

## **Final Technical Report**

# **Creating an educational consortium to support the recruitment and retention of expertise for the nuclear weapons complex**

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**Submitted by  
Idaho Accelerator Center and Idaho State University**

**to**

**U. S. Department of Energy**

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### Executive summary

From FY 02-05 IAC has been a part of the DOE Advanced Fuel Cycle Initiative and its predecessor organization Advanced Accelerator Applications. The technical components of this national program have been: Transmutation Engineering, Separations, and Fuels viewed in the context of the fuel cycle. In the IAC program effort has been divided into three parts; Student Research, Accelerator Driven Nuclear Research and Materials Science. Within the three parts specific research and development activities have been undertaken in:

1. Student Research which supported undergraduate and graduate students, post-docs, engineering staff, program administration, project infrastructure, visiting and summer faculty appointments, visiting scientists, and support of students and faculty at the University of Michigan, Texas A&M University, University of Texas and UNLV. Twenty nine graduate students have been supported and 17 graduate theses have been developed on various aspects of the program. 23 undergraduate students and 9 Post Docs have also been involved in AFC projects.
2. Accelerator Driven Nuclear Research included the use of electron accelerators to study driven sub-critical nuclear systems (ADS) and to provide practical methods of monitoring and assaying nuclear materials for accountancy in non proliferation applications (Materials Accountability and Control, MA&C). The former includes neutron multiplication, reactor dynamics and sub-criticality investigations (Reactor Accelerator Coupling Experiment, RACE). The latter includes development of accelerator beam induced phenomena to provide technology for materials identification and assay. Faculty and scientific staff from UM, UNLV, UT, TAMU, LANL, INEL, ANL, and CEA, have been directly involved with various aspects of these programs. The work has resulted in 31 peer reviewed publications, presentations and reports.
3. Materials Science research at IAC supported all AFC national technical areas. During the grant period IAC discovered accelerator positron-annihilation spectroscopy (AG-PAS) has been developed as a cost effective tool to ascertain atomic level defect based damage in standard structural applications and in radiation induced damage of materials and measurement of dynamic defect producing phenomena. Detailed comparisons between AG-PAS and standard materials stress/strain metrology have been carried out to assure that the method has predictive capability. Also, the first ever defect images of stressed materials have been obtained. The work has resulted in 18 peer reviewed publications, presentations and reports.

The public benefit of the IAC program has been high, in addition to education and training of students, there have been developed new data on ADS systems, new defect analysis methods for materials, and technologies for detection of concealed nuclear materials supporting nonproliferation and national security needs.

### Goals and Accomplishments

1. A principle goal of the project was to educate students in applied nuclear science in preparation for careers in the private sector, national laboratories and in education. This has been achieved 17 students have received their M.S. degree. Students and thesis titles are listed below.
2. An important goal was to establish unique accelerator based resources to support R&D in Materials Studies, including AG-PAS; facilities to test nuclear techniques in Materials Accountability and Control, and for the RACE ADS experiments. The following experimental resources have been established:
  - a) High Repetition Rate Accelerator for PAS studies and imaging. The accelerator can operate with pulse repetition rates up to 2000 Hz, making it one of the few high duty factor machines in the world. This facility includes sample scanning hardware for image generation.
  - b) MA&C accelerator inspection and assay facilities for research and testing of methods for detection and analysis of special nuclear materials. This facility includes a mobile sample flow system that simulates piping in a fuel recycle facility.
  - c) Tunable x-ray system based on laser/electron beam interaction (Laser Compton Scatter LCS). This LCS system is used to support the MA&C work as stimulating source for fluorescent x-rays and nuclear gamma rays. The LCS is a world class facility the only one covering the x-ray energy range, 5keV to 150 keV.
  - d) For RACE experiments mobile accelerator technology was developed allowing electron accelerators up to 25 MeV to be configured in a portable format. Two such machines were developed and deployed at different sites including at the TAMU reactor facility.
3. A major goal was to demonstrate phenomena in coupled reactor accelerator systems using a full scale reactor and a sub-critical assembly that could not become critical and test current predictive reactivity codes. The former task was accomplished through a series of experiments conducted on the TRIGA reactor at UT Austin. An IAC linac accelerator was used to produce pulses of neutrons in the core of the TRIGA. Coupling effects were studied over a wide range of core reactivities. Data from these experiments and from the manifestly sub-critical assembly at IAC showed, among other results, that conventional core criticality calculations were not adequate and that new codes will be needed for ADS systems.

