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TRP Task 27
Project Title:

Reactor Physics Studies for the AFCI RACE Project (Reactor-Accelerator Coupling Experiments Project)

July 21, 2004

Principal Investigator (PI):	Prof. Denis Beller Department of Mechanical Engineering, UNLV 4505 S. Maryland Pkwy, Las Vegas, NV 89154-4027 (702) 895-1452, beller@egr.unlv.edu
UNLV Collaborators:	Grad student thesis advisor (TBD) One UNLV graduate student (TBD, office: TBD) One UNLV undergraduate student (TBD)
AFCI Project Laboratory Collaborator:	George Imel, Argonne National Laboratory (director of experiments in the MUSE and TRADE programs in Europe)
Other Collaborators:	Prof. Alan Hunt, Idaho State University Prof. John Bennion, Idaho State University Prof. William Charlton, Texas A&M University Prof. John C. Lee, University of Michigan Staff and students at ISU, U of Michigan, and Texas universities RACE Technical Advisory Group
AFCI research Area:	Accelerator Driven Transmutation
Requested Funds:	$105,001

Abstract

In the RACE Project of the U.S. Advanced Fuel Cycle Initiative (AFCI), a series of accelerator-driven subcritical systems (ADSS) experiments will be conducted at the Idaho State University's Idaho Accelerator Center (ISU-IAC), at the University of Texas (UT) at Austin, and at the Texas A&M University. In these experiments we will use electron accelerators to induce bremsstrahlung photon-neutron reactions in heavy-metal targets; this source of about 10^{12} to 10^{13} n/s will then initiate fission reactions in the subcritical systems. These systems will include a compact, transportable assembly at ISU and TRIGA reactors at UT-Austin and Texas A&M. These experiments will provide a variety of cores, fuel types and enrichments, and target/reactor configurations for many separate accelerator coupling studies. The UNLV portion of this project will be a three-year, three-phase project employing a principal investigator (as well as the UNLV TRP RACE Project Director), a graduate student, and an undergraduate student to support computational and experimental research at the ISU and the Texas universities, to integrate the UNLV Transmutation Research Project with this accelerator-driven transmutation research, and to further develop UNLV's computational infrastructure for reactor physics research.

1. Work Proposed for Academic Year Phase I:

Part 1: A UNLV student will join the Idaho-lead multi-university RACE Project to design, conduct, and analyze a source-driven sub-critical reactor experiment at UT Austin and/or Texas A&M Universities. The student will develop a strong understanding of the reactor kinetics and dynamics underlying these experiments by studying historical as well as ongoing work in this field. The student will develop computational capabilities at UNLV to support this work, including modeling with MCNPX and other codes. The student will then formulate a research plan to conduct an experiment that couples an electron Linac (accelerator) to the TRIGA reactor at the University of Texas at Austin. Depending upon timing, this student may or may not participate in that experiment, but the ground will be established for follow-on students to do so. The student will coordinate research at UNLV with students and faculty at the other RACE universities (Idaho State, UT-Austin, Texas A&M, and the University of Michigan). The student will also have an opportunity to interact and consult with the RACE Technical Advisory Board.
Part 2: This project also includes the PI acting as the UNLV project director for the RACE Project, integrating the UNLV TRP and the growing nuclear engineering research program into the national RACE project as well as EUROTRANS. The PI is the Director of the RACE Project at ISU, the National RACE Project Director, and will be the UNLV RACE Project Director. Acting in this capacity requires additional time commitment and travel funding which will be shared between ISU and UNLV.

