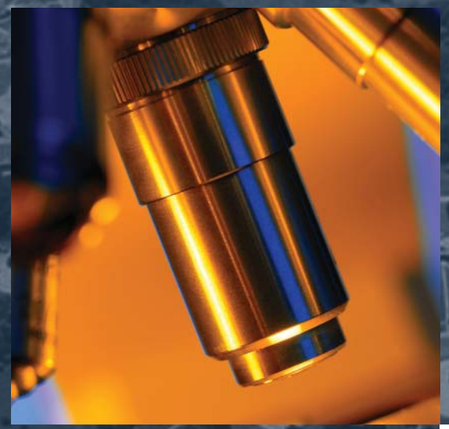
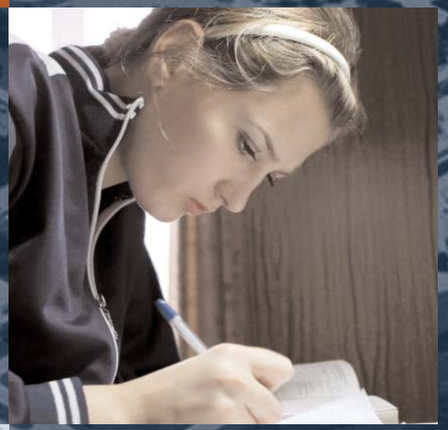
AFCI/GNEP-168277, Rev. 0

U.S. Department of Energy
Office of Nuclear Energy
Office of Fuel Cycle Management



Report to Congress

Advanced Fuel Cycle Initiative/ Global Nuclear Energy Partnership Status Report for FY 2006



Disclaimer

This information was prepared as an account of work sponsored by an agency of the U.S. Government. Neither the U.S. Government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. References herein to any specific commercial product, process, or services by trade name, trademark, manufacturer, or otherwise, do not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

August 2008

Appendix A – Energy Policy Act of 2005 Excerpts

Advanced Fuel Cycle Initiative Language

119 STAT. 886 PUBLIC LAW 109–58—AUG. 8, 2005

(C) use fuels that are proliferation resistant and have substantially reduced production of high-level waste per unit of output; and

(D) use improved instrumentation.

(e) REACTOR PRODUCTION OF HYDROGEN.—The Secretary shall carry out research to examine designs for high-temperature reactors capable of producing large-scale quantities of hydrogen.

42 USC 16273.

SEC. 953. ADVANCED FUEL CYCLE INITIATIVE.

(a) IN GENERAL.—The Secretary, acting through the Director of the Office of Nuclear Energy, Science and Technology, shall conduct an advanced fuel recycling technology research, development, and demonstration program (referred to in this section as the "program") to evaluate proliferation-resistant fuel recycling and transmutation technologies that minimize environmental and public health and safety impacts as an alternative to aqueous reprocessing technologies deployed as of the date of enactment of this Act in support of evaluation of alternative national strategies for spent nuclear fuel and the Generation IV advanced reactor concepts.

(b) ANNUAL REVIEW.—The program shall be subject to annual review by the Nuclear Energy Research Advisory Committee of the Department or other independent entity, as appropriate.

(c) INTERNATIONAL COOPERATION.—In carrying out the program, the Secretary is encouraged to seek opportunities to enhance the progress of the program through international cooperation.

(d) REPORTS.—The Secretary shall submit, as part of the annual budget submission of the Department, a report on the activities of the program.

42 USC 16274.

SEC. 954. UNIVERSITY NUCLEAR SCIENCE AND ENGINEERING SUPPORT.

(a) IN GENERAL.—The Secretary shall conduct a program to invest in human resources and infrastructure in the nuclear sciences and related fields, including health physics, nuclear engineering, and radiochemistry, consistent with missions of the Department related to civilian nuclear research, development, demonstration, and commercial application.

(b) REQUIREMENTS.—In carrying out the program under this section, the Secretary shall—

(1) conduct a graduate and undergraduate fellowship program to attract new and talented students, which may include fellowships for students to spend time at National Laboratories in the areas of nuclear science, engineering, and health physics with a member of the National Laboratory staff acting as a mentor;

(2) conduct a junior faculty research initiation grant program to assist universities in recruiting and retaining new faculty in the nuclear sciences and engineering by awarding grants to junior faculty for research on issues related to nuclear energy engineering and science;

(3) support fundamental nuclear sciences, engineering, and health physics research through a nuclear engineering education and research program;

(4) encourage collaborative nuclear research among industry, National Laboratories, and universities; and

(5) support communication and outreach related to nuclear science, engineering, and health physics.

Advanced Fuel Cycle Initiative: Status Report for FY 2006

Executive Summary

AFCI/GNEP aims to: 1) enable expansion of nuclear power in the United States and around the world; 2) facilitate nuclear waste disposal; and 3) promote nuclear non-proliferation.

The Department of Energy (DOE), Office of Nuclear Energy (NE) prepared this report in response to the requirements of Section 953(d) of the Energy Policy Act of 2005 (EPACT) which direct the Secretary of Energy to submit an annual report to Congress on the activities of the Advanced Fuel Cycle Initiative (AFCI).

DOE initiated the AFCI in 2002. The AFCI supports near-term technology development and demonstration activities that advance the goals of EPACT by developing the enabling technologies needed to reduce high level waste volume and separate and transmute long-lived, highly radiotoxic elements. In February 2006, DOE announced the Global Nuclear Energy Partnership (GNEP) and refocused the AFCI effort to address GNEP technology development needs. As a result, the AFCI is referred to in this report as AFCI/GNEP. AFCI/GNEP aims to: 1) enable expansion of nuclear power in the United States and around the world; 2) facilitate nuclear waste disposal; and 3) promote nuclear non-proliferation.

In FY 2006, AFCI/GNEP focused on Systems Analysis, Separations Technology Development, Advanced Fuels Development, Transmutation Science, Transmutation Education, and early fuel cycle facility planning activities. This report summarizes the activities and accomplishments of AFCI/GNEP in FY 2006.

The two most significant AFCI/GNEP accomplishments in FY 2006 were in the areas of Separations Technology Development and Advanced Fuels Development. High extraction efficiencies resulting in uranium purity greater than 99.9999 percent, more than sufficient to have the recovered uranium classified as a Class C low-level waste as defined in the Nuclear Regulatory Commission (NRC) regulations, were achieved in the laboratory scale tests. In FY 2006, the laboratory scale tests of the Uranium Extraction Plus 1a (UREX+1a) process met test goals for group transuranic extraction efficiency, including separation of transuranics from lanthanides; efficient separation of the lanthanides is desirable because lanthanides attack fuel cladding in transmutation fuels. Additional tests are needed to show repeatability, and successful scale-up of these processes must be demonstrated.

