INL/CON-11-22404
PREPRINT

Current Reactor Physics Benchmark Activities at the Idaho National Laboratory

2011 ANS Winter Meeting and Nuclear Technology Expo

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November 2011

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INTRODUCTION

The International Reactor Physics Experiment Evaluation Project (IRPhEP) [1] and the International Criticality Safety Benchmark Evaluation Project (ICSBEP) [2] were established to preserve integral reactor physics and criticality experiment data for present and future research. These valuable assets provide the basis for recording, developing, and validating our integral nuclear data, and experimental and computational methods. These projects are managed through the Idaho National Laboratory (INL) and the Organisation for Economic Co-operation and Development Nuclear Energy Agency (OECD-NEA).

Staff and students at the Department of Energy – Idaho (DOE-ID) and INL are engaged in the development of benchmarks to support ongoing research activities. These benchmarks include reactors or assemblies that support Next Generation Nuclear Plant (NGNP) research, space nuclear Fission Surface Power System (FSPS) design validation, and currently operational facilities in Southeastern Idaho.

DESCRIPTION OF THE ACTUAL WORK

Validation of NGNP Methods with HTR-PROTEUS

The zero-power PROTEUS research reactor at the Paul Scherrer Institut (PSI) in Villigen, Switzerland was configured as a pebble-red reactor (PBR) critical facility for a series of experiments performed between 1992 and 1996 [3]. Measurements included criticality, differential and integral control and safety rod worths, kinetics, reaction rates, water ingress effects, and small sample reactivity effects. Eleven core configurations were created (with both random and deterministic pebble loadings), utilizing 16.7% enriched TRISO particles embedded in graphite pebbles and surrounding by thick graphite reflectors. Four deterministic configurations are currently being evaluated as benchmarks. The randomly packed configuration will later be evaluated; it is of specific interest for validation of the PEBBED code [4].

Design Validation with Space Nuclear Configurations

Two compact critical assemblies consisting of graphite-reflected, 93.2% enriched UO_2 rods were tested at the Oak Ridge Critical Experiments Facility (ORCEF) in 1962 [5]. Measurements included critical reflector thickness, reactivity effects, fission-rates with cadmium-ratio distributions. This benchmark supports the validation of compact reactor designs similar to some of the current design parameters for a space nuclear FSPS [6]. Later benchmark activities include two additional ORCEF experiments: a third graphite-reflected experiment and a beryllium-reflected experiment [7,8].

In the early 1970s, spherical gas core critical experiments were conducted at the INL to provide benchmark results for the cold critical conditions of a typical nuclear rocket concept. Variations of core reflector material and control mechanisms were investigated. The core consisted of gaseous 93.2% enriched UF_6 surrounded by foamed polyethylene and polystyrene (mockup propellant) and a D_2O reflector [9]. While there are no current plans to develop a gaseous core reactor, this experiment represents a valuable benchmark for the storage of UF_6 material; currently there are no UF_6 benchmarks available and the evaluation of this experiment has been initiated.

Moderation Effects in Light Water Reactors

A series of critical experiments were performed at ORCEF in the late 1960s involving square and triangular lattices with unclad ~5% enriched uranium metal rods in water. The purpose of the experimental series was to determine critical mass of uranium in water for various rod diameters and pitches [10]. The part of this series consisting of 0.3-in.-diameter rods in square-pitched arrays was previously evaluated as a benchmark. The benchmark evaluation of another portion of this experimental series, 1.0-in.-diameter rods in triangular-pitched lattices, is being completed. Benchmarks from this series of experiments support validation of computational methods in LWR design, including lattice effects as the configurations are adjusted from under-moderated to over-moderated conditions.

Supporting Local Research Reactor Activities

The AGN-201M reactor [11] at the Idaho State University (ISU) is a small, self-contained, remotely-operated, low-power thermal reactor with 19.5% enriched UO_2 powder dispersed in polyethylene fuel. It was originally deployed in the 1950s as a reactor for education, medicine, and industrial. A series of measurements including criticality, control rod worths, and a thermal flux profile were recently performed at this facility. Benchmarking of this unique, passively-designed reactor is nearing completion and the models can be used to support ongoing research at the university.

The Advanced Test Reactor Critical (ATRC) Facility located at the INL is a 5 kW pool-type reactor designed to support the Advanced Test Reactor (ATR), comprised of 93% enriched UAl_x fuel plates situated in a characteristic cloverleaf design, and reflected by beryllium. Previously an intern initiated a benchmark of the 1994 critical configuration of the ATRC [12]. Staff at the INL are performing and modeling experiments using the current ATRC configuration, which can lead to the development of an accurate, well-validated benchmark, using activation spectrometry for neutronics validation [13]. Additional student activity includes evaluation of the ATRC with criticality/worth measurements to improve integral neutron cross section data.

