclear sponsored projects. Research topics are often designed with a single end-point goal but may have optional starting points of interest, allowing the summer fellows to develop critical thinking skills and immersion into a summer of pure research and/or practical application [10]. Some summer tasks represent a single step in a much larger project. Next Degree students have the advantage of overseeing multiple summers of projects and developing connections with young engineers that represent a variety of disciplines from around the world.

2.3 Nuclear and Criticality Safety Engineers at the Department of Energy – Idaho

The Battelle Energy Alliance (BEA) and U.S. Department of Energy Idaho Operations Office have established a pilot program to train new nuclear and criticality safety engineers. Students participating in this program attend either Idaho State University or the University of Idaho in graduate nuclear engineering curriculum. They augment their studies with hands-on training courses in nuclear/criticality safety, programmatic technical support, participation in the ICSBEP/IRPhEP benchmark process, and travel for participation in American Nuclear Society (ANS) and benchmark technical review meetings. Students are expected to complete a benchmark in support of their Master's Thesis and may submit their work for journal and/or conference publication. As with the CSNR Next Degree Program, students typically work part-time during the school year and full-time during the summer. Additional advantages to this program include the opportunity to shadow a mentor to gain experience in day-to-day criticality safety issues, involvement with nuclear standards and DOE Orders, and planned participation with training and experimental programs at the Criticality Experiments Facility (CEF) at the Nevada National Security Site.

3 RESULTS

National laboratory, institute, university, and industry participation has provided benchmark research and evaluation experience to at least 30 students since 1995. Over that period students have authored or coauthored more than 50 ICSBEP or IRPhEP evaluations and several technical papers for various conferences and journals [8]. An updated summary of student contributions to the ICSBEP and IRPhEP Handbooks here at the INL is provided in Table I. A total of 14 students, representing eight universities, have participated in the ICSBEP and IRPhEP. Student participants at the INL have contributed to 23 benchmark evaluation with five additional evaluations currently in progress; combined, the total contributions represent approximately half of the total quantity of student evaluations.

As can be seen in Table I, some students generate more than one benchmark. As the opportunity is extended for continued participation in the benchmark programs, students further develop their skills and apply them towards additional benchmark evaluations.

4 CONCLUSIONS

Opportunities for student participation in the ICSBEP and IRPhEP are being developed to address the challenge of limited opportunities for students to receive significant experience prior to graduation. Participation in the evaluation of benchmark experiments provides valuable peer-reviewed data to the international user community and assists in the training of our next generation of nuclear criticality safety and reactor physics engineers.

5 ACKNOWLEDGMENTS

The ICSBEP and IRPhEP are collaborative efforts that involve numerous scientists, engineers, and administrative support personnel from 24 different countries. The authors would like to acknowledge the efforts of all of these dedicated individuals without whom these projects would not be possible.

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Table I. Summary of Student Contributions to the ICSBEP and IRPhEP at the INL.

