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Title: UNIVERSITY PROGRAMS OF THE U.S. DEPARTMENT OF ENERGY ADVANCED ACCELERATOR APPLICATIONS PROGRAM

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University Programs of the U.S. Department of Energy Advanced Accelerator Applications Program

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Abstract–*The Advanced Accelerator Applications (AAA) Program was initiated in fiscal year 2001 (FY-01) by the U.S. Congress, the U.S. Department of Energy (DOE), and the Los Alamos National Laboratory (LANL) in partnership with other national laboratories. The primary goal of this program is to investigate the feasibility of transmutation of nuclear waste. An Accelerator-Driven Test Facility (ADTF), which may be built during the first decade of the 21st Century, is a major component of this effort. The ADTF would include a large, state-of-the-art charged-particle accelerator, proton-neutron target systems, and accelerator-driven R&D systems. This new facility and its underlying science and technology will require a large cadre of educated scientists and trained technicians. In addition, other applications of nuclear science and engineering (e.g., proliferation monitoring and defense, nuclear medicine, safety regulation, industrial processes, and many others) require increased academic and national infrastructure and student populations. Thus, the AAA Program Office has begun a multi-year program to involve university faculty and students in various phases of the Project to support the infrastructure requirements of nuclear energy, science and technology fields as well as the special needs of the DOE transmutation program. In this paper we describe university programs that have supported, are supporting, and will support the R&D necessary for the AAA Project. Previous work included research for the Accelerator Transmutation of Waste (ATW) project, current (FY-01) programs include graduate fellowships and research for the AAA Project, and it is expected that future programs will expand and add to the existing programs.*

I. INTRODUCTION

The Advanced Accelerator Applications (AAA) Program was initiated in fiscal year 2001 (FY-01) by the U.S. Congress, the U.S. Department of Energy (DOE), and the Los Alamos National Laboratory (LANL) in partnership with other national laboratories. The primary mission of the AAA Program is development of technology for transmutation of nuclear waste and demonstration of its practicality and value for long-term waste management. Other goals are to help revitalize the U.S. nuclear infrastructure, to provide a test-bed for advanced nuclear projects, and for the U.S. to resume an international leadership role in nuclear technologies. As part of this effort, the DOE and the national laboratories are investigating building an Accelerator-Driven Test Facility (ADTF) during the first decade of the 21st Century. The ADTF would include a large, state-of-the-art charged-particle accelerator, several proton-neutron target systems, and accelerator-driven R&D systems. This new facility and its underlying science and technology will require a large cadre of educated scientists and trained technicians in addition to that required for our broader national nuclear infrastructure.[1, 2]

During the next decade, the nation will need additional nuclear scientists and engineers for national security programs like counter-proliferation, global monitoring activities, stewardship of our nuclear stockpile, and naval nuclear propulsion. We will also need more college graduates for design and federal regulation of next-generation reactors, and we will need young people for nuclear medicine and medical research using radioisotopes. We will need still more for expanding industrial radiation applications such as manufacturing, oil and gas exploration, and irradiation to sterilize hundreds of consumer products and most medical equipment. In addition, we'll need a larger nuclear workforce for irradiation of food as well as livestock feed to eliminate pathogens like Listeria and e-Coli from our food, Hoof-and-mouth from our feedstocks, and Anthrax from our mail.

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Because of the requirements for educated scientists and engineers in a wide variety of nuclear- and accelerator-related fields, the AAA Program Office has begun a multi-year program to involve university faculty and students in various phases of the AAA Project. In this paper we first describe university programs that have supported research for the ATW Project at the University of Michigan, the University of California at Berkeley, and the University of Texas at Austin. We then describe current (FY-01) programs to contribute to the R&D necessary for the AAA Project. These current programs include ongoing university research, a University Participation Program (AAA UPP) at the University of Nevada, Las Vegas, and a new University Fellowship Program (AAA UFP) that is managed for DOE/NE by the Amarillo National Research Center. In accordance with the public law that established the AAA Project and the UNLV funding, the UNLV AAA UPP will include "… research and development of technologies for economic and environmentally sound refinement of spent nuclear fuel."[3] Student-conducted research has begun, and improvements to infrastructure at the UNLV will be described. Another new program, a $500,000 fellowship program (AAA UFP), which began earlier this year with a competitive application process, supports ten highly motivated students who are working on research projects that support the research and development needs of the AAA Project. We also discuss the large number of students supported with FY-01 AAA funding.

