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Criticality Studies of Dilute Plutonium Mixtures for UREX Processes

Denis Beller
University of Nevada, Las Vegas

Criticality Studies of Dilute Plutonium Mixtures for UREX Processes
(to support the Global Nuclear Energy Partnership)

May 10, 2006

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:	1 Graduate Student (TBD) 1 Undergraduate Student (TBD)
AFCI Program Laboratory Collaborator:	Dr. David Loaiza, N-2, Los Alamos National Laboratory
Other Collaborators:	Dr. Michael Dunn, Nuclear Data Division, Oak Ridge National Laboratory Mr. Adolf Garcia, DOE Idaho Operations Office (criticality safety group)
AFCI research Area:	Transmutation Engineering
Requested Funds:	$99,536; new funds: $37 k ($100 k FY07, $103 k FY08)

Abstract—The completion of criticality experiments for mixtures of higher actinides (HA, includes neptunium, plutonium, americium, and curium) that will be created during the separation of used nuclear fuel has been identified as a requirement to construct prototype plants such as the Engineering-Scale Demonstration (ESD) and the Advanced Fuel Cycle Facility (AFCF) for the Global Nuclear Energy Partnership (GNEP). GNEP is a program to develop a worldwide consensus to enable the expanded use of economical, environmental nuclear energy to meet growing electricity demand. In this program and the Advanced Fuel Cycle R&D program (AFC) that supports it, we are developing economic and environmental methods to reduce the impact of waste from commercial nuclear fuel cycles. Recycling of used fuel by chemically separating it into uranium, fission products, and higher actinides (HA) would be the first step in this new fuel cycle. Proposed mixtures and concentrations of HA covering a wide range of conditions must be examined theoretically and experimentally to demonstrate criticality safety in advance of construction of a processing facility. Theoretical studies may be limited because of insufficient nuclear data for the rarer isotopes of plutonium (Pu), americium (Am), curium (Cm), and neptunium (Np). One aspect of this is a previously indicated positive reactivity coefficient for dilute mixtures of Pu. As MCNP will be used in future design studies, this trend must be confirmed for MCNP. This will also require generation of cross section libraries and thermal scattering ($S(\alpha,\beta)$) data bases. In addition, a series of integral criticality experiments will be required to validate computational results. In this project, which is a collaboration between UNLV, LANL, and ORNL, we will study thermal feedback effects in dilute mixtures of Pu, then through parametric studies determine the capabilities of a liquid-core critical assembly to measure these criticality parameters and validate design calculations.

1. Proposed Work.

In this project faculty and students will develop cross section and S(α,β) (thermal scattering) data bases for dilute mixtures of Pu for use with the MCNP radiation transport code. These will then be used to determine whether MCNP predicts a positive reactivity effect for these mixtures. Models will then be adapted to conduct parametric studies of capabilities for conducting experiments to measure this effect. Conceptual configurations of equipment and solutions will be modeled using MCNPX or MCNP and associated data libraries. Students will conduct parametric and design studies to predict results of future experiments.

2. Background and Rationale

Future actinide separations facilities in the U.S., such as the proposed Engineering-Scale Demonstration (ESD) and the Advanced Fuel Cycle Facility (AFCF) for the Global Nuclear Energy Partnership (GNEP), will require the establishment of a criticality safety culture and methods to ensure their safety. These methods will include radiation transport codes and data bases that have been validated through an extensive set of experiments that have demonstrated the ability to predict the criticality of mixtures of higher actinides throughout separations and fuel fabrication plants. Integral critical experiments on a variety of mixtures of higher actinides have never been conducted in the U.S. To have confidence in our ability to design, construct, and operate an ESD and/or AFCF, these experiments will be needed to validate codes, data libraries, and measurement methods.

In one of the issues that may face the designers of an ESD or AFCF, several studies have suggested that highly diluted plutonium solutions may exhibit positive reactivity temperature coefficients. Most of these studies are based on calculations performed with deterministic neutron transport codes using cross section data that was calculated as a function of temperature. The purpose of this research is two fold. The first part of the research will be to determine if indeed positive reactivity temperature coefficients are seen when solving the neutron transport equation with Monte Carlo methods. In order to do this, temperature dependent cross section data for MCNP must be developed. In addition, because solutions are thermal systems, the S(α,β) thermal scattering kernel that takes into account the binding energy of the water molecule must also be generated as a function of temperature. The second part of the research will be to design a system or configuration similar to Super SHIBA with the ideal plutonium concentration and dimensions where this effect will be easily measured.

