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Task 27

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

D. Beller

BACKGROUND

Investigation of transmutation using accelerator-driven subcritical systems (ADS) was an original component of the Advanced Fuel Cycle Initiative. The Reactor Accelerator Coupling Experiments (RACE) represented the nations efforts in ADS experimental research. The RACE project was a university-based research project lead by the Idaho Accelerator Center of Idaho State University (ISU). The RACE project was initiated in 2003 at ISU and experiments were conducted there and at the University of Texas (UT) at Austin from 2004 to 2006. In these experiments, source neutrons were generated by using electron accelerators to produce high-energy bremsstrahlung photons that then induced photon-neutron reactions in heavy-metal targets. These compact, transportable accelerator/target systems produced a source of about 10^{10}-10^{12} n/s, which then initiated fission reactions in the subcritical systems.

RESEARCH OBJECTIVES AND METHODS

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

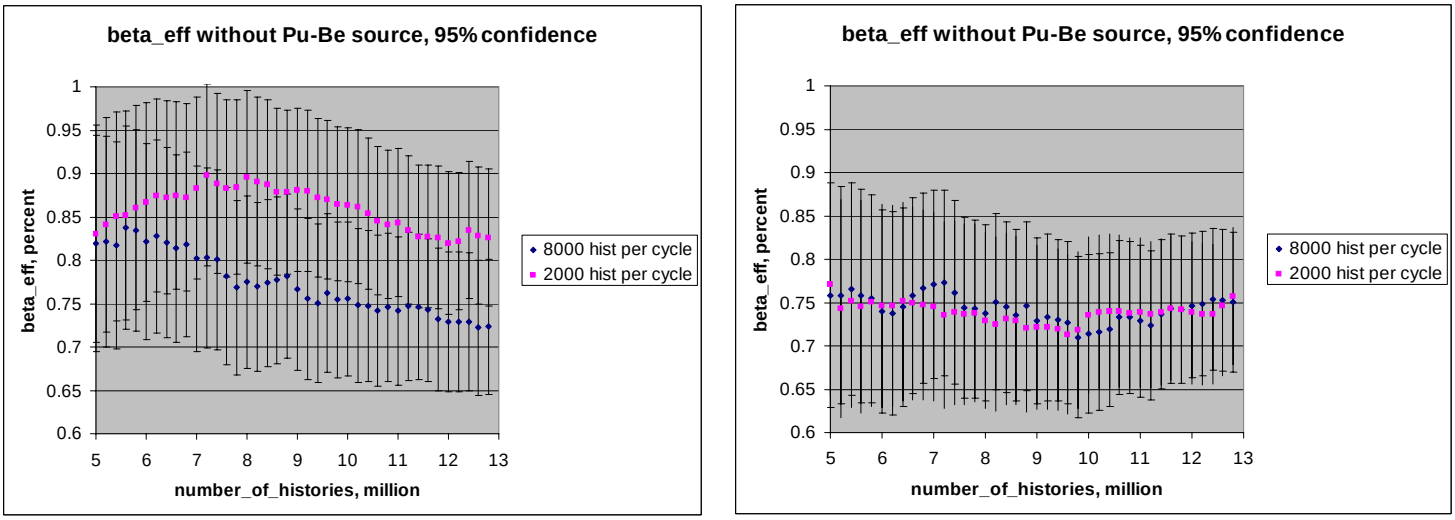
RESEARCH ACCOMPLISHMENTS

Full-core ADS experiments were conducted at ISU in a compact, subcritical assembly that was constructed at the ISU and fueled with a modular core. Accelerator-coupled experiments with the TRIGA reactor at the UT-Austin were also conducted beginning summer 2005, and were completed in March 2006. The most extensive experimental program was conducted at ISU, where accelerators were assembled, the beam-target neutron generators were developed, a subcritical assembly was licensed and constructed, and RACE tests were conducted for more than two years. These experiments are described in a wide array of papers.

