Report of

ADVANCED NUCLEAR TRANSFORMATION TECHNOLOGY SUBCOMMITTEE

Of the

NUCLEAR ENERGY RESEARCH ADVISORY COMMITTEE

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I. EXECUTIVE SUMMARY

Introduction

The Global Nuclear Energy Partnership (GNEP) marks a major change in the direction of the DOE's nuclear energy R&D program. It is a coherent plan to test technologies that promise to markedly reduce the problem of nuclear waste treatment and to reduce the proliferation risk in a world with a greatly expanded nuclear power program. It brings the U.S. program into much closer alignment with that of the other major nuclear energy states.

GNEP proposes to take spent fuel from existing light water reactors (LWRs), separate the four transuranics (plutonium, neptunium, americium, and curium called here TRU) that are the main components contributing to repository problems and to proliferation concerns, and destroy them through multiple recycles in fast-spectrum reactors (FRs). GNEP builds on the technology developed over the past five years for efficiently separating the main components of spent reactor fuel into uranium that can be easily disposed of, fission fragments of relatively short lifetimes, and the plutonium and other actinides that generate both the waste isolation and proliferation potential problems. It is a bold program that has a high expectation of success, but will require twenty or so years of R&D to fully evaluate its promise.

Our subcommittee had its first briefing on GNEP on February 28 and March 1, 2006. This report summarizes our observations. The program's details are evolving rapidly, not surprising considering how new it is. We have had a first look at the program's timelines, its major facilities, the role of pyroprocessing and aqueous processing, fast reactor fuel, manpower issues, and the possible role that the previous program of recycling TRU in LWRs might have even in this new world. Of particular importance is the creation of a carefully constructed roadmap with a realistic time line and clear mission statements for major facilities proposed for this program. Considering the fast pace of the program's evolution many of the issues we raise here may have already been addressed by the time this report is reviewed by NERAC.

Engineering Scale Demonstration (ESD) Facility's Capacity

We are recommending that each major facility proposed for the GNEP program have a specific mission statement. The questions raised about the capacity of the ESD relate to what we see as a possible confusion over its mission.

As we understand it, the standard in the chemical industry for a pilot plant is a capacity of roughly 1% of full-scale production. Exactly what the fraction should be will of course depend on the complexity of the process. Full scale for our present fleet of LWRs would be about 2500 tons of spent fuel per year, implying roughly a 25 ton per year capacity for the ESD. The proposed capacity of the

ESD is 100-200 tons per year. We understand that this large capacity relates to that needed to produce starter fuel for a fleet of advanced breeder reactors (ABRs) beyond the GNEP Advanced Burner Test Reactor (ABTR) that is part of the GNEP program. We believe that imposing this requirement on ESD is premature. Planning for a follow on fleet of ABRs can wait until the 1% scale ESD has been debugged and the process has been fully proved.

Timeline

The timeline for this program needs clarification. Different participants seem to have different ideas, leading, in some cases to unrealistic schedules and duplication of effort. For example, only oxide fuel is consistent with the start up of the ABTR around the middle of the next decade. The first phase of ABTR operation is as a neutron source (driver mode) used to qualify the actinide fuels to be used in the next phase. If it were determined to be desirable to switch to metallic fuel for the next phase of operation, there would be sufficient time to develop such fuel. We note that large amounts of oxide fuel are potentially available from our international partners; the single largest source being approximately 40 tons of fresh fuel fabricated for, but not used in, the French Super PHENIX facility.

A further important issue in the time line itself is the composition of the TRU based fuel used in the burner test phase. The continuous recycle model requires a fraction of fuel be on its first pass through the ABR, a fraction on its second pass, a fraction on its third pass, and so forth. The program needs to include time for these tests. We cannot find where time for these multiple-recycle testing program is included in the program plan, how many passes are required to get close enough to satisfy regulators, or how long this multi-cycle phase will take.

Pyroprocessing

At present, pyroprocessing does not meet the requirements for efficiently separating LWR fuels. The problem lies in the actinide leakage into the uranium waste stream. In pyro, this is much larger than allowed for disposition of the Uranium as Class C or Class B waste. Pyro may, however, be useful for separation of spent fuel from the ABRs where the uranium will be mixed with additional actinides to make new fuel. Development of pyroprocessing can be slowed without any impact on the near term program.