2. Funding Profile:

Academic Year:	2004-2005	2005-2006	2006-2007
Total (k$)	105	110	113

3. Background and Rationale:

In the RACE Project of the U.S. Advanced Fuel Cycle Initiative (AFCI), a series of accelerator-driven subcritical systems (ADSS) experiments will be conducted at the Idaho State University's Idaho Accelerator Center (ISU-IAC), at the University of Texas (UT) at Austin, and at the Texas A&M University. In these experiments, we will use electron accelerators to induce bremsstrahlung photon-neutron reactions in heavy-metal targets. A beam power of 1 kW will produce a neutron source of 10^{12} n/s, which will then initiate fission reactions in the subcritical systems. These systems will include a compact, transportable assembly at ISU and TRIGA reactors at UT-Austin and Texas A&M. A variety of fuel and assembly geometries will be studied: at ISU we will use 150 flat plates of 20%-enriched uranium-aluminum alloy plated with aluminum; at UT-Austin we will use 20%-enriched UZr-H fuel; and at Texas A&M we will use 70%-enriched UZr-H "FLIP" fuel as well as a used core of 20%-enriched UZr-H fuel. The use of compact accelerators and a small target will allow us to place the target 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 like the TRADE project. 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 produce a mono-energetic source of 2.45 or 14.1 MeV and a maximum strength of ~10^{10} n/s. For TRADE (ENEA, Cassacia, Italy), the source will be provided by spallation from a proton cyclotron, with an anisotropic source up to ~140 MeV and ~10^{15} n/s.

For design of full scale ADSS and predictions of performance, 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 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 up to 40 MeV) and with a stronger and more isotropic source than the MUSE experiments. In addition, RACE will provide valuable information on thermal feedback effects in the TRIGA reactors. Finally, and possibly most important, because of the mobility of compact electron linacs connected to compact targets by easily fabricated vacuum tubes, RACE will permit source importance mapping and adjoint flux studies because of the ability to relocate the target between experiments. This combination of attributes of the RACE Project will provide highly valuable information in advance of the TRADE program.

Tentative RACE Schedule:

FY03 Initiate RACE, develop concepts, design experiment, construct accelerator system.
FY04 Conduct ISU sub-critical test, initiate feasibility studies for UT and Texas A&M TRIGA experiments.
FY05 Conduct UT-Austin TRIGA sub-critical test.
FY06 Conduct Texas A&M TRIGA sub-critical tests.
FY07 Option: testing at Texas A&M with a used TRIGA core.
FY08 Option: testing at Texas A&M with a used TRIGA core with lead-bismuth "coolant."

4. Research Objectives & Goals (three years)

- Design and conduct an accelerator driven experiment.
- 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 subcritical multiplication by comparing experimental results with predictions.
- Demonstrate the ability to predict and analyze subcritical source-driven transients.
- Create both steady state and transient benchmarks for ADSS for the nuclear community to develop and test new computational codes and methods.
- Map the importance of a driving neutron source in various regions of different subcritical assemblies.
- Serve as an important intermediate step between the recent MUSE experiments and the future TRADE experiments and contribute data and knowledge for TRADE.
- Assist the RACE Project team in developing new computational methods and measurement techniques.
- Integrate UNLV and its students and faculty into this accelerator-driven transmutation project.

5. Technical Impact

A critical element of accelerator-driven transmutation is the coupling of the driving neutron source and the sub-critical nuclear reactor. Understanding of this coupling requires complete knowledge of effects of source characteristics. Experiments are ongoing to refine our ability to predict and measure this coupling, but results have not always been as expected. The objective of the RACE R&D to be conducted within the UNLV TRP is for a UNLV student to support the

overall goals of the RACE Project, to design and conduct an experiment, to test our ability to predict sub-critical reactor kinetics by comparing experimental results with predictions, and/or to assist the RACE team in developing new computational methods and measurement techniques. A sub-objective of this research project is to insure the inclusion of UNLV and its students and faculty in this accelerator-driven transmutation project. This UNLV student-based research project will contribute to international progress on the development of accelerator-driven nuclear systems, possibly contributing to design and evaluation of experiments to be conducted in the $90 M TRADE Project in Europe.