In August 2006, the Advanced Fuels Development program successfully fabricated, packaged, and, after a coordinated effort between several government agencies, received approval for transfer of transuranic-bearing test fuels to the French Commissariat à l'Énergie Atomique (CEA) for irradiation in the Phénix fast spectrum test reactor located at Marcoule, France. These test fuels will be irradiated in the Phénix reactor for up to two years. This fuel test (FUTURIX-FTA) has been in development since 2002, and irradiation of these test fuels will provide the first opportunity for the United States to evaluate the behavior of transuranic-bearing fast reactor fuels in a fast spectrum reactor; since there is no domestic fast reactor in which to conduct these tests. The FUTURIX-FTA fuel test is the first nuclear fuel test in a foreign irradiation facility for the program. In addition, on-going irradiations in the United States' Advanced Test Reactor of transuranic bearing test fuels are producing exciting results. Preliminary results of the post-irradiation examination of low burnup tests completed in FY 2006

indicate that additional transmutation fuels being tested in the reactor could be safely irradiated to higher burnup than previously predicted. Increased fuel burnup is directly related to increased fuel utilization and overall fuel cycle efficiency.

In FY 2006, AFCI/GNEP focused efforts on three types of facilities:

- An advanced recycling reactor
- A nuclear fuel recycling center
- An advanced fuel cycle research facility.

In FY 2006 AFCI/GNEP also continued robust research collaborations with universities and international partners including Japan, France, Switzerland, Brazil, Canada, the European Union, and the Republic of Korea, and began to plan for expanded international collaboration.

10.4 France

A broad bilateral agreement was established in 2000 and renewed in 2006 between AFCI/GNEP and the CEA covering a range of research areas under subsequent arrangements. The most active of these research areas are separations technology, materials and coolants, and advanced fuels development. In the separations technology area, collaboration on the development of advanced aqueous processing technologies is ongoing. In the materials and coolants area, the MATRIX-Structural Materials Irradiation (SMI) materials test arrangement will provide fast reactor irradiation data on ferritic-martensitic steels (e.g., HT-9 and T91, and other advanced alloys) from irradiation in the Phénix sodium cooled fast reactor at temperatures of 400°C and 500°C to doses of 35 and 70 displacements per atom (dpa). Collaboration also continues in coolant technology including exchange of oxygen sensors used in lead-bismuth corrosion testing. In the advanced fuels development area, the Phénix reactor joint irradiation transmutation fuel test agreement FUTURIX-FTA, and high-temperature materials test arrangement FUTURIX-MI, will respectively provide irradiated advanced transmutation fuel samples and irradiated matrix material samples for candidate gas fast reactor fuels. Nitride fuel pellets were completed in the early part of FY 2006 and the fabricated nitride and metal test fuels were sent to CEA/France for insertion in the Phénix reactor.

CEA is also engaged with DOE and the Japan Atomic Energy Agency in developing the collaboration arrangements for the JOYO and MONJU transmutation fuel irradiation tests and advanced separations technologies.

The Phénix reactor joint irradiation transmutation fuel test agreement FUTURIX-FTA and FUTURIX-MI will respectively provide irradiated advanced transmutation fuel samples and irradiated matrix material samples for candidate gas fast reactor fuels.

International collaborations were an important component of the AFCI previously, and now, with the introduction of GNEP, collaborations between the United States and other countries are expected to be heightened and become increasingly important.

10.0 International Collaborations

International collaborations were an important component of the AFCI previously, and now, with the introduction of GNEP, collaborations between the United States and other countries are expected to be heightened and become increasingly important. In FY 2006 international collaborations included those between individual researchers, institutional agreements, and bilateral and multilateral governmental agreements. International collaborations allow the United States to leverage its research and development investment with other countries interested in the same research areas. The following sections highlight some of the international collaborations related to AFCI in FY 2006.

10.1 International Nuclear Energy Research Initiative (I-NERI)

DOE established the International Nuclear Energy Research Initiative (I-NERI) in 2002 as an international component of the NERI to promote bilateral and multilateral research in advanced nuclear energy systems. In FY 2006, four new projects were awarded in the area of advanced fuel cycle R&D including work on cross-cutting materials and core design studies for transuranic fast burner reactors, fission product separation, and reactor safety investigations.

10.2 Switzerland

The Swiss Spallation Neutron Source (SINQ) at the Paul Sherrer Institute (PSI) continued to provide an important neutron irradiation source supporting AFCI research. The SINQ Target Irradiation Program (STIP) has provided neutron irradiated samples of candidate core structural materials. In addition, the AFCI/GNEP is providing support to the PSI Megawatt Pilot Experiment (MEGAPIE) test program through the Transmutation Science program element. The MEGAPIE effort seeks to demonstrate the feasibility of a liquid lead-bismuth target for spallation neutron facilities. In FY 2006 the MEGAPIE target was inserted into the SINQ target. The testing will be performed in the first quarter of FY 2007.

10.3 Japan

Negotiations, initiated with Japanese officials in 2004, continued in 2006 on the use of the Japan Experimental Fast Reactor (JOYO) and MONJU fast reactors as material and fuel irradiation facilities. The JOYO and MONJU facilities can provide a valuable international resource for fast neutron irradiation environments after the Phénix reactor in France is decommissioned in 2009. Discussions were held in 2006 with representatives of the Japan Atomic Energy Agency (JAEA) on potential collaboration in the development of separations technologies for LWR and fast reactor used fuel. Meetings were held in December 2005, and March and June 2006, on a trilateral basis with JAEA and the French Commissariat à l'Énergie Atomique (CEA) with the intention of defining specifics of collaborative experiments and technical information exchanges for both fuels and separations technologies.