Program Coordination

Since the GNEP is new it is not surprising that coordination between various elements of the DOE is not yet fully in place. The program and all its elements will involve The Office of Civilian Radioactive Waste Management (RW), The Office of Environmental Management (EM), The Office of Science (SC), and The National Nuclear Security Administration (NNSA) in addition to The Office of Nuclear Energy (NE). RW and EM will be involved in setting standards for waste

and fuel packaging technology; SC will be involved in basic research; and NNSA will be involved in non-proliferation issues and the development of advanced technical safeguards. A formal coordination mechanism will be useful and one should be set up.

LWR Recycle

The GNEP program plan calls for focus on actinide destruction in fast-spectrum reactors (FR). Until now the focus of transmutation work has been on a two-tier system where actinides were first treated in the existing fleet of LWRs. The hard-to-treat residues from this LWR recycle were to be saved for treatment in an FR.

The GNEP assumption is that the FR treatment can do it all, and in that case the LWR treatment is an unnecessary complication. We agree, but note, however, that large-scale deployment of fast-spectrum burner reactors (FBR) envisaged in the GNEP may not occur until the middle of the century. When the schedule for FBR large-scale deployment is better known, it may be appropriate to review the decision to go to an FR-only model. A first treatment in LWRs can limit the plutonium build up that will occur if FBRs are delayed.

We note that France, Japan, Russia and others will continue their programs of using MOX fuels without minor actinide recycling in their LWRs, saving the spent MOX fuel for later treatment in ABRs.

University Programs

We have great concerns about the apparent major cutback in University and student support in the GNEP program from that provided by its predecessor programs. If nuclear energy is to undergo an expansion in the next decades, an adequate supply of students in the pipeline must be maintained.

NERAC Chair, William F. Martin, in his letter to Secretary Bodman of 7 March 2006 has expressed NERAC's concern about the effect of cutbacks in the University Reactor Fuel Assistance and Support Program on nuclear engineering educational programs. However, NE has been supporting university programs in many ways and it is the totality of them that is the university support base. We cannot tell from the budget information available what is happening to all of them.

There seems to be considerable confusion about the university programs. We understand that support for existing programs at the universities will continue for the short term, but we feel that is insufficient and recommend that a robust university program including student support be maintained for the long term as an essential part of the GNEP program.

Summary of Recommendations for NERAC Consideration

1. Each major GNEP facility should have a specific mission statement.

2. An integrated timeline for the entire GNEP program should be created and maintained. It should cover the period up to the deployment of the first ABRs.

3. In light of recommendations 1 and 2 above, the initial design capacity of the EDF should be reviewed.

4. A formal coordination mechanism should be created involving NE, RW, EM, SC, and NNSA.

5. The potential of existing stocks of oxide fuel for use in the ABTR should be investigated.

6. Recycle of TRU in LWRs should be kept as an option to limit Pu build up if deployment of a fleet of ABRs should be delayed.

7. There seems to be considerable uncertainty in the scale of NE's university programs. NERAC should review this across all of NE's programs.

II. PROPOSED PROJECT ELEMENTS AND SCHEDULE

Key project elements, missions, and schedule dates presented to the subcommittee are summarized in Table1.