6. Research Approach for Phase I (year 1)

1. Conduct a literature search to gain an understanding of past experiments, reactor physics theory for operation of sub-critical systems, and measurement of sub-criticality.
2. Study results of ISU RACE and develop a plan for an experiment at the UT-Austin TRIGA reactor.
3. Develop computational capabilities at UNLV for modeling neutron multiplication and sub-critical reactor kinetics.
4. Travel to UT-Austin to conduct an accelerator-driven experiment, collect data for analysis, and begin analysis.

7. Research Approach for Phase II (years 2 and 3)

1. Analyze data from UT-Austin RACE, compare to predictions.
2. Refine computational methods.
3. Travel to Texas to conduct an accelerator-driven experiment on a different fuel type and/or reactor configuration with thermal feedback, collect data for analysis, and analyze data.
4. Contribute to improvement of reactor physics codes.
5. Design future RACE projects, possibly with fast reactor fuel, lead-bismuth “coolant,” or other TRIGA cores.

8. Capabilities at UNLV, Other Universities, and International Laboratories

UNLV: The Department of Mechanical Engineering within the College of Engineering will provide office space and Internet connections for the PI and one graduate student during the duration of this project. UNLV has developed a parallel computing cluster that includes the MCNPX Monte Carlo N-particle reactor physics code that may be used for this research.

Prof. Denis Beller is a Research Professor in the Mechanical Engineering Department at the University of Nevada, Las Vegas. He is also a Visiting Research Professor and the RACE Project Director at the Idaho State University, with responsibility for overall design, planning, execution, and budget. He will serve as Principal Investigator for this project. Prof. Beller has a long career in nuclear engineering, reactor physics, systems analysis and radiation effects.

Prof. Alan Hunt is a Physics Professor at ISU who is designing and conducting the first of the RACE tests, the coupling of a 40-MeV electron Linac to a sub-critical assembly at ISU-IAC.

Prof. John Bennion is a Professor of Nuclear Engineering at ISU who is responsible for the ISU sub-critical assembly. He is responsible for licensing the new location/configuration and for packaging and transportation of the fuel.

Prof. William Charlton is a Professor of Nuclear Engineering at Texas A&M. He is responsible for feasibility studies for RACE at both Texas universities. UT-Austin and Texas A&M have existing reactor physics models and detailed knowledge of their TRIGA reactors, including the content of the fuel and its exposure history.

Prof. John C. Lee is a Professor and Head of the Department of Nuclear Engineering at the University of Michigan. Prof. Lee has supervised a student who had developed the theory and application of space-time corrections to point kinetics calculations for the measurement of subcriticality of nuclear systems.

Mr. George Imel, Argonne National Laboratory, is the director of international accelerator-driven experiments in the MUSE and TRADE programs in Europe. As a key member of the RACE Technical Advisory Group, Mr. Imel will assist project participants to insure close integration with the international program.

9. Project Timetable and Deliverables

The initial phase of the RACE Project includes a subcritical experiment to be conducted at the ISU during 2004. This experiment and much analysis will have been completed when UNLV participation commences. UNLV will join this project during preparations for the first experiments in Texas, which will be conducted during Year 1 of the UNLV research. During the year, various meetings are scheduled: RACE Technical Advisory Group, AFCI Semiannual Technical Program Reviews, RACE Workshops at ISU, and possibly others. Participation in some of these meetings will be necessary for the student to learn from other collaborators. Travel expenses for the PI will likely be shared with or covered by other TRP tasks. Because of the many meetings of AFCI participants from eight national laboratories and thirty universities, a $1,000 travel contingency is included in the budget each quarter.

Deliverables

- Monthly reports within 5 workdays of the end of the month.
- Quarterly Reports: end of December, March, June, and September.
- Technical publications submitted to conferences and technical journals.