An accelerator was constructed at ISU, shipped to Texas, and installed in the summer of 2005. It was assembled in a cave at the floor level of the UT Nuclear Engineering Teaching Laboratory (NETL), adjacent to the NETL TRIGA reactor. This reactor can operate at 1 MW_{th}, and can produce pulses up to 1000 MW_{th}. The accelerator target was placed immediately adjacent to one side of the core, centered on that side.

The first UT experiments were conducted with the reactor completely shut down with a criticality of about 0.92, similar to the criticality at ISU experiments. Follow-on experiments were conducted with k_{eff} between 0.92 and 0.95 to possibly 0.97, 0.98, or even critical. Measurements were made with flux wires, fission chambers, and other detectors. In addition, beam diagnostics and monitoring techniques were developed at UT to improve the performance of the linac/target system.

In the early phases of the RACE project, modeling studies were also conducted at both the University of Michigan and Texas A&M University. Texas A&M examined different experiments: (1) use of the TAMU Nuclear Science Center (NSC) TRIGA, which is fueled with 70%-enriched "FLIP" fuel, and has a capability to be pulsed to 1000 MW_{th}; and, (2) assembly of an existing used-fuel, 20%-enriched core around the accelerator target in a different part of the NSC pool (the Texas Transmutation System). The University of Michigan supported the RACE project with computational reactor physics studies of the kinetics of subcritical systems. They studied dynamic response and optimized the ERANOS transport theory model for a RACE configuration by using



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.

several different energy group structures and orders of polynomial expansion for the neutron flux. In addition, they worked to resolve difficulties encountered with the time-dependent VARIANT transport theory solution.

A low-power phase of the RACE project was conducted in collaboration with the European Community (EC) at ISU with the participation of a member of the EC, ISU, and UNLV. Participants investigated the potential to increase neutron generation by one to two orders of magnitude, which would allow for high-average-power experiments with significant, and easily measured, thermal feedback. In a separate effort, ISU investigated connecting a high-power modulator and klystrons to existing 20 and 25-MeV linacs. This new configuration would provide 20 to 30 kW of electron current, compared to 1 to 2 kW with the existing ISU and Texas accelerators. In addition, incorporating depleted or natural uranium into existing heavy metal targets was investigated to increase the photon-neutron yield. A high-power RACE target was designed and constructed at UNLV and tested for thermal and neutron generation performance at ISU. Simultaneously, an EC Target Working Group examined several alternate high-power target designs. The combination of these two enhancements, if successful, would generate 5 x 10^{13} to 10^{14} n/s in the center of one of the Texas reactors.

TASK 27 PROFILE

Start Date: September 2004
Completion Date: September 2007

The RACE project produced M.S. and Ph.D. graduates from five universities and more than 90 publications, presentations, and posters directly linked to faculty and students at UNLV. Selected publications are listed below.

Theses Generated:

Evgeny Stankovskiy, Ph.D., Department of Mechanical Engineering, UNLV, "Reactor Physics Studies for the Advanced Fuel Cycle Initiative Reactor-Accelerator Coupling Experiments Project," May 2008.

Timothy Beller, M.S., Department of Mechanical Engineering, UNLV, "Neutronics Analysis of the High-Power Race Target," December 2007.

Ryan LeCounte, Department of Mechanical Engineering, UNLV, "Thermal Hydraulic Analysis of the High-Power Race Target," December 2007.

Journal Articles:

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*, pp 892-895, 2006.

V. Kulik, J. Lee, and D. Beller, "Dynamic Analysis of Space-Time Effects in the ISU RACE Configuration," *Nuclear Instruments and Methods-A, 562*, p 838, 2006.

Conference Proceedings:

R. LeCounte, T. Beller, and D. Beller, "Thermal Analysis of the High-Power RACE Target," *Proceedings*, Eighth International Topical Meeting on Nuclear Applications and Utilization of Accelerators (AccApp'07), Pocatello, ID, July 30-August 2, 2007.