Finally, Future projects are described on the assumption of long-term budgets that may include expansion of these existing programs as well as a major, competitive, peer-reviewed University Research Program (AAA URP) that is expected to be initiated in the more distant future. The AAA URP is intended to include faculty-centered R&D in support of the AAA Project.

II. PRIOR-YEAR SUPPORT THROUGH THE ATW PROJECT

In fiscal year 2000 (FY-00), the Accelerator-driven Transmutation of Waste (ATW) Project began as a $9M effort following a decade of laboratory-funded research at Los Alamos National Laboratory. During the ATW Project, Los Alamos National Laboratory contracted with three universities—the University of California-Berkeley, the University of Michigan, and the University of Texas-Austin—to support ongoing research in transmuter design and analysis, in planning for experiments, and in assessing proliferation-resistance attributes of separations and transmutation technologies. Research projects at these three universities have employed undergraduate and graduate students during that past academic year. Faculty and students at the University of California-Berkeley conducted research to evaluate designs of transmuters and to optimize the destruction of neptunium (the isotope of primary concern for long-term storage).[4] In one design study of a once-through, graphite-moderated $NaF\text{-}ZrF_4$ molten-salt reactor, its potential for transmuting ^{237}Np and its precursors was examined. If one could be built economically, a molten-salt transmuter with continuous removal of all fission products offers a remarkably high fractional transmutation, greater than 90 percent, if concentrations of actinides in the molten salt greatly exceed the current known limit of 2 percent. Berkeley researchers learned that thick fuel channels produce strong self-shielding effects, particularly for ^{240}Pu, so heterogeneous calculations are required to determine accurate isotopic composition and fractional transmutation. They determined that for a given feed rate of heavy metal, smaller feed/removal rates result in longer mean residence times, increased overall transmutation effectiveness, and lower k_{eff}. And for a given graphite-moderator lifetime (with respect to radiation damage), thinner channels achieve greater transmutation. Other conclusions of this analysis of molten-salt transmutation reactors are discussed in a companion paper.[5]

At the University of Michigan, researchers have supported the ATW Project with studies for the design of integral experiments as well as evaluations of a variety of technical issues.

Three companion papers present results of ATW research projects at Michigan. In one, mono-energetic neutron sources of sufficiently high energy (e.g. 14 MeV) to contribute to the science of accelerator-driven transmutation in lead and bismuth moderators are shown to produce flux depressions just below the source energy.[6] In the work reported in another companion paper, neutronics tools are being compared to validate design methods.[7] In another project that is reported in this conference, a Michigan student is developing numerical algorithms based on a two-dimensional time-dependent diffusion theory code that can accurately account for step changes in localized sources in time.[8] This involves separate treatments for the shape-function and amplitude-function calculations that can represent prompt space-time variations in neutron flux within the quasi-static formulation. Other work at Michigan has included design and analysis of transmutation systems, integral experiments for fuel, reaction rate, and other studies, and prioritization of research requirements.

A FY-00 research project was completed at the University of Texas-Austin to evaluate the impacts of ATW on proliferation resistance of separations, fuel fabrication, transmutation, and disposal.[9] They have begun the development of a set of high-level metrics in conjunction with research staff at Sandia National Laboratories to compare the "International Acceptability" of proliferation risk from transmutation with the risk from the once-through fuel cycle.

