Combined Radiation Detection Methods for Assay of Higher Actinides in Separations Processes

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Combined Radiation Detection Methods for
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(Advanced Fuel Cycle Initiative**)**

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UNLV Collaborators:	Prof. Warnick Kernan, Department of Physics, UNLV 2 Graduate Students (TBD) 1 Undergraduate Student (TBD)
AFCI Program Laboratory Collaborator:	Dr. James Laidler, AFCI NTD for Separations, Argonne National Laboratory
Other Collaborators:	Dr. Frank Harmon, Director, Idaho Accelerator Center Dr. Thomas Ward, UNLV Russian Collaboration Science Adviser, TechSource, Inc., Gaithersburg, MD
AFCI research Area:	Separations
Requested Funds:	$109,403 ($156 k FY06, $143 k FY07)

Abstract—Monitoring of higher actinides (HA, includes neptunium, plutonium, americium, and curium) during the separation of used nuclear fuel has been identified as a critical research area in the U.S. Advanced Fuel Cycle Initiative (AFCI). The AFCI is a program to develop 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 HA would be the first step in this new fuel cycle. This will present challenges in terms of protecting fissile materials, monitoring processes and process equipment for the presence or absence of various constituents, and accounting for quantities of transuranics from beginning to end of fuel processing (MPC&A). Characteristics of HA that may allow for the detection and/or measurement of these materials in batch or continuous processes involve fission, activation, and radioactive decay. Two readily exploited characteristics are gamma-ray emission during radioactive decay and neutron emission during spontaneous fission. Other characteristics that may permit the identification of actinides and isotopes include neutron multiplicity, that is, the measurement of multiple neutrons from single fission events, and absorption of high-energy photons. The UNLV Neutron Multiplicity Detector System, which was developed in a previous UNLV Transmutation Research Project, combined with other detection techniques as well as the capability at the Idaho Accelerator Center (IAC) to produce highly intense pulses of gamma rays and neutrons provides an opportunity to investigate this potential. In the project described herein, we will investigate the use of multiple detection technologies to identify and quantify transuranics in processing stages through theoretical studies and experiments at UNLV and in a collaboration with the Idaho Accelerator Center (IAC).

1. Proposed Work.

In this project faculty and students will investigate the potential to use combined neutron and gamma-ray detector systems to measure quantities and isotopic constituents contained during separations and intermediate storage. This will require knowledge of the nuclear and decay characteristics of materials during processing, the development of conceptual designs of monitoring systems, radiation transport studies to develop an understanding of operational regimes, and experiments to confirm performance. The project will begin with a literature search, compilation of characteristics of separations systems under development in the AFCI program, as well as a compilation of known data about nuclear characteristics (gamma-ray and neutron cross sections, neutron multiplicity, and spontaneous fission) of individual isotopes of the higher actinides. AFCI Separations staff members will provide information about processing equipment and process chemistry (constituents of solutions). This information will then be used in radiation transport and scoping studies to develop concepts for combined gamma-ray, neutron, and active and passive detection techniques. In subsequent years experiments will be conducted at UNLV and/or the Idaho State University, where an electron linac at the Idaho Accelerator Center (IAC) will be used to induce radioactivity and/or fission in process streams or containers.

2. Background and Rationale

Future actinide separations facilities in the U.S. will require the establishment of a new standard of performance for actinide materials protection, control, and accounting (MPC&A). New technology, or new applications of existing technology, will be necessary to provide assurance and precision in these tasks. Concepts include x-ray spectroscopy, light absorption technologies, passive gamma-ray and neutron measurements, and active methods that may include inducing fission with accelerator generated photons or external neutron sources. This MPC&A is necessary for materials accounting, criticality monitoring, and assurance of proliferation resistance. In this project, we will investigate the potential to use a combination of gamma-ray and neutron detection with both passive and active interrogation technology that has been recently demonstrated at ISU.

One piece of equipment to be used in this project was previously developed under the UNLV TRP. The Neutron Multiplicity Detector System (NMDS) was designed, constructed, and tested in collaboration with the V. G. Khlopin Radium Institute (KRI) in St. Petersburg, Russia. The system has since been extensively tested at UNLV and ISU. The NMDS is a modular system consisting of 64 ^{3}He detectors (tubes), electronics, and lead and polyethylene bricks. These detectors operate at ~1 microsecond timing resolution and collect data from each multiplicity event for a 256 microsecond duration. The data acquisition and analysis system subsequently allows correlation of the neutron multiplicity to each event. Other equipment that is available at UNLV and ISU that may be used in this project, depending on concepts developed and feasibility, includes gamma-ray spectroscopy systems (e.g. germanium and sodium iodide crystals) in a variety of laboratories.

3. Research Objectives & Goals

The ultimate goals of this project are to develop technology to detect and measure quantities of higher actinides in processing systems without taking frequent samples. These systems include separations batches and pipelines. A variety of measurements may be combined to calculate flow rates of actinide elements with a to-be-determined precision. Scoping and design studies will first be performed using validated data sets (decay properties and reaction cross sections) and the sophisticated and internationally accepted radiation transport code MCNPX. Basic measurements will then be performed and compared to predictions. Experiments to be conducted in years 2 and 3 are to be determined, but may include small quantities of radioactive actinides at UNLV in addition to accelerator-coupled experiments at ISU.

4. Technical Impact

AFCI Separations must demonstrate the ability to monitor the HA constituents in process streams before continuing to engineering demonstration. We must show through detector development and research that systems can be developed to monitor or quantitatively assess on-line the amount of fissile material in the fuel cycle processing stages. The use of the UNLV NMDS combined with gamma-ray spectroscopy and active interrogation techniques previously developed may provide part of the assurance needed to proceed with engineering design of a separations demonstration plant.