Super SHEBA is the successor to the current SHEBA critical assembly located at the Los Alamos Critical Experiments Facility (LACEF). Super SHEBA, which will be located at the Nevada Test Site near UNLV, will feature the capability to perform both static and dynamic experiments under a wide range of conditions. The Super SHEBA design concept consists of two independent assemblies served by a common fuel storage system. The first assembly is a large prompt burst assembly that will conduct various dynamic experiments. The second assembly will be a general-purpose platform with replaceable vessels, such as spheres or cylinders, for various static experiments. The conceptual design of the static component also includes a "general-purpose" assembly vessel. This assembly is rectilinear in shape with a variable height core. This design will allow a variety of core reflectors, in any shape or thickness, to be stacked around the core. Also, the core may be fitted with experiment wells to accommodate a variety materials or "add-on" experiments.

3. Research Objectives & Goals

The ultimate goals of this project are to investigate the existence (or lack thereof) of a positive thermal reactivity effect in dilute mixtures of Pu when using MCNP to calculate criticality. Part of this work will require the generation of cross section and $S(\alpha,\beta)$ (thermal scattering) data. In addition, a conceptual experiment will be designed to measure this effect.

4. Technical Impact

We must demonstrate the ability to predict the criticality of mixtures of higher actinides throughout separations and fuel fabrication plants. A positive reactivity coefficient has been indicated for dilute mixtures of Pu, but this needs to be verified using the latest computational methods and data libraries. In addition, an integral experiment on a dilute mixture of Pu will be designed to measure this effect. To have confidence in the ability to design, construct, and operate an ESD and/or AFCF, these studies will be needed to confirm predictions and to validate codes, data libraries, and measurement methods.

5. Research Approach

- Gather information about liquid-core criticality experiments, including SHEBA and super SHEBA.
- Collect information on separations processes of interest: size, construction, chemical constituents, and range of isotopic abundance.
- Use radiation transport codes (MCNP, MCNPX, and/or deterministic) to evaluate conceptual experiment configurations and to conduct a survey of potential configurations.
- Develop cross section and $S(\alpha,\beta)$ data.
- Complete design studies for experiments for measuring reactivity feedback to insure the safety of future GNEP separations facilities.

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

UNLV: The Harry Reid Center for Environmental Studies (HRC) will provide laboratory and office space as well as Internet connections for the PI, one graduate student, and one undergraduate student during the duration of this project. The PI leads a team of beta testers for the Los Alamos MCNPX team, and the latest versions of the code and data libraries are available at UNLV. A new personal computer will be purchased for the radiation transport and other studies.

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 national Director for the AFCI Reactor-Accelerator Coupling Experiments Project (RACE) 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.

Dr. David Loaiza is the Team Leader for the Los Alamos Critical Experiments Facility at Los Alamos National Laboratory. He specializes in reactor physics, radiation detection and criticality, and he has performed over 100 critical mass experiments with highly enriched uranium, plutonium and neptunium. He is a certified Crew Chief (senior reactor operator) for Planet, Comet, SHEBA and Flat Top critical assemblies. He has also contributed several benchmark evaluations to the “International Handbook of Evaluated Criticality Safety

Benchmark Experiments." Dr. Loaiza will serve as the technical advisor on the design of a critical assembly with higher actinides.

Dr. Michael Dunn is the Nuclear Data (ND) Group Leader in the Nuclear Science & Technology Division (NSTD) at the Oak Ridge National Laboratory (ORNL). He oversees the development of cross-section processing and the ORNL cross-section measurement and evaluations for the U.S. Evaluated Nuclear Data File (ENDF/B) system. His expertise in the areas of nuclear criticality safety, radiation transport, and cross-section processing methods development will be invaluable for this project.

Mr. Adolf Garcia is a Senior Nuclear Criticality Safety Specialist at DOE-ID (1995 to present). He has 29 years of experience in the nuclear criticality safety field, and was involved in criticality safety at (ANL for twenty years. He has served as a member of ANL's Criticality Hazards Control Committee and was a charter member of the Laboratory's Nuclear Facility Safety Committee. Since 1978 Mr. Garcia has provided criticality safety assistance to DOE Headquarters, DOE Field Offices, and DOE contractors in numerous, including nuclear facilities operational readiness reviews for various DOE sites.