### *Summary of Project Technical Activities:*

The Idaho Accelerator Center (IAC) at Idaho State University provides facilities for research and education in charged-particle accelerator applications in nuclear and radiation science. The purpose of the IAC is to study and develop applications of nuclear and radiation science, low-energy charged-particle accelerators, and related technology for the DOE and other entities. For the AFCI program the IAC has developed, in collaboration with national labs and other universities, capabilities in Radiation Effects/Materials Science and Accelerator-related Nuclear Science and Technology.

## RADIATION EFFECTS AND MATERIALS SCIENCE

### *Oxygen Sensor Radiation Tests Collaboration with LANL*

The aim of this work was a one year effort in FY 2004 to test in a mixed gamma and neutron radiation field oxygen sensor (OS) elements supplied by LANL. The sensors were tested in an LBE liquid target device. The project accomplished the design of a Lead/LBE target/irradiator for in-situ radiation effects testing on oxygen sensors, the prediction of mixed-field radiation doses to oxygen sensor samples in the LBE target by using MCNPX modeling, the fabrication and testing of the target/irradiator, and variable temperature tests.

### *Positron Annihilation Spectroscopy*

The positron-annihilation spectroscopy (PAS) method developed at IAC is able to detect defect and damage in bulk materials, at the micro structure level, caused by induced stress. By focusing a beam of high-energy gamma rays on materials, positrons are created inside the materials. The positrons then annihilate locally, thus sending their signal from inside the bulk material. A collaborative effort with Professor A. Roy's materials group (Mechanical Engineering Department at UNLV) over the period of the project used standard stress analysis techniques to benchmark the new PAS technique and demonstrate its effectiveness and sensitivity. The positron stress measurements group at the IAC collected data on a wide range of sample types including standard engineering test specimens. Several ISU and UNLV students have used this work as part of MS theses.

An extension of the PAS technique allowed IAC researchers to make the first ever multi-dimensional defect measurement and form the information into a defect map or image. Difficulties of providing adequate radiation sources for this type of image generation led to the development of the High Repetition Rate Accelerator at IAC.

### *Advanced Positron Annihilation Methods and Radiation Damage*

Dynamic Measurements of Structural Changes in Matter: This methodology takes advantage of the PAS technique's unique ability to do dynamic measurements. The pulsed electron accelerator used in PAS in bulk materials was synchronized with a pulsed laser. PAS was performed on a sample during and shortly after a thermal stress was induced in the sample with an intense and very brief laser pulse. The thermal shock

created by the laser pulse was seen in the behavior of the PAS signal demonstrating the possibility of obtaining detailed information about the structural changes in materials during shocks and other dynamic changes and extends positron studies to the dynamic effects in materials.

In other Advanced Positron Annihilation Methods and Radiation Damage research, a new technique developed at IAC for performing Positron Annihilation Lifetime Spectroscopy (PALS), another useful probe of defects in materials, was extended to include application in radiation damaged materials. The new method allows PALS to be performed on bulk samples for the first time. PALS allows the lifetime in bulk materials, a powerful key to mechanical failure, to be measured, something that is not possible by any other technique.

The Radiation Effects and Materials Science effort was coordinated with Stuart Maloy, Mike Cappiello, and Ning Li of Los Alamos National Laboratory as well as Ajit Roy at UNLV and Mich Meyer at ANL. The IAC Principle Investigators for Materials were Farida Selim, Douglas Wells and Alan Hunt.

#### *Reactor-Accelerator Coupling Experiments (RACE) Project*

The AFCI RACE Project was a multi-university collaboration led by the IAC that also included Texas A&M University, University of Texas at Austin, UNLV, and the University of Michigan. Other major coupling research programs in the time period of the RACE project were, MUSE (CEA, Cadarache, France) and a follow-on program called the TRADE Project (TRIGA Accelerator Driven Experiment, ENEA, Cassacia, Italy) this project was terminated in FY 2004. Other international ADSS projects are in Japan, Russia (SAD Project, Dubna), and China. The RACE project was the only experimental U.S. program for accelerator-reactor coupling research during the project period and it maintained strong collaborations with the European program throughout the project.