5. Research Approach

- Collect data on fissile isotope characteristics: photon and neutron cross sections, neutron multiplicity, decay schemes and half lives, and characteristics of neutron and gamma ray emissions.
- Collect information on separations processes of interest: size, construction, chemical constituents, and range of isotopic abundance.
- Use actinide decay schemes and MCNPX to evaluate conceptual detector configurations.
- Use an Idaho Accelerator Center electron linac (pulsed) or ^{252}Cf (continuous) source in out years to investigate active interrogation.

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 NMDS is currently located within a detector laboratory in the HRC. Other detector systems are available in UNLV and ISU labs and the IAC. In addition, 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.

Prof. Warnick Kernan is a Research Professor in the Physics Department at the University of Nevada, Las Vegas. He is in an endowed position from the U.S. Nevada Test Site's Remote Sensing Laboratory. Dr. Kernan is extensively involved in radiation detection applications.

Dr. James Laidler of Argonne National Laboratory is the National Technical Director for Separations for the AFCI Project. He will collaborate and provide information related to separations processes of interest.

Idaho State University-Idaho Accelerator Center will provide equipment and staff for creating accelerator-generated photons and neutrons for developing neutron multiplicity measurement technology.

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 AFCI Separations (ANL), non-proliferation, and MPC&A specialists. Nuclear reactions, decay schemes, and other information will be used to develop concepts for combined analysis methods. Conceptual configurations of equipment and solutions, neutron sources, and modular detector components will then be modeled using MCNPX and associated data libraries. Information from these design studies will be used to develop experiments with both gamma-ray and neutron radiation sources at UNLV and accelerator-generated neutrons at ISU-IAC. This later phase will involve moving detector systems to the IAC. Technical reports and/or theses will be written on each of these experiments. 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 AFCI 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. Prepare for exp.						X	X					
6. Conduct exp.								X	X			
7. Analyze exp.										X	X	
8. Report on exp.											X	X
9. Quarterly reports				X			X			X		
10. Semi-annual Report							X					
11. AFCI Semiannual Review				X								
12. Annual report draft												X
Trips												
Meetings	1			2		3		4	5		6	

Trip 1, 4, & 6	Separations Working Group Meeting—PI (date & location TBD)
Trip 2 & 5	AFCI Semiannual Technical Reviews—PI (date & location TBD)
Trip 3	ANS Annual Meeting—PI (Nov., Washington DC)

(Work is assumed to begin June 1, 2005).

8. 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).
3. "Modeling Neutron Multiplicities in a 60-element ^{3}He Detector System," Dean Curtis, Denis Beller, Carter Hull, Alexander Rimsky-Korsakov, and Thomas Ward, *Proc. of the Sixth International Topical Meeting on Nuclear Applications of Accelerator Technology, AccApp'03*, June 1-5, San Diego, CA, American Nuclear Society, to be published in Feb. 2004.
4. "The UNLV Neutron Multiplicity Detector System," T. Beller, D. Curtis, D. Beller, A. Rimsky-Korsakov, and T. Ward; to be published in the Proceedings of the Eighth Information Exchange Meeting on Actinide and Fission Product Partitioning & Transmutation, 9-11 November 2004, Las Vegas, Nevada
5. "Proliferation Resistance Fundamentals for Future Nuclear Energy Systems," Department of Safeguards, International Atomic Energy Agency, STR-332, Dec. 2002.

Delivered-To: beller@egr.unlv.edu
Subject: RE: AFCI MPC&A
Date: Tue, 1 Mar 2005 09:34:05 -0600
X-MS-Has-Attach:
X-MS-TNEF-Correlator:
Thread-Topic: AFCI MPC&A
Thread-Index: AcUecgUSy0JlgVpsRCG8iW7C3//KZQAAV5Kw
From: "Laidler, James J." <laidler@cmt.anl.gov>
To: "Denis Beller" <beller@egr.unlv.edu>
X-Spam-Checker-Version: SpamAssassin 2.63 (2004-01-11) on stewie.Egr.UNLV.EDU
X-Spam-Level:
X-Spam-Status: No, hits=0.6 required=5.0 tests=AWL,HTML_20_30,
HTML_FONTCOLOR_BLUE,HTML_MESSAGE,SUBJ_ALL_CAPS autolearn=no
version=2.63

Hello Denis,

I am fully supportive of this work and hope that we will be able to expand its scope in the future. I encourage you and your colleagues to explore a broad range of measurement methods, perhaps including some neutron resonance measurement schemes. And please remember my message at the Alexandria meeting: we are going to establish a new world standard for materials protection, control and accountancy in reprocessing plant design and we will demonstrate the needed technologies in a significant way. I think that the efforts you have proposed here are a strong step in the right direction.

Best regards,
Jim

> Date: Fri, 25 Feb 2005 16:30:59 -0800
> To: Frank Harmon <harmon@athena.physics.isu.edu>, Tom Ward <tward@techsource-inc.com>, Jim Laidler <laidler@cmt.anl.gov>
> From: Denis Beller <beller@egr.unlv.edu>
> Subject: AFCI MPC&A

snip snip

> Jim: let me know if you support this; e-mail message is sufficient for now, but I'll probably need a letter in a week or so.
>
> Denis

Abbreviated Curriculum Vitae
Dr. Denis E. Beller

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Phone: 702-895-0423
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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 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.

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.

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)

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

"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)