Time Schedule and Major Milestones

	Qtr 1			Qtr 2			Qtr3			Qtr 4		
TASKS	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
1. Literature review, ISU orientation	X											
2. Examine results from ISU RACE		X	X									
3. Develop Plans for UT-Austin RACE				X	X	X	X	X	X			
4. Conduct RACE at UT-Austin										X		
5. Begin analysis of results											X	X
6. Quarterly reports				1			2			3		
7. Semi-Annual Reports							1					2
8. Oral Report AFCI Semi-Annual Review						1						2
9. Draft of annual report												X
Meetings	1		2			3	4			5		6
TRIP EXPLANATION												
Trip 1	grad student—familiarization with accelerator and target, sub-critical assembly, instrumentation											
Trip 2	PI—Winter ANS meeting (shared funding with other AFCI research projects, no cost to this project)											
Trip 3	PI—AFCI Semiannual Review, possibly students											
Trip 4	grad student, conduct UT-Austin RACE											
Trip 5	PI—Annual ANS meeting (shared funding with other AFCI research projects, probably no cost to this project)											
Trip 6	grad and undergrad students—annual RACE Workshop at ISU											

(Work is assumed to begin September 1, 2004).

10. References:

1. D. BELLER, “Reactor-Accelerator Coupling Experiments (RACE) Program,” white paper, Idaho State University, September 22, 2003.
2. S. MONTE and M. SALVATORES, “TRADE: A Full Experimental Validation of the ADS Concept in a European Perspective,” *Proc. of the Sixth International Mtg. on the Nucl. Appl. of Accelerator Tech., AccApp’03*, Jun. 1-5, 2003, San Diego, CA.
3. R. Rosa, et al., “The TRADE Project: First Results of the Preliminary Experimental Program,” *Proc. of the Sixth International Mtg. on the Nucl. Appl. of Accelerator Tech., AccApp’03*, Jun. 1-5, 2003, San Diego, CA.
4. V. V. KULIK and J. C. LEE, “Space-Time Correction in Reactivity Determination for Subcritical Systems,” *Proc. of the Sixth International Mtg. on the Nucl. Appl. of Accelerator Tech., AccApp’03*, Jun. 1-5, 2003, San Diego, CA.
5. V. V. KULIK and J. C. LEE, "Space-Time Correction to Reactivity Determination in Pulsed Source Experiments," *Trans. Am. Nucl. Soc., 87*, 410 (2002).
6. V. V. KULIK, J. C. LEE, and G. ALIBERTI, "Evaluation of Different Reactivity Definitions for Subcritical Systems," presented at the American Nuclear Society Conference, Nov. 16-20, 2003, New Orleans, LA.
7. V. V. KULIK and J. C. LEE, "Applications of Modal-Local Analysis for Source-Driven Subcritical Systems," presented at the PHYSOR 2004 Conference, Apr. 25-29, 2004, Chicago, IL.

Abbreviated Curriculum Vitae
Dr. Denis E. Beller

Department of Mechanical Engineering
University of Nevada, Las Vegas
4505 Maryland Parkway, Box 454027
Las Vegas, NV 89154-4027
Phone: 702-895-1452
E-mail: beller@egr.unlv.edu

Education

Ph.D., Purdue University, May 86, (areas: nuclear engineering, reactor physics, fusion)
M.S. in Nuclear Engineering, Air Force Institute of Technology, March 81, (Honors)
B.S. in Chemical Engineering, University of Colorado, May 76, (Honors)

Current Occupation

Research Professor — July 03 to present
Department of Mechanical Engineering, University of Nevada, Las Vegas, NV

Conduct nuclear criticality analysis, radiation transport and shielding, and thermal analysis for developing separations processes for recycling used fuel for the Advanced Fuel Cycle Initiative of the U.S. Department of Energy. Write research proposals, counsel students, write reports.

Visiting Research Professor — July 03 to present
Idaho Accelerator Center, Idaho State University, Pocatello, ID

Direct the Reactor-Accelerator Coupling Experiments project at ISU, University of Texas at Austin, and Texas A&M University for the Advanced Fuel Cycle Initiative of the U.S. Department of Energy. Plan the experimental program; conduct nuclear criticality analysis, radiation transport and shielding, and safety analysis; supervise post-docs and students. Direct national efforts and integration with international programs.