Table of Contents

Executive Summary i

Acronyms iv

1.0 Introduction 1

2.0 AFCI/GNEP Overview 2

3.0 Fuel Cycle Facilities 3

3.1 Advanced Burner Reactor 3

3.2 Consolidated Fuel Treatment Center 4

3.3 Advanced Fuel Cycle Facility 4

4.0 Systems Analysis 6

5.0 Separations Technology Development 8

5.1 Advanced Aqueous Processing - UREX+ Experiment 8

5.2 Electrochemical Processing Development 9

6.0 Advanced Fuels Development 10

6.1 Fabrication of Transuranic Bearing Fast Reactor Fuel 10

6.2 Irradiation of High-Burnup Transmutation Fuels in the Advanced Test Reactor 11

6.3 Post-Irradiation Examinations (PIE) of Low-Burnup Transmutation Fuels 11

7.0 Transmutation Science 13

8.0 Materials Test Station 14

9.0 Transmutation Education 15

9.1 AFCI/GNEP Fellowships 15

9.2 University Transmutation Education and Research Programs 15

9.3 Nuclear Energy Research Initiative (NERI) 16

10.0 International Collaborations 17

10.1 International Nuclear Energy Research Initiative (I-NERI) 17

10.2 Switzerland 17

10.3 Japan 17

10.4 France 17

Figures

Shipment and receipt of the DOE metallic and nitride FUTURIX-FTA fuel pins in France. 11

A cross-section photomicrograph of the A1F4 rodlet fuel and clad. 12

Acronyms

ABR	Advanced Burner Reactor
AFCF	Advanced Fuel Cycle Facility
AFCI	Advanced Fuel Cycle Initiative
AG-PAS	Positron-annihilation spectroscopy
ATR	Advanced Test Reactor
BNG	British Nuclear Group
CCD/PEG	chlorinated cobalt dicarbolide/polyethylene glycol
CEA	Commissariat à l'Énergie Atomique
CFTC	Consolidated Fuel Treatment Center
DOE	Department of Energy
dpa	displacements per atom
DYMOND	Dynamic Model of Nuclear Development
EAS	Engineering Alternatives Studies
EBR	Experimental Breeder Reactor
EPACT	Energy Policy Act of 2005
Eurotrans-ECATS	European Experimental activities on the Coupling of an Accelerator, a spallation Target and a Sub-critical blanket
FPEX	Fission Product Extraction
FUTURIX-FTA	FUTURIX-Fuel Test Assembly
FUTURIX-MI	FUTURIX-Materials Irradiation
GNEP	Global Nuclear Energy Partnership
IAC	Idaho Accelerator Center
I-NERI	International Nuclear Energy Research Initiative
INL	Idaho National Laboratory
JAEA	Japan Atomic Energy Agency
JOYO	Japan Experimental Fast Reactor
LANSCE	Los Alamos Neutron Science Center
LWR	light water reactor
MEGAPIE	Megawatt Pilot Experiment
MTS	Materials Test Station
NE	Office of Nuclear Energy
NERI	Nuclear Energy Research Initiative
OCRWM	Office of Civilian Radioactive Waste Management
OECD-NEA	Organization for Economic Cooperation and Development-Nuclear Energy Agency
PEER	planar electrorefiner
PIE	Post Irradiation Examination
PSI	Paul Sherrer Institute, Switzerland
R&D	research and development
RACE	Reactor-Accelerator Coupling Experiments
SBIR	Small Business Innovative Research
SINQ	Swiss Spallation Neutron Source
SMI	Structural Materials Irradiation
STIP	SINQ Target Irradiation Program
STTR	Small Business Technology Transfer
TRU	transuranic
U.S.	United States
UNLV	University of Nevada, Las Vegas
UNR	University of Nevada, Reno
UREX+	Uranium Extraction Plus
VISION	Verifiable Fuel Cycle Simulation Model

The University of Nevada, Reno (UNR) began supporting the AFCI/GNEP in FY 2006. The objective of the research at UNR is to develop thermal analysis tools for storage, transfer, and offsite transport of advanced cycle fuels and materials as well as corrosion testing of advanced materials. Much of this work is an extension of research funded in the past by the DOE Office of Civilian Radioactive Waste Management (OCRWM) and focuses on current generation light water reactor spent fuel. The project has three components: heat transfer processes within dry casks under normal conditions, transient response of fuel cladding within transport casks during fire events, and fire tests to benchmark computer simulations used to predict fire heat transfer. The tasks have been integrated into the AFCI/GNEP. Work that was initiated at UNR during FY 2006 included set up of a test facility that will simulate heat transfer from used light water reactor fuel to the interior of transport and storage casks, and preparation for large scale rail cask fire tests to be performed during FY 2007.

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. IAC students and researchers have been supporting the AFCI since 2002. Activities conducted by the IAC program during the 2005-2006 academic year included continued planning for collaborative work between the U.S. Reactor-Accelerator Coupling Experiments (RACE) and European Experimental activities on the Coupling of an Accelerator, a spallation Target and a Sub-critical blanket (Eurotrans-ECATS) reactor-accelerator coupling experiment. A set of experiments was performed at the IAC that demonstrated using prompt neutrons to detect fissionable material. Detection of fissionable material is necessary for materials accountability. Preliminary analysis suggests that analyses using prompt neutrons are 100 times more sensitive than those using delayed neutrons, making it possible to detect smaller quantities of fissionable material than delayed neutron methods.

9.3 Nuclear Energy Research Initiative (NERI)

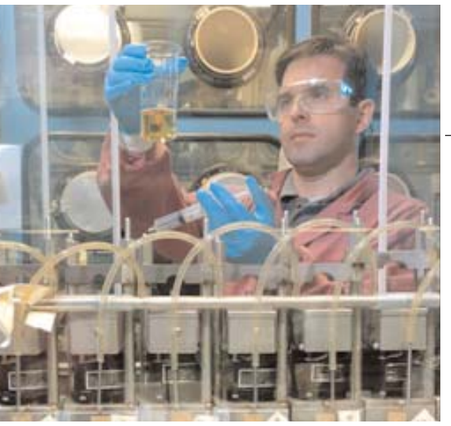
The Nuclear Energy Research Initiative (NERI) was established by DOE-NE in 1999 to fund nuclear science and engineering research through university, laboratory, and industry partnerships. In 2004 the program was modified to promote university participation in the major DOE-NE research and development programs (AFCI, Generation IV, and Nuclear Hydrogen Initiative). Each of these research programs dedicate a portion of their annual funding to the NERI projects. In 2006, the AFCI funded 35 new NERI projects at 27 U.S. universities. Notable contributions have been made by NERI research projects to a number of AFCI elements, including:

- Development of lead-cooled fast reactor coolant technology
- Investigation of irradiation damage in iron
- Development of advanced inert matrix fuel materials
- Fuel irradiation research
- Reprocessing engineered waste product research.

The objective of the research at UNR is to develop thermal analysis tools for storage, transfer, and offsite transport of advanced cycle fuels and materials as well as corrosion testing of advanced materials.

9.0 Transmutation Education

The Transmutation Education element supports university research and development in nuclear science and engineering through a number of funded research activities and graduate fellowships. These AFCI/GNEP university programs support DOE-NE's investment in human resources and infrastructure in nuclear science and engineering and related fields. The demand for trained workers to support nuclear energy development is increasing, and is expected to continue to increase, and this program is an important part of meeting that demand.



9.1 AFCI/GNEP Fellowships

In 2006, DOE selected and issued AFCI/GNEP Fellowships for Masters Degrees in nuclear-related technical fields to the largest group (12) of outstanding candidates from the largest pool of applicants in the six-year history of the fellowship program. All thesis topics were reviewed and approved as supportive of AFCI technical activities as well as those of the new Global Nuclear Energy Partnership.

