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## Reactor Physics Studies for the AFCI Reactor-Accelerator Coupling Experiments Project

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## Task 27

# Reactor Physics Studies for the AFCI Reactor-Accelerator Coupling Experiments Project

D. Beller

## BACKGROUND

In the Reactor-Accelerator Coupling Experiments (RACE) Project of the U.S. Advanced Fuel Cycle Initiative (AFCI), a series of accelerator-driven subcritical systems (ADSS) experiments have been conducted at the Idaho State University's Idaho Accelerator Center (ISU-IAC) and at the University of Texas (UT) at Austin. In these experiments, electron accelerators are used to induce Bremsstrahlung photon-neutron reactions in heavy-metal targets. They produce a neutron source of  $0.8$  to  $1.0 \times 10^{12}$  n/s per kW of electron beam, which will then initiate fission reactions in the subcritical systems. These subcritical systems include a compact, transportable assembly at ISU and a TRIGA reactor at UT-Austin. A variety of fuel and assembly geometries are being studied: at ISU 150 flat plates of 20%-enriched uranium-aluminum alloy plated with aluminum are used; and at UT-Austin 20%-enriched UZr-H fuel are used. A third phase at Texas A&M using 70%-enriched UZr-H "FLIP" fuel has been put on hold. The use of compact accelerators and a small target allow the target to be placed in various positions in or adjacent to these subcritical assemblies to "map" the coupling of driven neutron sources; measuring core coupling and mapping adjoint flux.

The RACE Project is an important intermediate step between the recent European program MUSE and a future near full-scale demo. For MUSE, which was conducted by the CEA at Cadarache, France, the driving neutron source was produced by D-D or D-T reactions which produced a nearly mono-energetic source of 2.45 or 14.1 MeV and a maximum strength of  $\sim 10^{10}$  n/s. For design of full scale ADSS, a complete knowledge of the effects of the driving neutron source is essential. This will ultimately require spectral, temporal, directional, and intensity fidelity in prototype experiments. In the absence of this fidelity, simulated sources should match some of the characteristics of projected driving sources to build confidence in the predicting performance of these systems, and codes and methods must be validated. The RACE Project will provide experience in a higher energy range (above 14.1 MeV) and with a stronger and more isotropic source than the MUSE experiments. In addition, a high-power RACE

phase could provide valuable information on thermal feedback effects in TRIGA reactors. This combination of attributes of the RACE Project will provide highly valuable information in advance of the prototype or demonstration programs.

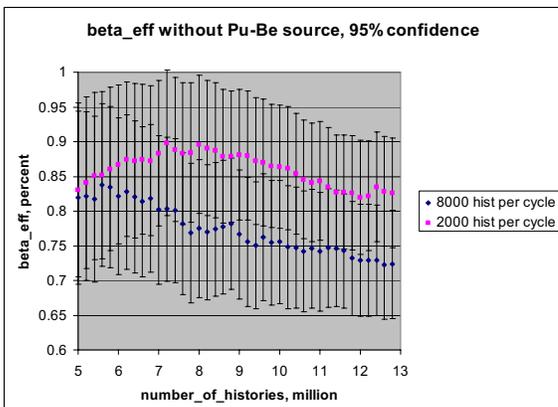
## RESEARCH OBJECTIVES AND METHODS

The specific research objective of this three-year project is to design and conduct accelerator driven experiments, which will help demonstrate in the U.S. the ability to design, compute, and conduct ADSS experiments and to predict and measure source importance, coupling efficiency, sub-critical reactor kinetics and source-driven transients. In addition, databases will be created for both steady state and transient ADSS experiments for the nuclear community to develop and test new computational codes and methods, and the importance of a driving neutron source in various regions of different subcritical assemblies will be mapped. Experiments will be conducted and compared to calculations with radiation transport and thermal-hydraulics codes such as MCNPX and RELAP.

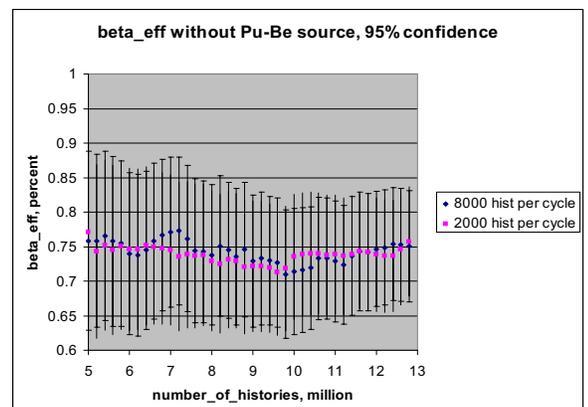
## RESEARCH ACCOMPLISHMENTS

**ISU RACE Experiments:** UNLV collaborated with ISU and CEA in a series of ADSS experiments at the Idaho Accelerator Center. This series of ADSS experiments was conducted with a low-power, 20-MeV electron accelerator coupled to the Subcritical Assembly (SCA) with a tungsten-copper neutron generating target. Dozens of individual experiments were conducted to measure a variety of parameters and ADSS responses, including break-point frequency, flux stability, a long-duration reference pulsed-neutron-source experiment, a beam trip experiment, and a variable criticality experiment, which was conducted by observing the neutron response while water was drained from the SCA. The last series of these experiments were completed in October, 2006.