Principal Nuclear Engineer — July 03 to present
TechSource, Inc., Santa Fe, NM

Develop university programs and intercollegiate collaborations for the U.S. Advanced Fuel Cycle Initiative of the U.S. Department of Energy. Plan workshops, initiate collaborations between university researchers and laboratory technical specialists.

Previous Experience

Transmutation Research Project Intercollegiate Collaborations Leader — April 01 to July 03
Harry Reid Center for Environmental Studies, University of Nevada, Las Vegas, NV

Coordinated intercollegiate collaborations between U.S. national laboratories, U.S. universities, and UNLV and Idaho State University for participation in the Advanced Fuel Cycle Initiative of the U.S. Department of Energy. Arranged research programs, reviewed and recommended funding levels, recruited faculty and students, reported successes. Co-PI on AFCI research projects ongoing at UNLV, visiting research professor at ISU's Idaho Accelerator Center.

Technical Staff Member Apr 98 to March 01
Los Alamos National Laboratory (University of CA), Los Alamos, NM

As LANL ATW, AAA, and AFCI University Programs Leader, coordinated research projects among several laboratories and universities that annually supported more than 100 students nationwide. Managed seven LANL-funded university research contracts for the LANL AFCI Program Office. As Technical Staff Member in Systems Engineering and Integration, analyzed systems related to long-term national and global deployment of nuclear energy in conjunction with LANL's AAA program and Nuclear Materials Management Systems projects. Key contribution to DOE's Roadmap for Accelerator Transmutation of Waste. Analyzed thorium-uranium fuel cycle coupled to accelerator-driven transmutation of waste; demonstrated resource savings, reduction of proliferation risk, and greatly reduced waste for permanent disposal. Primary Investigator on DOE Nuclear Energy Research Initiative project to investigate Direct Energy Conversion Fission Reactors. Adjunct professor with Purdue University's School of Nuclear Engineering.

Consultant, Nuclear Technology and Education, Bellbrook, OH, 1995-1998: Advised Lawrence Livermore National Lab on the design of a system for neutron effects testing: established requirements, developed innovative design, performed radiation transport computations to demonstrate neutron physics and material feasibility. Coordinated work of scientists and engineers at three national laboratories. Developed public education program in conjunction with the American Nuclear Society. Created, planned, coordinated, and conducted activities of students and other volunteers to operate exhibits that provided nuclear information to more than one hundred thousand people.

Division Head, Information Exploitation, National Air Intelligence Center, Wright-Patterson AFB, OH, 1994: Managed more than 100 civilian and military personnel and an annual budget of $10 M for the Information Services Business Unit--provided information acquisition, storage, and retrieval and translation services in 45 languages for hundreds of customer organizations worldwide in the DoD, the CIA, and other U.S. agencies. Maintained capabilities during a 25% downsizing by reorganizing along product and service lines, reducing management, building quality teams and processes, and securing external funding to offset budget reductions.

Associate Professor of Nuclear Engineering, AF Institute of Technology, Wright-Patterson AFB, OH, 1986-1993: Taught Graduate Nuclear Engineering (nuclear weapons effects program); conducted and supervised research in computational radiation transport applied to defense issues. First military professor awarded tenure in AFIT's 70-year history because of teaching excellence (award), nationally recognized and published research, consulting, and faculty and professional activities. Developed concepts for simulation of nuclear weapons effects testing with inertial confinement fusion (ICF). Research was endorsed by National Academy of Science and DOE's ICF Advisory Committee, was included in DOE's Five Year Plan, and resulted in a decision (KD-0) for $1B construction of the National Ignition Facility. Acquired grants totaling more than $750k, established Nuclear Engineering Computation Laboratory.