III. CURRENT UNIVERSITY PROGRAMS

During FY-01, research and development of ATW technology was expanded, the project was combined with the Accelerator Production of Tritium Program, and it was re-named the Advanced Accelerator Applications (AAA) Program. Increased academic participation was one of the major goals of the AAA Program, which includes continuation of directed university research as well as new university programs. An integral component of the AAA Program is continued Directed University Research at Berkeley, Michigan, and Texas. This continued research leverages the Project's prior investment in computer systems, software, and other resources, in faculty expertise, and gives us the opportunity to increase the value of research conducted by faculty and students at these institutions. In addition to these current research projects, the AAA Program has implemented two major new university programs. A $3 million University Participation Program (AAA UPP) was begun at the University of Nevada, Las Vegas, and a new University Fellowship Program (AAA UFP) is managed for DOE/NE by the Amarillo National Research Center. In accordance with the public law that established the AAA Project and the UNLV funding, the UNLV AAA UPP will include "… research and development of technologies for economic and environmentally sound refinement…" of used nuclear fuel. Student-conducted research has begun, and substantial improvements to infrastructure at the UNLV are underway. The $500 k AAA UFP fellowship program, which began earlier this year with a competitive application process, will support ten highly motivated students who this fall will begin working on projects that support the research and development needs of the AAA Project. In addition, a number of students, from high school through doctoral, are employed at the national laboratories in support of the AAA Project. These new programs are described below.

IV. AAA UNIVERSITY PARTICIPATION PROGRAM

The UNLV AAA University Participation Program (UNLV AAA UPP) is designed to benefit the National AAA Project and the University's goals to enhance student-focused and internationally recognized research programs. The strategic plan to accomplish these objectives has the following three main components:
1. Program Support to ensure the smooth operation of the UNLV AAA UPP and all non-research functions such as maintenance of communication links and information management, organization of workshops and conferences, and administration of the competitive proposal process;
2. Research Infrastructure Augmentation under which the UNLV nuclear research infrastructure is being enhanced through the hiring of new researchers and the acquisition of scientific equipment to allow researchers to perform more AAA-relevant research on campus; and,
3. Student Research to support projects at UNLV on tasks relevant to AAA research and technology development needs.

In a companion paper at this conference, the director of the UNLV AAA UPP will discuss the vision and implementation of this new program including the research projects that are underway in the first year of the program, important decision points, and a new paradigm in grant research exemplified by the program.[10] Immediately after funding was established for this the UNLV AAA UPP, four projects were competitively selected for research beginning the summer of 2001, and another eight were selected for fall starts. To illustrate the kinds of research projects that are being initiated at UNLV, the first four of these projects are described in the following:

- "Design and Analysis for Melt Casting Metallic Fuel Pins Incorporating Volatile Actinides" is a project in the UNLV Mechanical Engineering Department that is being conducted in collaboration with Argonne National Laboratory-West. In this project students will investigate methods and equipment to cast fuel pins for transmutation while preventing the evaporation of volatile actinides such as americium.
- In a project titled "Experimental Investigation of Steel Corrosion in Lead Bismuth Eutectic: Characterization, Species Identification, and Chemical Reactions," UNLV Physics Department faculty and students initiated a program to investigate experimentally the corrosion of steels by Lead-Bismuth Eutectic. Corrosion products and related chemical reactions will be identified using facilities at UNLV for the Scanning Electron Microscope (SEM) and x-ray diffraction (XRD). Thirty samples of steel now at UNLV were exposed to high-temperature LBE and have been analyzed by Russian scientists. Several samples have been examined with the SEM, and the most recent experimental results are reported in a companion paper.[11]
- Researchers in the Department of Mechanical Engineering will investigate "Hydrogen-Induced Embrittlement of Candidate Target Materials for Applications in Spallation-Neutron-Target Systems, Phase I" with LANL scientists and engineers.
- "Modeling, Fabrication, and Optimization of Niobium Cavities" is a collaboration between the Department of Electrical and Computer Engineering, the Department of Mechanical Engineering, and the AAA Technology Project Office (Superconducting RF Engineering Development and Demonstration). In this project researchers will perform research to maximize the performance of the accelerator cavities by studying multipacting (a localized resonance process resulting from the impact of electrons on

cavity surfaces), by studying the effect of chemical etching on cavity surface roughness, and by redesigning cavities.