The 2006 fellowship class traveled to the Idaho National Laboratory at the end of July 2006 where they toured relevant parts of the laboratory and received an orientation on AFCI/GNEP activities at INL. They also traveled to Washington D.C. in August 2006, met with DOE AFCI/GNEP management staff, and received an orientation on the program.

9.2 University Transmutation Education and Research Programs

AFCI/GNEP research activities and transmutation education activities were also supported by university research programs at the University of Nevada and the Idaho Accelerator Center (IAC) at Idaho State University in FY 2006.]

The University of Nevada, Las Vegas (UNLV) supports AFCI/GNEP through research and development of technologies for economic and environmentally sound refinement of spent nuclear fuel. The UNLV program has four components: infrastructure, international collaboration, student-based research, and management and program support. The Student Research component is the core of the UNLV Transmutation Research Program. The milestones, schedules, and deliverables of the student research projects are detailed in the individual research proposals. UNLV has 16 active student research tasks and 14 tasks that have concluded. The tasks are divided in terms of their research area: fuels, separations, and transmutation sciences. Significant UNLV research activities performed during FY 2006 include the following: development of a reliable method for x-ray fluorescence of uranium oxide materials; experiments performed examining the sorption of TcO4 to cation exchange resins and the preparation of Tc metal from the sorbed material; x-ray diffraction studies conducted to prove that UO2 is soluble within cubic zirconia; and evaluation of reactivity feedback coefficients for fertile free plutonium-containing fuels and comparison with conventional UO2 fuel coefficients. The potential for improving reactivity coefficients through the use of different burnable poisons and geometric arrangements was also investigated.

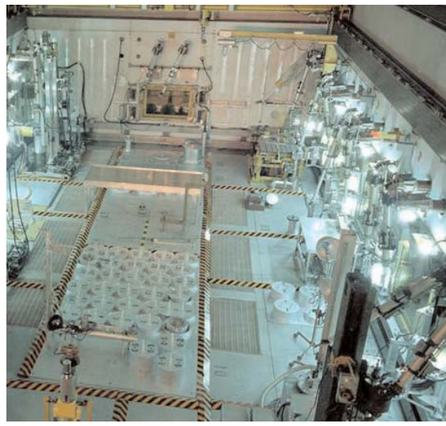
1.0 Introduction

The Department of Energy's (DOE) Office of Nuclear Energy (NE) prepared this report in response to the requirements of the Energy Policy Act of 2005 (EPACT). Section 953(a) of EPACT (see Appendix A) directs the Secretary of Energy, acting through the Assistant Secretary of DOE-NE, to:

> conduct an advanced fuel recycling technology research, development, and demonstration program… to evaluate proliferation-resistant fuel recycling and transmutation technologies that minimize environmental and public health and safety impacts as an alternative to aqueous reprocessing technologies deployed as of the date of enactment of [the EPACT] in support of evaluation of alternative national strategies for spent nuclear fuel and the Generation IV advanced reactor concepts.

Furthermore, Section 953(d) requires the Secretary to submit, as part of the annual budget submission of the Department, a report on the activities of the program.

This report summarizes the FY 2006 activities and accomplishments of the Advanced Fuel Cycle Initiative/Global Nuclear Energy Partnership (AFCI/GNEP) for which DOE received an appropriation in the amount of $80 million in FY 2006, less a 1% rescission, and less allocations for Small Business Innovative Research (SBIR) and Small Business Technology Transfer (STTR) Programs for a total adjusted appropriation amount of $78,408,000. The technical areas funded as part of the program are listed in the table below.



Technical Area	FY 2006 Funding ($000)
Separations Technology	$16,137
Advanced Fuels Development	$8,187
Transmutation Science	$5,316
Systems Analysis	$5,940
Transmutation Education	$13,365
Advanced Fuel Cycle Facility	$6,930
Recycling Demonstration Program	$14,118
Advanced Burner Reactor Demonstration Analysis	$4,950
Materials Test Station	$3,465
TOTAL	**$78,408**

One of the greatest challenges that must be addressed to enable a future expansion in the use of nuclear energy in the United States and worldwide is dealing effectively with used fuel

2.0 AFCI/GNEP Overview

With the announcement of the vision for a GNEP by the Administration in February 2006, AFCI was refocused on GNEP technology development needs. The AFCI is now the main domestic component of the GNEP and includes early planning for the development of U.S. fuel cycle capabilities which may be pursued in support of the GNEP. As a result, the program is referred to as AFCI/GNEP in this report. In the future, technologies developed under AFCI/GNEP could be deployed as part of the nuclear fuel cycle to support operation of current nuclear power plants, Generation III+ advanced light water reactors (LWRs), and Generation IV advanced reactors. Once deployed, this new approach could enable the United States to separate commercial nuclear power plant used nuclear fuel into waste and usable components, allowing reactors to extract additional energy, and providing options for more effective management of the residual waste.

One of the greatest challenges that must be addressed to enable a future expansion in the use of nuclear energy in the United States and worldwide is dealing effectively with used fuel (otherwise referred to as “spent fuel.”) Compared to other industrial waste, the used fuel generated during the production of electricity is relatively small in quantity. However, it remains toxic for many thousands of years, and its disposal requires that many political, societal, technical, and regulatory issues be addressed. For many years, several countries around the world (e.g., France, Japan, Russia, and the United Kingdom), have pursued advanced technologies that could treat and transmute spent nuclear fuel from nuclear power plants. These technologies have the potential to significantly reduce the volume and radiotoxicity of waste requiring geologic disposal. The United States has joined this international effort and found considerable merit in collaborations on separations, transmutation fuels, fast reactors, waste form development and systems analysis.

In FY 2006, AFCI/GNEP consisted originally of five main elements spanning activities necessary to support advanced fuel cycles including:

- Systems Analysis
- Separations Technologies Development
- Advanced Fuels Development
- Transmutation Engineering/Science
- Transmutation Education

With the announcement of GNEP, AFCI/GNEP also began facility evaluations, initially at an engineering or test scale, on three types of facilities:

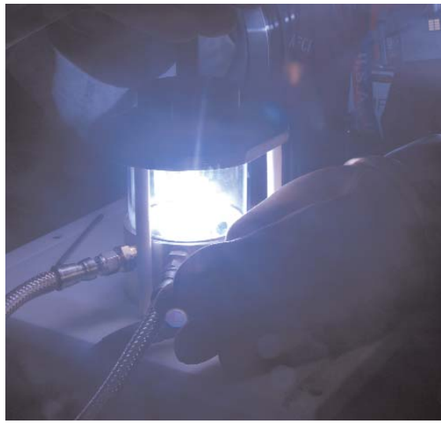
- An advanced recycling reactor
- A nuclear fuel recycling center
- An advanced fuel cycle research facility.