Since the conclusion of the ISU RACE Project experiments, results were compared from ISU RACE experiments conducted at ISU in October with Monte Carlo radiation transport modeling to



*Calculated effective delayed neutron fraction for a subcritical (left side) versus a critical (right side); without a PuBe source.*





*UNLV graduate students Timothy Beller and Ryan LeCounte couple the UNLV High-Power RACE Target to a linear electron accelerator at the Idaho Accelerator Center.*

analyze effective delayed neutron fraction ( $\beta_{\text{eff}}$ ) in these far-subcritical, under-moderated systems using MCNP. The simplest approach based on 2 k-eigenvalue predictions with and without accounting for delayed neutrons gave unsatisfactory results due to the lack of convergence. Calculations have been completed with and without a plutonium-beryllium neutron source, which, although it was small, did affect the results. Two more-suitable techniques based on different weighting functions are currently under investigation.

The statistical behavior of calculated effective delayed neutron fraction based on two independent calculations (with and without delayed neutrons) for a critical system was more stable than for the subcritical case. Again, calculations have been completed with and without a plutonium-beryllium neutron source. Two more-suitable techniques based on different weighting functions are currently under investigation. The importance function is being used as an approximation of an adjoint weighting of the space- and velocity-dependent neutron population to calculate the effective neutron lifetime. Use of the value of a particle leaving a collision is being compared to that of a particle entering an event. Another computational approach that is based on a power iterations method (KCODE) to directly assess the efficiency of delayed neutrons is under development. The shape function for the steady-state problem, which will be used as a weighting function, was calculated and the relative efficiency of neutrons causing fission was determined.

**High-power Target Design:** The High-power RACE Target was transported to ISU's IAC in August 2006 for further tests to measure neutron generation and heat transfer while coupled to an electron linac. An accelerator-driven neutron production experiment was conducted and temperatures were recorded at several points. Since completing the experiments, experimental results are being evaluated. The Target is being modeled using Gambit and the CFD code FLUENT for comparison with experiments. During this reporting period, the potential complexity of the CFD modeling was upgraded with a parallel processing system. Refinement was continued of the MCNPX transport model to reduce

## ACADEMIC YEAR HIGHLIGHTS

- ◆ C.O. Maidana, A.W. Hunt, D. Beller, and K. Folkman, "Design, Modeling and Simulations in the RACE Project: First Study for the Development of a Transport Line," *Nuclear Instruments and Methods-A*, 562, 2, pp. 892-895 (2006).
- ◆ D. Beller, F. Harmon, E. Stankovskiy, T. Ward, and F. Goldner, "Reactor Accelerator Coupling Experiments (RACE) Project," poster, International Conference on Research Reactors in the 21st Century (RR-XXI), Moscow, Russia, June 20-23, 2006.
- ◆ D. Beller, "Update on the Reactor-Accelerator Coupling Experiments (RACE) Project;" T. Beller, R. LeCounte, and D. Beller, "Analysis of Neutron Production in the High-Powered RACE Target;" and, R. LeCounte, T. Beller, and D. Beller, "Thermal Analysis of Neutron Production in the High-Powered RACE Target," Winter Meeting of the American Nuclear Society, Albuquerque, NM, November 12-16, 2006.
- ◆ E. Stankovskiy, "The Experimental Results and Computational Analysis of the RACE-ISU," American Nuclear Society Student Conference, Corvallis, OR, March 29-31, 2007.

statistical uncertainty and to perform parametric studies to study impacts of accelerator performance and characteristics, such as beam spread in energy or position.

**RACE Project Management:** In his role as national RACE Project Director, the PI began to conclude the RACE Project with several universities and several European organizations. These organizations have contributed to several aspects of the RACE Project, including target design and analysis for High-Power RACE. Contracts supporting RACE Project work at the University of Michigan, Texas A&M University, and University of Texas at Austin ended during the summer, the Idaho participation was terminated in December, and the UNLV portion of the RACE Project will end summer 2007. EUROTRANS participants may continue to evaluate experimental data.

UNLV hosted, and students and faculty attended, an Advanced MCNPX Workshop at UNLV. As a result, the group was able to greatly improve statistical results of calculations of electron-photon-neutron transport.

## FUTURE WORK

During the summer of 2007, graduate student Evgeny Stankovskiy will complete his doctoral dissertation, which will be the final research within the RACE Project. In addition, the PI will be the General Chair of the Fifth Workshop on Accelerator-Driven Subcritical Systems Experiments will be conducted at the Idaho State University as part of the Eighth International Topical Meeting on Applications and Utilization of Accelerators (AccApp'07).

### Research Staff

Denis Beller, Principal Investigator, Research Professor, Department of Mechanical Engineering

### Students

Evgeny Stankovskiy, Graduate Student, Department of Mechanical Engineering

Timothy Beller, and Ryan LeCounte, Graduate Students, Department of Mechanical Engineering

### Collaborators

George Imel, Argonne National Laboratory; John Bennion and Alan Hunt, Idaho State University; William Charlton, Texas A&M University; Sean O'Kelly, University of Texas at Austin; and, John C. Lee, University of Michigan