V. AAA UNIVERSITY FELLOWSHIP PROGRAM

Earlier this year the AAA Program Office in DOE/NE established a new fellowship program that is administered by the Amarillo National Research Center, a consortium of Texas Universities. This new program is intended to support top students across the nation in a variety of disciplines that will be required to support AAA research and technology development in the coming decade. In the first year, ten AAA Fellows were selected from a large pool of highly qualified applicants. The students who were awarded Fellowships will be attending graduate school this fall at the following institutions: the University of Illinois-Urbana/Champaign, the Massachusetts Institute of Technology, the University of Texas-Arlington, the University of California-Berkeley, the University of Massachusetts-Lowell, the University of Texas-Austin, the Ohio State University, Texas A&M University, and the Chemical Engineering and Nuclear Engineering Departments of the University of Michigan. These students will work on a variety of topics as they conduct research for their Masters theses and degrees. Topics that have already been identified include chemical separation processes and modeling, fuel development and fabrication, in-beam experiments at the Los Alamos Neutron Science Center (LANSCE), lead-bismuth loop experiments at LANL, and systems studies to evaluate technology readiness levels for ATW systems. Four of the ten AAA Fellows are also employed at the laboratories this summer (three at LANL, one at ANL-West). This program is described in greater detail in a companion paper at this conference.[12]

Table I.
Summary of Annual AAA Student Support

Total:	87	students supported by FY-01 AAA Project funds
Laboratory interns	14	(count does not include 3 of the AAA Fellows)
Indirect-support interns	6	(estimate)
AAA University Fellowship Program	10	
UNLV AAA University Participation Program	40	(23 graduate and 17 undergraduate students)
Directed University Research Programs	12	
Seaborg Transactinium Science Institute Summer School	5	

VI. AAA STUDENT SUPPORT

A significant aspect of the AAA Program is that it supports a substantial U.S. student population. These students are supported through the AAA University Fellowship Program, the UNLV AAA University Participation Program, research contracts with three universities, and internship programs at national laboratories. This year, at least 70 students have been, are, or will be supported by FY-01 AAA funding (this includes both AAA and APT funding). In addition, students are working on AAA-related research with support from other DOE programs (special student programs, other research projects, etc.) We expect the number of students who are supported by AAA funding to increase with additional support from FY-02 funding. The following sections briefly describe the different AAA categories of student support, and the information is summarized in Table I.

VI.A. Direct Support for Laboratory Intern Students

Most interns conduct research during the summer, however, several students are supported during other portions of the year, and Ph.D. students work at the laboratories year-round. Eighteen high school, undergraduate, and graduate students are supported directly by the FY-01 AAA funding (sixteen at LANL and two at ANL-West). This total includes five of the AAA Fellows mentioned in the AAA UFP Students section (they are counted with the "AAA UFP" category for the summary in Table I, not here).

VI.B. Indirect Support for Laboratory Intern Students

The AAA Project at Argonne National Laboratory-East is employing several students who are conducting research on AAA-related research. Because of the employment mechanisms used there, they are not funded directly from AAA Work Packages. However, an estimated six students are included in this category who are or will be supported at ANL-East.

VI.C. UNLV AAA UPP Students

Students at UNLV are employed in research projects and as support to the project administrators in the Harry Reid Center for Environmental Studies (some of this support to administrators is technical in nature, however). The first four approved research projects include twelve undergraduate, Masters, and Ph.D. students. Five students are providing support to the administrators. In addition, three to four more research projects will be selected this summer for support beginning this fall; thus, approximately twelve additional students will be supported by FY-01 AAA UPP funds. Therefore, 25 to 30 students will be working and going to school under AAA UPP funding this calendar year. We hope to add research projects next year with FY-02 funding while continuing current FY-01 research.

VI.D. AAA UFP Students

As previously discussed, ten AAA Fellows are attending classes and conducting research contributing to their Masters degrees.