Laboratory Manager, Gas Operations, McClellan Central Laboratory, McClellan AFB, CA,1981-1983: Supervised 3 scientists and 25 technicians and managed production environmental measurements laboratory responsible for radio-analysis of gaseous environmental samples from the U.S. Atomic Energy Detection System.

PUBLICATIONS AND PRESENTATIONS. Authored or co-authored fourteen archival publications in *Foreign Affairs, Inertial Confinement Fusion, Journal of Radiation Effects Research and Engineering, Fusion Technology, Nuclear Instruments and Methods—A*, and *Nuclear Science and Engineering*; plus numerous proceedings and classified reports. Gave presentations (many invited) at international conferences (in the U.S., Russia, Korea, and England), to Congressional Staffers and State Legislators, joint DoD/DOE meetings, and public and academic forums.

COMPUTER SOFTWARE & HARDWARE. Installed and/or used many radiation transport codes, radiation hydrodynamics (LASNEX), mathematics, accounting, word processing and presentation, and graphics. Have used IBM, VAX, Cray, Cyber 205, Sparcstation, and PC computers; UNIX, VMS, COS, Sun OS, Windows, and DOS operating systems.

SCIENTIFIC AND PROFESSIONAL SOCIETIES, OTHER ORGANIZATIONS.
American Nuclear Society, Chairman, Public Information Committee
Accelerator Applications Division (ANS), Member of the Executive Committee
Eagle Alliance (pro-nuclear activist organization), Member of the Board of Directors, 2nd V.P.
Tau Beta Pi (national engineering honor society)

SECURITY CLEARANCE. DOE "Q" clearance. Previous DoD Top Secret/SBI (SCI).

PERSONAL. Happily married, excellent health, love to travel and fly fish.

Some of my archival publications (title and source only):

"Atomic Time Machines Machines: Back to the Nuclear Future," *Journal of Land, Resources, and Envir. Law 24*, 1 (2004).

"Reports of DEC's Death 'Greatly Exaggerated,'" *Nucl. Engr. Int'l, 46,* 569, (2001).

"A Roadmap for Developing ATW Technology: System Scenarios & Integration," *Progress in Nuclear Energy*, 38, 1-2 (2001).

"The U.S. Accelerator Transmutation of Waste Program," *Nucl. Instr. and Meth.--A 463*, (2001).

"Disposition of Nuclear Waste Using Subcritical Accelerator-Driven Systems: Technology Choices and Implementation Scenarios," *Nucl. Tech. 132*, 1 (2000).

"The Need for Nuclear Power," R. Rhodes and D. Beller, *IAEA Bulletin, 42*, 2 (2000).

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"Contributions of the National Ignition Facility (NIF) to ICF Weapons Effects Testing in the Laboratory Microfusion Facility," *Journal of Radiation Effects Res. and Engr., 12-1A*, (1994).

"Parametric Design Study of a Nuclear-Pumped-Laser-driven Inertial Confinement Fusion Power Plant," *Laser and Particle Beams, 11*, 3 (1993).

"Use of Inertial Confinement Fusion for Nuclear Weapons Effects Simulations," *Inertial Confinement Fusion, 2*, 4 (1992).

"Initial Investigation of the Feasibility of Antiproton-Catalyzed Inertial Confinement Fusion," *Fusion Tech., 20,* No. 4, part 2, (1991).

"A Benchmark Comparison of Predicted X-ray and Neutron Doses in a Nuclear Effects Test in the Laboratory Microfusion Facility," *Fusion Technology, 19*, 3 (1991).

"Enhancement of Predicted X-ray Effects with Advanced-Fuel Pellets for Nuclear Effects Tests in the Laboratory Microfusion Facility," *Fusion Technology, 19*, 3 (1991).

"Parametric Design Space and Neutronics Analysis of a Nuclear-Pumped-Laser-driven ICF Reactor," *Fusion Technology, 15*, 2 (1989).

"Conceptual Design and Neutronics Analyses of a Fusion Reactor Blanket Simulation Facility," *Nucl. Science and Engr., 97*, 3 (1987).