EVALUATION ID & TITLE (YEAR APPROVED)	AUTHOR (University)
HEU-MET-FAST-007 – Uranium Metal Slabs Moderated with Polyethylene, Plexiglas, and Teflon (1995)	Catherine Crawford (North Western University)
HEU-SOL-THERM-006 – Experiments with Boron-Poisoned Highly Enriched Uranyl Nitrate Solution (1997)	Catherine Crawford (North Western University)
U233-SOL-THERM-012 – Water-Reflected Spherical Vessels Partially Filled or Filled with $^{233}UO_2(NO_3)_2$ Solution (2002)	Paul Foster (Brigham Young University)
U233-SOL-THERM-013 – Unreflected Spherical Vessels Partially Filled or Filled with $^{233}UO_2(NO_3)_2$ Solution (2003)	Paul Foster (Brigham Young University)
MIX-MISC-THERM-004 – Water-Reflected Triangular-Pitched Lattice of Mixed Oxide Fuel Rods Immersed in Plutonium / Uranyl Nitrate Solution Containing Gadolinium (2003)	Paul Foster (Brigham Young University)
MIX-SOL-THERM-007 – Water-Reflected Plutonium-Uranyl Nitrate Solution Containing Gadolinium (2004)	Wade Butaud (Texas A&M University)
HEU-SOL-THERM-050 – Unreflected Aluminum Cylinders Containing Uranyl Fluoride Solutions (2005)	Wade Butaud (Texas A&M University)
HEU-MET-FAST-076 – Uranium (93.14 ^{235}U) Metal Annuli and Cylinders with Thick Polyethylene Reflectors and/or Internal Polyethylene Moderator (2006)	Tyler Sumner (Georgia Institute of Technology)
HEU-MET-FAST-084 – HEU Metal Cylinders with Magnesium, Titanium, Aluminum, Graphite, Mild Steel, Nickel, Copper, Cobalt, Molybdenum, Natural Uranium, Tungsten, Beryllium, Aluminum Oxide, Molybdenum Carbide, and Polyethylene Reflectors (2007)	Bernard Jones (Georgia Institute of Technology)
HEU-MET-FAST-085 – Highly Enriched Uranium Metal Spheres Surrounded by Copper, Cast Iron, Nickel, Nickel-Copper-Zinc Alloy, Thorium, Tungsten Alloy, or Zinc Reflectors (2007)	Jessica Feener (Georgia Institute of Technology)
PU-MET-FAST-042 – Plutonium Hemispheres Reflected by Steel and Oil (2008)	John D. Bess (University of Utah)
LEU-COMP-THERM-028 – Water-Moderated $U(4.31)O_2$ Fuel Rods In Triangular Lattices with Boron, Cadmium and Gadolinium as Soluble Poisons (2008)	Jose Ignacio Marquez Damian (Georgia Institute of Technology)
LEU-MISC-THERM-004 – U(4.31)O2 Fuel Rods In Uranyl Nitrate Solution Containing Gadolinium (2008)	Jose Ignacio Marquez Damian (Georgia Institute of Technology)
IEU-COMP-THERM-012 – RA-0 Reactor: Graphite Reflected Arrangement of UO_2-Graphite Fuel Rods in Water (2008)	Jose Ignacio Marquez Damian (Instituto Balseiro - Universidad Nacional de Cuyo)
IEU-COMP-THERM-009 – Power Burst Facility: $U(18)O_2$-CaO-ZrO_2 Fuel Rods in Water (2009)	Jose Ignacio Marquez Damian Alexis Weir (Instituto Balseiro - Universidad Nacional de Cuyo)
HEU-SOL-THERM-026 – Highly Enriched Uranyl Nitrate in Annular Tanks with Concrete Reflection: 1 × 3 Line Array of Nested Pairs of Tanks (2009)	James Cleaver (Idaho State University)
FFTF-LMFR-RESR-001 – Evaluation of the Initial Isothermal Physics Measurements on the Fast Flux Test Facility, A Prototypic Liquid Metal Fast Breeder Reactor (2010)	John D. Bess (University of Utah)

Table I. Summary of Student Contributions to the ICSBEP and IRPhEP at the INL.

EVALUATION ID & TITLE (YEAR APPROVED)	AUTHOR (University)
HEU-SOL-THERM-034 – Water-Moderated and -Reflected Slabs of Uranium Oxyfluoride (2010)	Margaret A. Marshall (University of Utah)
HEU-MET-FAST-054 – Concrete Reflected Arrays of Highly Enriched Uranium Cylinders (2010)	Mackenzie L. Gorham (Idaho State University)
HEU-MET-FAST-056 – Polyethylene-Reflected Arrays of HEU(93.2) Metal Units Separated by Vermiculite (2010)	Mackenzie L. Gorham (Idaho State University)
NRAD-FUND-RESR-001 – Fresh-Core Reload of the Neutron Radiography (NRAD) Reactor with Uranium(20)-Erbium-Zirconium-Hydride Fuel (2011)	Margaret A. Marshall (University of Idaho)
HEU-MET-FAST-081 – GROTESQUE: Complex Geometric Arrangement of Unreflected HEU (93.15) Metal Pieces (2011)	Mackenzie L. Gorham (Idaho State University)
LEU-MET-THERM-004 – Triangular Lattices of 2.49 cm Diameter LEU (4.948) Rods in Water (2011)	Joseph Christensen (University of Idaho)
PU-SOL-THERM-037 – Arrays of Bottles of Plutonium Nitrate Solution (Scheduled for 2012)	Margaret A. Marshall (University of Idaho)
SCCA-FUND-EXP-001 – ORNL Graphite Moderated Small Compact Critical Assembly (SCCA) (Scheduled for 2012)	Margaret A. Marshall (University of Idaho)
HEU-COMP-FAST-002 – A Small Array of Graphite-Reflected Highly Enriched UO_2 Fuel Rods (Pitch = 1.506 cm) (Scheduled for 2012)	Margaret A. Marshall (University of Idaho)
AGN-FUND-RESR-001 – Reactor Physics Measurements on the AGN-201 Reactor at the Idaho State University (Scheduled for 2012)	Mackenzie L. Gorham (Idaho State University)
GCCR-FUND-RESR-001 – Spherical Gas (UF6) Core Cavity Reactor (Scheduled for 2012)	Jay Turnbull (Idaho State University)