VI.E. AAA Directed University Research Students

Several students are currently working on AAA research at Michigan, Berkeley, and Texas, and they and others will begin research projects this fall and next year. Approximately twelve students per year are funded by these AAA Directed University Research projects.

VI.F. Seaborg Institute Students

In addition to the programs that provide direct research support to the AAA Project, in 2001 DOE/NE sponsored five students to attend the Glenn T. Seaborg Institute for Transactinium Science (GTS-ITS) Summer School at Lawrence Livermore National Laboratory. Of these highly qualified students, two were fully supported and three were partially supported.

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VII. FUTURE GROWTH

Expansion of academic collaborations for the AAA Project next year (FY-02) and beyond depends on projected budgets. AAA Program management intends at the very least to continue the existing programs (UNLV UPP, existing Directed University Research, and UFP). However, an increased budget may allow these programs to expand and others to be added. Even without an increase in the AAA UPP budget, investments in infrastructure will decrease in future years such that additional funding may be available for student-based research. Thus, 50 or more students may be supported at UNLV even with level AAA UPP funding. The University Fellowship Program may expand to twenty students per year, may remain at the current level, or may be curtailed either by funding constraints or in favor of support of the proposed competitive faculty-directed, student-based research programs.

The proposed University Research Program (AAA URP) is expected to be a major, competitive program to solicit proposals for a peer-reviewed award process that may be initiated in the future by the Amarillo National Research Center for the DOE/NE. If it is implemented, the AAA URP will include faculty-centered, student-conducted R&D in support of goals of the AAA Project. If there is significantly increased AAA funding in FY-02 and beyond, we expect this project to be on the order of $1 million in FY-02, expanding to perhaps $3 to $5 million per year in later years.

With growth in the AAA UPP and Directed University Research, along with initiation of the AAA URP, university collaborations could reach the order of $10 million per year within a few years.

VIII. MEETING THE GOALS

In the introduction we described the goals of the AAA Project: to develop transmutation technology, to revitalize nuclear infrastructure, to provide a test-bed for advanced nuclear projects, and to resume an international leadership role. AAA University research supports all of these goals while expanding on and leveraging other DOE/NE programs such as the Nuclear Energy Education Research Program (NEER), the Nuclear Energy Research Initiative (NERI) as well as International NERI (I-NERI), and reactor research programs such as Generation 4 research. Much of the research and development that is being conducted for the AAA Project will support the development of Generation 4 concepts and nuclear systems. With more than 80 students supported this year, and the expectation of more than 100 in 2002, the contribution to the U.S. nuclear infrastructure is obvious. In addition, U.S. participation in international conferences will increase substantially as a result of the many research projects supported by AAA funding. This will demonstrate to the international community an emerging major role for the U.S. in this technology. As a prime example, the student mini-conference that is being held in conjunction with this conference is dominated by AAA-supported student presentations (more than half of the oral papers are for AAA-sponsored research). We believe that AAA University Programs strongly support the mission and goals of the AAA Project.

IX. SUMMARY

The Advanced Accelerator Applications (AAA) Program will require a large cadre of educated scientists

and trained technicians in the next decade or more. Other applications of nuclear science and engineering also require increased academic and national infrastructure and student populations. The AAA Program Office has begun a multi-year program to involve university faculty and students in various phases of the Project to support the infrastructure requirements of nuclear energy, science and technology fields as well as the special needs of the DOE transmutation program. These AAA University Programs complement other DOE-NE programs such NEER, NERI and I-NERI, and reactor research programs like Gen-4 by connecting students to nuclear research projects in a wider variety of academic disciplines. In this paper we described university programs that have supported, are supporting, and will support the R&D necessary for the AAA Project. These include the Accelerator Transmutation of Waste (ATW) project, the AAA University Fellowship Program, the UNLV AAA University Participation Program, AAA Directed University Research, and several other efforts. The AAA Project is well poised to contribute to the future education of nuclear scientists and engineers while conducting research that is essential to the success of the project. We expect AAA University Programs to grow substantially in the coming years.

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