In FY 2006 AFCI/GNEP also continued robust research collaborations with international partners including Japan, France, Switzerland, Brazil, Canada, the European Union, and the Republic of Korea.

7.0 Transmutation Science

Transmutation science activities focus on developments in physics and materials that support the implementation of fast neutron spectrum transmutation systems. Transmutation physics provides the nuclear data needed for accurate predictions of the overall performance of transmutation systems. The transmutation materials activities include development, testing, and modeling of structural materials, as well as research and testing of coolant materials and systems for advanced fast reactors.

In FY 2006, the Department refined physics cross sections important for advanced transmutation and fast reactor designs, and completed measurements of the chemistry and kinetics of the corrosion of stainless steels in the presence of flowing lead-bismuth at high temperatures. In conjunction with the Advanced Fuels Development work, materials irradiation test containing advanced material specimens that may improve future reactor system performance was installed in the Phénix reactor in mid-2006. The test is scheduled to be irradiated through FY 2007 and FY 2008 and will be removed in FY 2009.



A new set of nuclear capture cross-section data for neptunium-237 (237Np) was evaluated and accepted for inclusion in the Evaluated Nuclear Data File based on fission and capture cross-section measurements conducted in prior years. Cross section measurements are needed because we need to understand how efficiently the transuranics will be transmuted and the effect that these isotopes will have on the reactor performance. Data were also taken in FY 2006 for the isotopes 240Pu and 242Pu. Isotopically pure sample foils developed by the program are used for this purpose, and additional targets are being produced for other transuranics of interest for future tests.

8.0 Materials Test Station

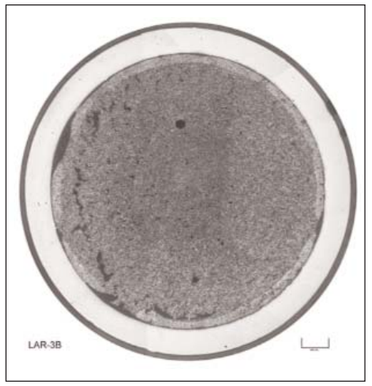
This activity includes the design, fabrication and installation of a spallation neutron source into an existing experimental area at an operating linear accelerator national user facility, the Los Alamos Neutron Science Center (LANSCE). U.S. domestic fuels and materials irradiation testing is currently conducted using thermal reactors. Testing in thermal reactors provides important information for fuels and materials development, but testing in an environment with higher energy neutrons is required for qualification for use in fast spectrum systems. Some irradiation tests are underway in, and planned for, foreign fast reactors; however, a domestic fast neutron test facility is very desirable due to the difficulties associated with testing in foreign reactors. The Materials Test Station (MTS) would provide an irradiation spectrum that is well matched to that of a fast reactor up to ~ 1 MeV. Our current knowledge of fast reactor systems provides some confidence that the combination of relevant fuel irradiations and select phenomenologically based irradiations performed in domestic thermal reactors and MTS, when combined with modeling, would yield AFCI/GNEP-relevant results. In FY 2006, the Department developed preconceptual designs for the proposed MTS at the LANSCE Accelerator. The target designs included both water-cooled and sodium-cooled designs, and plans were developed for a thermal-hydraulic target test. The thermal-hydraulic performance and the neutronic behavior of the target were also evaluated.

6.2 Irradiation of High-Burnup Transmutation Fuels in the Advanced Test Reactor

Irradiation of three high burnup transuranic fuel tests continued in the Advanced Test Reactor during FY 2006 and will continue through FY 2007 and FY 2008. During FY 2006, Post Irradiation Examination (PIE) was completed on sibling experiments as discussed in the next section. Design limits for burnup, fuel, and cladding temperature had been specified at the beginning of the AFC-1D test series in FY 2005 and FY 2006 using conservative analysis based on the limited understanding of transmutation fuels at the time. The PIE data of AFC-1B with a peak burnup of eight atomic weight percent showed that the fuel rodlets exhibited significantly less fission damage than projected (ranging from a factor 3-5 times lower for the different fuel compositions). There was also less swelling, porosity development, restructuring and fission gas release than expected. As a result of the PIE examination of these experiments, the programmatic design burnup limit on the AFC-1D metallic fuel experiment has been revised, increased from 25 atomic weight percent to 40 atomic weight percent.

6.3 Post-Irradiation Examinations (PIE) of Low-Burnup Transmutation Fuels

In FY 2006, results of post-irradiation hot cell examinations of AFC-1 irradiation tests were reported for eleven metallic alloy transmutation fuel rodlets and five nitride transmutation fuel rodlets. Non-destructive examinations included visual examination, dimensional inspection, gamma scan analysis, and neutron radiography. Detailed examinations, including fission gas puncture and analysis, metallography / ceramography and isotopics and burnup analyses, were performed on five metallic alloy and three nitride transmutation fuels. Fuel performance of both metallic alloy and nitride fuel forms was best correlated with fission density as a burnup metric rather than atomic weight percent depletion. The actinide-bearing transmutation metallic alloy compositions exhibited irradiation performance very similar to ternary metal (uranium, plutonium, zirconium) fuel at equivalent fission densities. The following figure shows a cross-section photomicrograph of the A1F4 rodlet fuel (metal fuel) and clad. A prime feature in this photomicrograph is the absence of any fuel-cladding interaction indicating the fuel performed as expected at this burn-up level.



A cross-section photomicrograph of the A1F4 rodlet fuel and clad.

FY 2006 highlights and major accomplishments for each of these elements are described in this report, along with a description of the FY 2006 international collaboration activities.

3.0 Fuel Cycle Facilities

In FY 2006, AFCI/GNEP supported initial studies related to three domestic fuel cycle facilities that could support advanced nuclear fuel recycling activities:

- An advanced recycling reactor – A fast neutron spectrum reactor that would be capable of converting long-lived radioactive elements (e.g., plutonium and other transuranics) into shorter-lived radioactive elements while producing electricity. Since in early planning activities this facility was referred to as the Advanced Burner Reactor (ABR), this is the terminology used in this FY 2006 status report.
- A nuclear fuel recycling center – A facility that would separate commercial LWR used nuclear fuel and fast reactor used fuel into their reusable and non-reusable constituents, and after completion of transmutation fuel development at the advanced fuel cycle research facility, would fabricate such fuel for use in the destruction of transuranic elements in the ABR. Since in early planning activities this facility was referred to as the Consolidated Fuel Treatment Center (CFTC), this is the terminology used in this FY 2006 status report.
- An advanced fuel cycle research facility – A facility that would support research and development (R&D) relating to separation technologies and fabrication of fast reactor transmutation fuel to enable the destruction of transuranic materials. This facility is referred to as the Advanced Fuel Cycle Facility (AFCF).