7. Project Timetable and Deliverables

Work will begin in June 2005 with a literature search, data collection, and acquisition of information on separations processes. In addition, collaborations will be initiated with the NTD for Transmutation Engineering, the N-2 group at LANL, and criticality safety advisors. Data bases and $S(\alpha,\beta)$ parameters will be developed, and MCNP will be used to determine the existence of a positive reactivity effect. Super SHEBA models will be adapted to conduct parametric studies of capabilities for conducting experiments. Conceptual configurations of equipment and solutions will be modeled using MCNPX or MCNP and associated data libraries. Information from these design studies will be used to develop experiments to measure integral properties of critical mixtures. Technical reports and/or theses will be written. During the year, meetings may include one or two AFCI Semi-annual Technical Program Reviews, working group meetings, and possibly others. Participation in some of these meetings will be necessary for the PI and student to learn from and work with other collaborators. Travel expenses for the PI will be shared with or completely covered by other 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.

Time Schedule and Major Milestones

	Year 1											
	Qtr 1			Qtr 2			Qtr 3			Qtr 4		
TASKS	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1. Literature search	X											
2. Seps systems data	X	X										
3. Evaluate data			X	X								
4. Computational studies				X	X	X	X	X	X	X	X	X
5. Quarterly reports				X			X			X		
6. Semi-annual Report							X					
7. AFCI Semiannual Review				X								
8. Annual report draft												X
Trips												
Meetings	7		1	2	8	3		4	5		6	

Trip 1, 4, & 6	Separations Working Group Meeting—PI (date & location TBD)
Trip 7 & 8	Consultant visit to UNLV
Trip 2 & 5	AFCI Semiannual Technical Reviews—PI (date & location TBD)
Trip 3	ANS Winter Meeting—PI (Nov., Washington DC)

(Work is assumed to begin June 1, 2006).

References:

1. *Report to Congress on Advanced Fuel Cycle Initiative: The Future Path for Advanced Spent Fuel Treatment and Transmutation Research*, Office of Nuclear Energy, Science, and Tech., U.S. Dep’t of Energy, (2003), http://www.ne.doe.gov/reports/AFCI_CongRpt2003.pdf.
2. *Advanced Fuel Cycle Initiative (AFCI) Comparison Report, FY 2003*, Office of Nuclear Energy, Science, and Tech., U.S. Dep’t of Energy, (2003), available at http://nuclear.gov/pdf/AFCICompRpt2003.pdf ((last visited Jan. 27, 2004).

Advanced Nuclear Technology
P.O. Box 1663, Mail Stop J562
Los Alamos, New Mexico 87545
(505) 667-4936/ FAX: (505) 665-3657

May 3, 2006

Professor Denis Beller,
Department of Mechanical Engineering, UNLV
4505 S. Maryland Pkwy
Las Vegas, NV 89154-4027

Dear Dennis,

I want to formally express my support for the criticality studies of mixed higher actinides and diluted Pu solutions. The theoretical investigation on the concentration of higher actinides necessary to achieve criticality is the first step in the long road to build an eventual prototype to support the Advanced Fuel Cycle. A solution critical assembly will feature the capability to perform both static and dynamic experiments. The objective of this study is to allow research in all areas of solution criticality, excursion dynamic and shutdown mechanisms.

The Plutonium solution investigation relates to the positive temperature coefficients in highly diluted plutonium solutions. There have been several studies that suggest that highly diluted plutonium solutions may exhibit positive reactivity temperature coefficients. Before designing or building a critical assembly with highly diluted Pu, the issue of positive reactivity temperature coefficients will need to addressed and investigated.

I fully supported these two topic of investigation. If you have any questions, please fee free to call me at 506-667-4936.

Sincerely,

David Loaiza, Ph.D
Los Alamos Critical Experiments Facility Team Leader

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: 702-895-0423
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

<u>Research Professor</u> July 03 to present

Department of Mechanical Engineering, University of Nevada, Las Vegas, NV

Conduct reactor physics analyses, radiation transport and shielding, and neutron measurements for the Advanced Fuel Cycle Initiative of the U.S. Department of Energy. Write research proposals, counsel students, write reports, coordinate the UNLV Materials & Nuclear Engineering Master's Degree Program.

<u>Visiting Research Professor</u> 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.

Previous Experience

<u>Transmutation Research Project Intercollegiate Collaborations Leader</u> 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)

<u>Some of my archival publications (title and source only)</u>:

"Atomic Time Machines: Back to the Nuclear Future," *Journal of Land, Resources, and Envir. Law 24*, 1, p 41-60 (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)

"The Need for Nuclear Power," R. Rhodes and D. Beller, *Foreign Affairs, 79*, 1, (2000)

"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)

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