Table 1

Facility	Mission	Schedule
Engineering Scale Demonstration (ESD)	• "Large scale" demonstration of UREX+1 separation process (100 to 500 MT/yr) sized to provide insights for designing a 2500 MT per year facility in the next 15-20 years • Provide "required" TRU* for ABR fuel (assumes deployment of commercial-scale ABRs will start in 2022 – 4 module units with each module 840 MWt (320 MWe)	Facility operational by 2011.
Advanced Fuel Cycle Facility (AFCF)	Four-module facility to develop and demonstrate advanced fuel cycle technologies at engineering scale • Remote TRU-bearing transmutation fuel fabrication (rod and subassembly scale; ≤8 LTA/yr) • Integrated aqueous separation process development and demonstration using LWR spent nuclear fuel (≤25 MT/yr) • Integrated dry process development and demonstration using fast reactor spent fuel (≤1 MT/yr) • Advanced safeguards instrumentation for materials protection, control, and accountability, and advanced control and monitoring systems.	Facility operational by 2016 (first module) Fuel fabrication module: 2016 Aqueous separation processing module: 2017 Pyroprocessing module: 2019
Advanced Burner Test Reactor (ABTR)	Burner demonstration reactor for: • TRU-bearing fuel multi-cycle demonstration • ABR licensing • ABR TRU-bearing fuel qualification.	Operational by 2014.
Advanced Burner Reactors (ABR)	Reactors for actinide treatment and Pu burn up.	Wide-scale deployment of 4-module plants (each module 840 MWt/320 MWe) beginning in 2022.

*TRU, in this section, refers solely to plutonium (Pu), neptunium (Np), americium (Am), and curium (Cm). ABR refers to Advanced Burner Reactors.

The subcommittee is concerned about the proposed mission, scale, and operational dates for these facilities. At first glance, there appears to be mission overlap and schedule inconsistencies in the plan. It is early in the planning cycle, but to address these questions the subcommittee recommends that the GENP program immediately develop detailed mission statements for each facility and an integrated schedule of all planned activities.

In some cases, detailed trade studies may be needed to support mission statements and the schedule for constructing, licensing, and starting up a facility. In addition, detailed evaluations may be needed to understand the time required for completing required tests that support the design of a subsequent facility (e.g., multi-cycle TRU-bearing fuel qualification demonstration tests may be needed in the Advanced Burner Test Reactor (ABTR) before ABRs can be launched). Likewise, evaluations are needed to clarify the time to restart test facilities required for fuel qualification (e.g., the TREAT reactor). The integrated schedule should identify evaluations and trade study inputs required for each facility. Associated cost estimates for tasks identified in this integrated schedule should also be compiled for estimating annual and total program costs. The subcommittee believes that this integrated schedule will ensure that project activities are well coordinated, appropriately prioritized, and possible within the proposed timeframe.

The subcommittee notes that DOE and laboratory personnel participating in GNEP are currently performing a “bottoms up” evaluation of proposed GNEP missions and dates. As noted above, the subcommittee recommends that a detailed schedule also be prepared and updated annually. The current schedule requires that several key program decisions are made this fiscal year. An integrated schedule may show that some of these decisions could be delayed because longer times are required for completing the required research tasks to support these decisions. More detailed evaluations may indicate that it is possible to explore options that appear attractive but require research to demonstrate their viability.

Several “key decisions” are identified below to emphasize this point and the impact of near-term decisions on other program research tasks:

1. The scale and schedule for the ESD: As noted above, the scale of the ESD appears to be driven by the need to provide TRU fuel for the ABRs that will be deployed in 2022. It is not clear that the necessary tests of TRU-bearing fuels can be completed in time, especially if tests involving fuels that have been recycled several times in the ABTR will be required. Also, the standard in industry for test facilities is about one percent of full scale. The currently proposed ESD is much larger than that, and it may not be wise to go to that scale before the tests at the one percent level. Note that a change in the scale and schedule for the ESD may lead to a facility whose mission could be accomplished by the proposed AFCF reprocessing module (if the proposed

schedule for the AFCF was accelerated and the “aqueous separation process” module built first).

2. The decision to use oxide or metal driver fuel selection in the ABTR: This decision is scheduled for this fiscal year. It is not clear that the program has identified all the tasks required to license various types of fuel or the facilities required for qualifying the fuel. As noted in the fuels section of this report, significantly more research is required for qualifying metal fuel including the need for transient test data that requires restart of the TREAT reactor. In the case of oxide fuel, one option under consideration is the use of unused fuel pellets from the Super PHENIX. However, detailed evaluations are needed to understand what would be required for starting up a U.S. reactor with foreign fuel. In addition to understanding the details associated with each option for the ABTR driver fuel, it is also important to understand when this decision must be made.