The Neutron Radiography (NRAD) Reactor at the INL is a 250 kW TRIGA® (Training, Research, Isotopes, General Atomics) Mark II tank-type research reactor. It was recently converted to 20% enriched U-Er-Zr-H fuel [14]. A benchmark of the critical configuration of the 60-fuel-element core was completed and is available in both handbooks [1,2]. Current benchmark activities include evaluation of control rod experimental assembly worth measurements. Four additional fuel elements will be added to the core, requiring further reactor physics measurements and analysis. Neutron flux distribution measurements and characterization of the neutron radiography beam lines are also being investigated.

RESULTS AND CONCLUSIONS

A significant quantity of benchmarks is available for the validation of integral data and analytical and computational methods through the ICSBEP and IRPhEP. Students and staff in Southeastern Idaho are engaged in the development of additional benchmarks to support ongoing research at operational reactor facilities and to provide validation of computational methods and future reactor designs.

ACKNOWLEDGMENTS

The ICSBEP and IRPhEP are collaborative efforts that involve numerous scientists, engineers, and administrative support personnel from 20 different countries. The authors would like to acknowledge the efforts of all of these dedicated individuals without whom these projects would not be possible.

This paper was prepared at the Idaho National Laboratory for the U.S. Department of Energy under Contract Number (DE-AC07-05ID14517).

REFERENCES

1. *International Handbook of Evaluated Reactor Physics Benchmark Experiments*, NEA/NSC/DOC(2006)1, OECD-NEA, Paris (2011).

2. *International Handbook of Evaluated Criticality Safety Benchmark Experiments*, NEA/NSC/DOC(95)03, OECD-NEA, Paris (2011).

3. T. WILLIAMS, M. ROSSELET, W. SCHERER (editors), "Critical Experiments and Reactor Physics Calculations for Low-Enriched High Temperature Gas Cooled Reactors," IAEA-TECDOC-1249, International Atomic Energy Agency, Vienna (2001).

4. H. D. GOUGAR, "Results of the Simulation of the HTR-Proteus Core 4.2 Using PEBBED-COMBINE: FY-10 Report," INL/EXT-10-19208, Idaho National Laboratory (2010).

5. J. T. MIHALCZO, "A Small Graphite-Reflected UO_2 Critical Assembly," ORNL-TM-450, Oak Ridge National Laboratory (1962).

6. J. R. PARRY, J. D. BESS, B. T. REARDEN, G. A. HARMS, "Assessment of Zero Power Critical Experiments and Needs for a Fission Surface Power System," INL/EXT-08-14678, Idaho National Laboratory (2008).

7. J. T. MIHALCZO, "A Small Graphite-Reflected UO_2 Critical Assembly, Part II," ORNL-TM-561, Oak Ridge National Laboratory (1963).

8. J. T. MIHALCZO, "A Small Beryllium-Reflected UO_2 Assembly," ORNL-TM-655, Oak Ridge National Laboratory (1963).

9. J. H. LOFTHOUSE, J. F. KUNZE, "Spherical Gas Core Reactor Critical Experiment," IN-1443, Idaho Nuclear Corporation (1971).

10. E. B. JOHNSON, "Critical Lattices of U(4.89) Metal Rods in Water," *Trans. Am. Nuc. Soc.*, **10**, 190 (1967).

11. A. T. BIEHL, et. al, "Compact, Low-Cost Reactor Emphasizes Safety," *Nucleonics*, **14**(9), 100-103 (1956).

12. R. T. MCCRACKEN, L. S. LORET, "Results of ATR Critical Facility Core Reconfiguration and Requalification Testing for Post-Core Internals Changeout Operations," PG-T-94-006, EG&G Idaho (1994).

13. D. W. NIGG, "ATR Neutronics Modeling, Simulation, and V&V Upgrade," *Presented at the 14th International ASTM Symposium on Reactor Dosimetry*, Bretton Woods, NH, May 22-27 (2011).

14. J. D. BESS, T. L. MADDOCK, M. A. MARSHALL, "Fresh-Core Reload of the Neutron Radiography (NRAD) Reactor with Uranium(20)-Erbium-Zirconium-Hydride Fuel," INL/EXT-10-19486, Idaho National Laboratory (2010).