D. Beller, Frank Harmon, Thomas E. Ward, and Frank Goldner, "Overview of the U.S. Reactor-Accelerator Coupling Experiments (RACE) Project," *Proceedings*, Eighth International Topical Meeting on Nuclear Applications and Utilization of Accelerators (AccApp'07), Pocatello, ID, July 30-August 2, 2007.

T. Beller, R. LeCounte, B. Howard, and D. Beller, "High-Power Accelerator Target Design for the AFCI RACE Project," *Proceedings*, Eighth International Topical Meeting on Nuclear Applications and Utilization of Accelerators (AccApp'07), Pocatello, ID, July 30-August 2, 2007.

T. Beller, R. LeCounte, and D. Beller, "Analysis of Neutron Production in the High-Power RACE Target," *Proceedings*, Eighth International Topical Meeting on Nuclear Applications and Utilization of Accelerators (AccApp'07), Pocatello, ID, July 30-August 2, 2007.

D. Beller, Frank Harmon, Thomas E. Ward, and Frank Goldner, "Overview of the U.S. Reactor-Accelerator Coupling Experiments (RACE) Project," *Proceedings*, Eighth International Topical Meeting on Nuclear Applications and Utilization of Accelerators (AccApp'07), Pocatello, ID, July 30-August 2, 2007.

D. Beller, "Update on the Reactor-Accelerator Coupling Experiments (RACE) Project," *Transactions of the ANS, 95*, Washington, DC, pp. 943-944 2006.

R.LeCounte, T. Beller, and D. Beller, "Thermal Analysis of Neutron Production in the High-Powered RACE Target," *Transactions of the ANS, 95*, Albuquerque, NM, 2006.

T. Beller, B. Howard, R. LeCounte, and D. Beller, "High-Power Accelerator Target Design for the AFCI RACE Project," *Proceedings*, 2006 International High Level Radioactive Waste Management Conference, Las Vegas, NV, April 30-May 4, 2006.

T. Beller, B. Howard, R. LeCounte, and D. Beller, "Design of the High-Powered RACE Target," 2006 Winter Meeting of the ANS, Student Design Competition.

D. Beller and J. Knebel, "Phase IV of the RACE Project: European Collaborations," *Transactions of the ANS, 93*, pp. 901-902, Washington, DC, 2005.

D. Beller, "Overview of the AFCI Reactor-Accelerator Coupling Experiments (RACE) Project," *Proceedings*, Eighth Information Exchange Meeting on Actinide and Fission Product Partitioning & Transmutation, OECD/NEA, pp 495-504, Paris, France, 2005.

D. Beller, A. Hunt, J. Bennion, M. Reda, K. Sabourov, R. Spaulding, and K. Folkman, "Initial Results from the AFCI Reactor-Accelerator Coupling Experiments (RACE) Project," *Proceedings*, Eighth Information Exchange Meeting on Actinide and Fission Product Partitioning & Transmutation, OECD/NEA, pp 699-710, Paris, France, 2005.

D. Beller, "The Need for Accelerator-Driven Transmutation of Nuclear Waste," *Proceedings*, 3rd Annual Idaho ADS Experiments Workshop, Pocatello, ID, June 2005.

D. Beller, A. Hunt, J. Bennion, M. Garfield, K. Folkman, and M. Reda, "Initial Results from the AFCI Reactor-Accelerator Coupling Experiments (RACE) Project," *Transactions of the ANS, 91*, 446-447, 2004.

D. Beller, "Overview of the AFCI Reactor-Accelerator Coupling Experiments (RACE) Project," *Transactions of the ANS, 90*, 2004.

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Students

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Brice Howard, Undergraduate Student, Department of Mechanical Engineering

Collaborators

George Imel, Argonne National Laboratory; John Bennion, Jianwei Chen, Konstantin Sabourov, and Alan Hunt, Idaho State University; Frank Harmon, Director, Idaho Accelerator Center; William Charlton, Texas A&M University; Sean O'Kelly, University of Texas at Austin; John C. Lee, University of Michigan; and, Christian Jammes, French Atomic Energy Commission