3.1 Advanced Burner Reactor

An advanced transmutation technology under evaluation as part of the AFCI/GNEP is the ABR, which would consume transuranic elements from used LWR and fast reactor fuels while generating electricity. A primary mission of the ABR is the transmutation of transuranics recovered from LWR spent fuel and hence demonstration of the benefits of fuel cycle closure for nuclear waste management. The transmutation or burning of the recovered transuranics is accomplished by fissioning, which is most effectively accomplished in a fast neutron spectrum. Thus, a fast-spectrum ABR is being evaluated for the AFCI/GNEP program. While several plutonium isotopes readily fission in the thermal spectrum of commercial LWRs, some transuranics capture neutrons and become higher transuranics rather than being fissioned; these heavier transuranics are more radioactive and complicate subsequent recycle of the transuranics. Multiple passes of transuranics in thermal reactors can lead to a buildup, or increased concentration of heavier transuranics, offsetting the nonproliferation and waste management benefits of destroying plutonium. With multiple passes in fast reactors, a broader spectrum of transuranics can be effectively fissioned to reduce or eliminate their long-term radiotoxicity and decay heat.

An advanced transmutation technology under evaluation as part of the AFCI/GNEP is the ABR, which would consume transuranic elements from used LWR and fast reactor fuels while generating electricity.

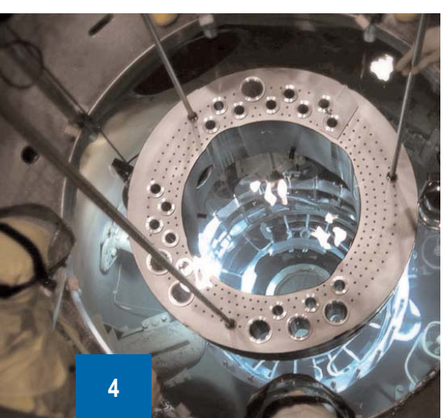
To satisfy the needs discussed in the previous paragraph, a pre-conceptual design of an initial low power test reactor, referred to as the Advanced Burner Test Reactor, was developed in FY 2006. In addition to meeting the transmutation mission, the lessons learned from earlier fast reactor programs in the United States and worldwide, and the operating experience of more than a dozen fast reactors around the world (and in particular, the Experimental Breeder Reactor-II) have been incorporated into the pre-conceptual design of this reactor. The design approach included the goals of demonstrating both safety and cost reduction design features.

To demonstrate the transmutation of transuranics, the initial reactor is required to provide a test environment sufficiently prototypic of future commercial reactors, which implies that the reactor power level should be high enough for demonstration purposes. Based on the initial pre-conceptual design evaluation, a lower threshold of ~250 Megawatts thermal (MWt) was proposed for balancing the need for a prototypic irradiation environment and the project cost, but additional factors remain to be considered. Predominant among these additional factors is how close in size to the commercial-scale reactor plant the first one needs to be. A commercial-scale ABR would be expected to have a higher power level to provide for more affordable electricity production due to economies of scale. Further studies are planned in FY 2007 and beyond to examine scaling considerations in formulating an optimal development strategy for an ABR.

3.2 Consolidated Fuel Treatment Center

The CFTC is envisioned to separate commercial LWR used fuel and fast reactor used fuel into their reusable and non-reusable constituents and, after completion of transmutation fuel development at the advanced fuel cycle research facility, would fabricate such fuel for use in the destruction of transuranic elements in the ABR. The CFTC would aim to recover additional energy value from used nuclear fuel for use in recycling and to reduce the volume and radiotoxicity of waste slated for disposal in a geologic repository.

Early planning studies for LWR used fuel separation focused initially on a UREX+1a Engineering Scale Demonstration, and a series of Engineering Alternatives Studies (EAS) was initiated late in FY 2006. The study requirements and data were specified and used to prepare a block flow diagram for the UREX+1a separations process, which was the process assumed for the EAS. The initial scope of the EAS study was revised to be based on the scale-up of the laboratory-scale work to a range of sizes up to a commercial scale process. This information will be utilized by the DOE in FY 2007 and FY 2008 to evaluate technology alternatives.



Development of advanced nuclear fuels for fast spectrum transmutation systems is conducted in three primary areas: development of fabrication techniques, irradiation of the fabricated transuranic bearing fuel, and post-irradiation examination of the resulting irradiation test fuel. Because irradiation facilities are limited, testing and irradiation of transuranic fuels is pursued in both thermal spectrum domestic U.S. irradiation facilities as well as in fast spectrum foreign irradiation facilities, primarily in France and Japan, until a domestic fast neutron source becomes available.

6.1 Fabrication of Transuranic Bearing Fast Reactor Fuel

Two metallic and two nitride fuel pins were fabricated for the FUTURIX-FTA irradiation experiment to be irradiated in the Phénix reactor in France. These tests represent the first prototypic (fast spectrum) irradiation of U.S. fabricated transmutation fuel. The results of these irradiations will be compared with the irradiations done in the Advanced Test Reactor (a thermal-spectrum reactor). After a coordinated effort between several government agencies, the fuel pins were successfully shipped to the Phénix reactor located at the CEA-Marcoule site. The four fuel pins that departed Idaho National Laboratory on August 14, 2006, were loaded aboard the British Nuclear Group (BNG) ship Osprey and departed the U.S. Port of Savannah, Georgia on August 17, 2006.

The following figure (a) shows the two metallic fuel pins after fabrication, and figure (b) shows the Osprey leaving the U.S. port. The Osprey docked at the French port of Cherbourg on September 4, 2006, and the shipping containers were unloaded and shipped by truck to the Phénix reactor site at Marcoule, France, where they were received on September 6, 2006. Shown in figure (c) is the actual unloading and receipt inspection of the TN-BGC-1 containers by French technicians. Radiographic inspection of the as-received fuel pins was conducted on September 11, 2006, confirming that no fuel damage occurred during shipment.

Shipment and receipt of the DOE metallic and nitride FUTURIX-FTA fuel pins in France.