The critical issues to be addressed in ADS experiments are dynamic behavior, reactivity control accelerator/reactor power relationships and start-up and shut-down operation. A more limited aim was taken by RACE ; data derived from RACE tests were to allow validation of existing and to-be-developed computer codes used to predict the performance of ADS. RACE provided a number of important features in the steps toward understanding important technical issues. The RACE concept used an electron linac driven neutron source which shares major characteristics with a spallation source needed for a commercial ADS, and will provided a more realistic source term than past experiments at MUSE. RACE demonstrated the effects of locating the accelerator target at various locations in and near a subcritical core, a feature not shared by other programs.

The IAC Principle Investigators were Profs. Denis Beller (ISU Physics), Alan Hunt (ISU Physics), and John Bennion (ISU Engineering). Prof. William Charlton at Texas A&M University, Prof. Sean O'Kelly at UT-Austin, and Prof. John Lee at the University of Michigan. The RACE Technical Advisory Group included Dr. Michael Cappiello of Los Alamos National Laboratory and Dr. George Imel of Argonne National Laboratory, who has also directed many of the European ADSS experiments.

### *Materials Accountability and Control*

In the last FY of the program IAC was asked by AFCI management to begin the development of advanced instrumentation for materials accountancy in advanced fuel cycle facilities. Results of other work at IAC suggested that techniques being developed for applications in non AFCI programs might be useful for MC&A applications. Three continuous real time/near real time measurement techniques that might serve for quantitative determination of fissile material and the minor Actinides in process streams were examined. Accelerator stimulated x-ray fluorescence (AXRF), neutron integral cross section spectroscopy (NICS) and delay neutron lifetime measurements (DNL). All three methods used accelerator based active interrogation methods. The specific needs of the various possible applications and uncertainties as to the capabilities of accelerator based methods (particularly for the MA, Pu presents much less uncertainty) to these applications were studied at IAC. This work was incomplete at the time of project ending.

#### **Publications and Presentations and Theses resulting from the project:**

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**Theses:**

UNLV	Subhra Bandyopadhyay	M.S.	Residual Stress Characterization and Defects Analyses by Microscopy
UNLV	Silpa Suresh Budugur	M.S.	Positron Lifetime Analysis of Tensile Steel Specimens
ISU HP	Vivek Manickam	M.S.	Estimation of Activation Products and a Decay Time for Havar Foils From a GE Pet-Trace Medical Cyclotron Using High Resolution Gamma Spectroscopy
ISU HP	Syed Naeem	M.S.	Transuramic Material Assay and Imaging
ISU/IAC	Raymond Rios	M.S.	Studying the Induced Deexcitation of $^{178m2}\text{Hf}$ with Low Energy X-rays
ISU/IAC	Kristen J. Smith	M.S.	Positron Annihilation Spectroscopy on Composite Materials
ISU/IAC	Scott Thompson	M.S.	Radiation Damage Studies with Positron Annihilation Spectroscopy
ISU/IAC	Nino Chelidze	M.S.	Positron Lifetime Studies in Radiate Damaged 55304 and 9LR1MO
ISU/IAC	Jennifer Farley	M.S.	Development at Delayed Gamma Techniques for Materials Identification
ISU/IAC	Marcus Gagliardi	M.S.	Development of a Positron Production Target
ISU/IAC	Cecil Joseph	M.S.	X-ray Induced Current Transient Spectroscopy and Characterization of CdZnTe Semiconductor Detectors
ISU/IAC	Matt Kinlaw	M.S.	Development of a New Delayed-Neutron Technique for Detection of Fissile material

ISU/IAC	Vakhtana Makarashvil	M.S.	Delayed Gamma Techniques for Detection of Fissile Material
ISU/IAC	Yoshimasa Toyoda	M.S.	Electron Beam Diagnostics Using LCS
ISU/IAC	Jason Williams	M.S.	Positron Annihilation Spectroscopy with Shocked Samples
Texas A&M Univ.	Taraknath Woddi	M.S.	Reactor Accelerator Coupling Experiments: A Feasibility Study