Development of advanced fuels containing transuranics for transmutation in next generation fast neutron spectrum systems is being conducted under the Advanced Fuels Development program element.

technology has primarily been tested with EBR-II uranium-zirconium alloy fuel. For ABRs, metallic fuel probably would be a uranium-transuranic-zirconium alloy. Also in FY 2006, laboratory scale electrorefining experiments were conducted to establish the process parameters for these advanced fuels. These tests established the process parameters that achieve greater than 99 percent dissolution of all actinides. These tests confirmed the results that have been observed in engineering scale operations with EBR-II uranium-zirconium fuels and further tests will be conducted in FY 2007 using uranium-plutonium-zirconium spent fuel.

In March 2006 the Report to Congress on "Preferred Disposition Plan for Sodium-Bonded Spent Nuclear Fuel" listed options that can reduce the life cycle costs for existing EBR-II sodium bonded fuel. (http://nuclear.gov/pdfFiles/DisPlanForSodBondedSNFMarch2006.pdf) By recovering the actinides to make new experimental fuels to support GNEP, the total life cycle costs and high-level waste volumes can be decreased. Different processing scenarios including the development of a new high throughput planar electrorefiner (PEER) were examined for possible ways to reduce total life cycle costs of existing EBR-II sodium bonded fuel. Although the new electrorefining technology may provide disposal cost reduction, the largest benefits were found by recovering transuranic materials and high enriched uranium for future advanced fuels.

6.0 Advanced Fuels Development

Development of advanced fuels containing transuranics for transmutation in next generation fast neutron spectrum systems is being conducted under the Advanced Fuels Development program element. Since FY 2003, the Advanced Fuels Development activity has been focused on developing advanced nuclear fuels for transmutation. These fuels will enable the consumption of significant quantities of plutonium and other transuranics from spent fuel while simultaneously extracting more useful energy from the spent fuel materials. Transmutation of the transuranics in these advanced reactor fuels would significantly reduce the transuranic inventory in the resulting high-level waste, thereby reducing the radiotoxicity and long-term heat load in a geologic repository. Preliminary results of the post-irradiation examination completed in FY 2006 on fuels irradiated in FY 2005, indicated that the low fuel density in the transmutation fuel compositions allows the fuels to achieve very high burnup. These tests are part of a series of tests designed to investigate various parameters to improve fuel performance. Increased fuel burnup is directly related to increased fuel utilization and overall fuel cycle efficiency. Additional tests and eventually a fuel qualification program will be needed once fuel designs are defined.

Three high-burnup transmutation fuel irradiation tests were continued in FY 2006 in the Advanced Test Reactor at the INL. These tests were installed in the reactor in FY 2003 and FY 2005 and will continue irradiation into FY 2007 and FY 2008 to achieve high burnup.

Metal and nitride transuranic-bearing test fuels were fabricated and shipped to the French Phénix fast reactor in August 2006 for the FUTURIX-FTA experiment, for installation in the reactor in FY 2007 for irradiation until FY 2009. This is an important accomplishment for the Advanced Fuel Development activity because this test will be the first irradiation test of transmutation fuels in a fast neutron spectrum reactor. Continued collaboration among the FUTURIX-FTA partners (the United States, France, and Japan) will be needed to complete development of advanced nuclear fuel systems.

3.3 Advanced Fuel Cycle Facility

The AFCF would enable research, development and engineering-scale demonstration of advanced fuel cycle technologies including research and development relating to separation and fabrication of fast reactor transmutation fuel to enable the destruction of transuranic materials. The facility would consist of four modules fundamental to the development and ultimate deployment of the following advanced nuclear fuel recycling technologies: Aqueous Separations, Electrochemical Processing, Fuel Fabrication, and Waste Forms. It would demonstrate, on a pre-commercial scale, the entire integrated fuel recycling system from receiving used nuclear fuel, to separating it into recyclable and waste materials, fabricating new advanced fuel forms including lead test assemblies, and developing advanced waste forms destined for final disposition. The AFCF would also be used to develop and demonstrate advanced safeguards technologies.

In FY 2006 work was initiated on a conceptual design of the AFCF. An extensive review of technology readiness, technical risk and programmatic risk was completed in 2006 for the candidate technologies (separations, fuel fabrication, and waste form development) for the initial demonstration. Each unit operation was examined in terms of the supporting testing and analyses. Based on this initial review, the risk for successful demonstration within the timeframe initially envisioned for the AFCF (as early as 2016) was assessed. The results were documented in an initial risk assessment document to set up the subsequent detailed analyses for the unit operations and their technical bases.

4.0 Systems Analysis

The primary function of the Systems Analysis program element is to develop and apply tools to formulate, assess, and guide program activities to meet programmatic goals and objectives. The focus of Systems Analysis is on operations research and modeling of various elements of the fuel cycle.

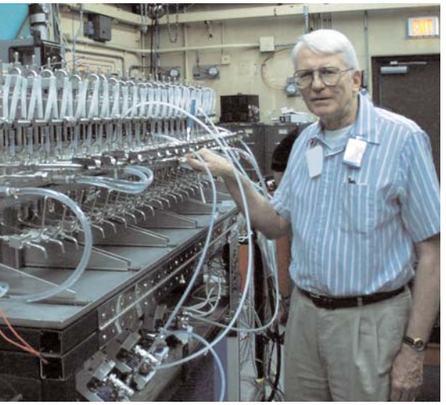
During FY 2006, the Department developed a number of reports and information supporting the objective of recycling used fuel, thus allowing reactors to extract additional energy and providing options for more effective management of the residual waste, along with a refocusing of the Systems Analysis effort to support the analyses needed for AFCI/GNEP. These analyses include evaluation of technology alternatives and deployment options. Examples of these reports include:

- The "Spent Nuclear Fuel Recycling Program Plan" (May 2006) describes the capabilities that the Department of Energy anticipates could be developed to implement spent nuclear fuel recycling, the technical options to provide these capabilities, and the activities necessary to make informed decisions on recycling. This report, requested by Congress, represented DOE's then-current analysis, which continues to evolve as the results of further research and other programmatic activities, as well as public comment, are considered (http://www.ne.doe.gov/pdfFiles/snfRecyclingProgramPlanMay2006.pdf).
- The "Advanced Fuel Cycle Initiative Comparison Report, FY 2006" (July 2006) is the latest version of a report provided to Congress annually since 2003 that provides qualitative and quantitative information to enable Congress to compare the various

An advanced transmutation technology under evaluation as part of the AFCI/GNEP is the ABR, which would consume transuranic elements from used LWR and fast reactor fuels while generating electricity.

strategies and technological approaches to managing spent commercial nuclear fuel (www.nuclear.energy.gov/pdfFiles/fy06AfciComparisonReportToCongress.pdf).

- The "Advanced Fuel Cycle Cost Basis Report" provides a cost basis for all stages of the fuel cycle (http://www.inl.gov/technicalpublications). This effort was initiated in 2004 and contains cost information collected from over 200 domestic and international sources, normalized to current U.S. currency. The fuel cycle has been broken down into functional elements called cost modules. In FY 2006, the Advanced Fuel Cycle Cost Basis report was substantially extended and issued as a reference report for fuel cycle cost analysis, and full fuel cycle cost analyses were initiated. These analyses included sensitivity studies to understand the largest cost drivers and the impact of cost uncertainties associated with closing the fuel cycle.



In FY 2006, an updated version (Release 1) of the dynamic simulation model, VISION (Verifiable Fuel Cycle Simulation Model), was released. This model, initially developed at the Argonne National Laboratory as the Dynamic Model of Nuclear Development (DYMOND) code and undergoing current development at the Idaho National Laboratory (INL), simulates facilities and material flows and associated costs across the full fuel cycle and enables comparative studies of fuel cycle options and transition studies for evolving from today's infrastructure to a future advanced fuel cycle. VISION tracks the isotopic mass-flows of uranium, plutonium, other transuranics and fission products throughout the fuel cycle and accounts for the decay of those isotopes, providing long-term repository assessments for a given scenario such as long-term heat load and radiotoxicity. The VISION model will be used to evaluate various scenarios in FY 2007.

5.0 Separations Technology Development

The AFCI/GNEP is investigating technologies in two primary separations areas – advanced aqueous-based processing and electrochemical processing. Many aqueous-based approaches to treat used nuclear fuel exist. The Uranium Extraction Plus (UREX+) suite of processes is a set of advanced aqueous processes with potential for meeting separations objectives while reducing the waste generation historically associated with aqueous separations technologies. While the UREX+ suite has potential to address the used fuel challenge associated with today's light water reactors, electrochemical processing may be better suited to address the needs of next generation fast neutron spectrum reactor fuels.

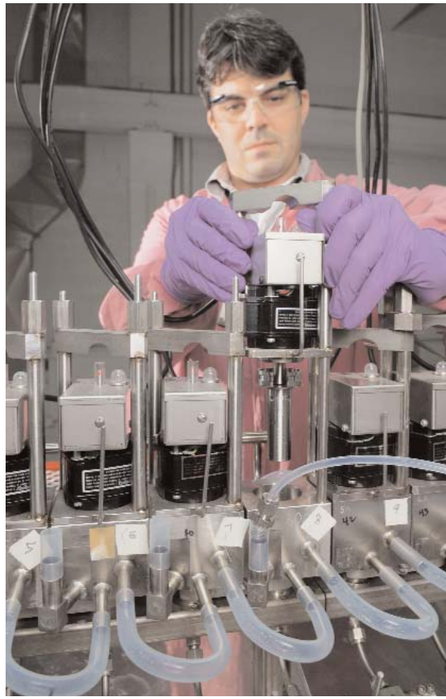
5.1 Advanced Aqueous Processing - UREX+ Experiment

The UREX+ advanced aqueous separations technology is being developed for processing of commercial LWR used fuel. UREX+1a is a variant of this technology that separates all transuranics as a group without separating plutonium, supporting the GNEP requirement for transmutation of the transuranics. The entire UREX+1a flowsheet using used LWR fuel was successfully demonstrated at laboratory scale in FY 2006 with all recovery efficiencies and product purity requirements met or exceeded.

The UREX+1a process has five aqueous effluent streams and one solid product: (1) a uranium product stream that will meet the specifications for Class-C low-level waste as defined in NRC regulations, (2) a technetium-loaded (Tc) resin, (3) a cesium and strontium (Cs/Sr) product stream (carrying with it short-lived rubidium (Rb) and barium (Ba) isotopes) that would meet the Class-C low-level waste requirements for transuranics and Tc content after decay in storage, (4) a fission-product waste stream with less than 1% transuranic (TRU) impurity, (5) a plutonium (Pu), neptunium (Np), americium (Am) and curium (Cm) (group transuranics or TRU) stream with less than 1% rare-earth and other fission-product impurities, and (6) a rare-earth-element waste stream with less than 1% TRU impurity. All effluent streams are converted into solid forms for recycle (transuranics), storage, or disposal (waste streams). In addition, the cladding hulls and fuel structural elements are washed and processed for disposal.

After unsuccessful laboratory scale tests using actual spent fuel in FY 2005, a multi-stage laboratory scale test was successfully conducted in FY 2006 to validate a process flowsheet for actinide-lanthanide separations. Results showed that greater than 99.9 % of the lanthanides in the used fuel was extracted, while much less than 1% of the TRU was extracted in the solvent product. High efficiency lanthanide extraction is desirable because the lanthanides attack the fuel cladding (liners are also under development in the program to protect the cladding from the lanthanides).

An ion exchange process for the quantitative separation of technetium from uranium and the later conversion of the separated technetium to metallic particles was developed and tested at laboratory scale in FY 2006. Also successfully tested at laboratory scale was the immobilization of metallic technetium in a zirconium alloy matrix, making it possible to utilize a portion of the used fuel cladding hulls in preparation of a corrosion-resistant high-level waste form. This waste form is a more robust version of a waste form developed under the Experimental Breeder Reactor (EBR)-II spent fuel treatment program. The technical feasibility of the new Fission Product Extraction (FPEX) process segment for the recovery of strontium and cesium in the UREX+1a process was also tested at laboratory scale in FY 2006 and offers potential advantages over the current chlorinated cobalt dicarbolide/polyethylene glycol (CCD/PEG) process.



5.2 Electrochemical Processing Development

Electrochemical processing (previously referred to as pyroprocessing) is a non-aqueous approach to separate the actinides in used fuel from fission products. Electrochemical processing technology development activities since FY 2003 have focused on treating highly-enriched, sodium-bonded driver fuel from the EBR-II reactor at Idaho National Laboratory (INL) while investigating more cost-effective alternatives for processing sodium-bonded blanket fuel.

For electrochemical processing technology, the uranium product from an electrorefiner is traditionally processed through the cathode processor which uses a zirconia coated graphite crucible. This operation removes the salt from the uranium metal but some of the uranium (approximately two weight percent) reacts with the zirconia coating to form uranium oxide. During FY 2006, an engineering scale crucible that is hafnium nitride coated niobium was tested with typical product from EBR-II spent fuel. These tests demonstrated better than 99 percent actinide metal recovery and the process could be simplified to enable higher throughput with less operating personnel effort. A full scale hafnium nitride coated niobium crucible will be developed and purchased during FY 2007.

In FY 2006, laboratory scale dissolution experiments of uranium-plutonium-zirconium spent metallic fuel resulted in greater than 99 percent dissolution of all actinides. These experiments confirmed the results that have been observed in engineering scale operations with EBR-II uranium-zirconium binary fuel. Electrochemical processing