3. The use of oxide or metal TRU fuel in the ABTR and ABRs: Another key program decision relates to whether TRU fuel should be oxide or metallic. As discussed in the fuel section of this report, the knowledge base on fast reactor fuel is larger for oxide fuel, though some claim that the safety case may be stronger for metallic fast reactor fuel. In the case of TRU-bearing fuel, there is limited information for either type of fuel. Detailed testing and demonstrations are required for making this decision. It is recommended that the integrated schedule identify what tasks are required for this decision and a date be selected that considers the time required for completing these tests. It should be noted that this decision may affect the separations processes that should be pursued for ABR fuel. The existing AFCI program has primarily focused on using aqueous separation techniques for TRU-bearing oxide fuels and pyroprocessing techniques for TRU-bearing metallic fuels.

4. The design and deployment schedule for ABRs: As noted above, the current plan calls for ABR deployment to begin in 2022. The subcommittee recommends that this date be reevaluated based on detailed studies that consider the required research that must be demonstrated (e.g., TRU-bearing fuel qualification and ABTR multi-cycle demonstrations) and realistic construction and licensing schedules. Furthermore, the “model” for ABR deployment should be considered. Some questions that must be addressed in developing this model include: Will these reactors be sited on government reservations or utility locations? Who will operate these reactors? Will the fuel be provided by the government if the reactors are operated by industry?

5. The decision to use fast reactors (ABTRs, ABRs) for transmutation: The current GNEP program relies solely on fast-spectrum reactors (FRs) for treating TRUs from spent LWR fuel. In the previous AFCI program, the focus of transmutation work was on a two-tier system where plutonium and minor actinides were first recycled in the existing fleet of LWRs. GNEP relies solely on FRs to avoid unnecessary complications associated with initial LWR treatment of minor actinides. However, large-scale FR deployment may not

likely to occur until the middle of this century. When the schedule for FR large-scale deployment is better defined (considering the time, cost, and facilities required to qualify TRU-bearing fuel and demonstrate multi-cycle TRU-bearing fuel, etc.), it may be appropriate to review the decision to go to an FR-only model. Initial recycle in existing LWRs can limit plutonium build up until FBRs are deployed.

In summary, the subcommittee had questions associated with the proposed mission and schedule for key program facilities. To address these questions, the subcommittee recommends that detailed mission statements for each facility be prepared and agreed upon by program participants and that an integrated schedule of all planned activities be developed immediately and updated annually. The integrated schedule should identify evaluations and trade study inputs required for each facility. Associated cost estimates for tasks identified in this integrated schedule should also be compiled for estimating annual and total program costs. The subcommittee believes that this integrated schedule will ensure that project activities are well coordinated, appropriately prioritized, and possible within the proposed timeframe.

III. FUEL SUPPLY FOR THE ADVANCED BURNER TEST REACTOR

First use of the ABTR is as a source of neutrons to test TRU bearing fuels for later use in ABRs. Acquiring a fuel supply for the first few cores for the ABTR is a key, open question. Although there are several possibilities, the accelerated schedule for the ABTR does impose some limitations on the available options. The most desirable candidates are Ternary Metal Fuel or Mixed Oxide Fuel (MOX). Ternary Metal Fuel is comprised of uranium, zirconium, and plutonium with a composition of about 70wt%U-20wt%Pu-10wt%Zr, with the exact plutonium amount depending upon the enrichment required by the reactor. MOX generally has a composition of about 80wt%U-20 wt%Pu, again with the plutonium amount depending upon the enrichment required by the reactor. Both fuels have been under development for many years and both are excellent candidates for long term operation of the reactor.

Both Metal Fuel and MOX have advantages and disadvantages. Considering only a major one in each case, the following may be said. The safety analysis of any reactor requires that a suite of accidents be considered. Within this suite, there are Design Basis and Beyond Design Basis accidents. One of the Beyond Design Basis Accidents is a Loss of Flow with Failure to Scram, which requires the sequential failure of two independent safety-class systems. This event does show a difference between the performance of Metal and MOX Fuel. Even though there are uncertainties in the analysis, the energy release with Metal Fuel is considerably less and it is possible that a containment vessel around the reactor may not be required. In contrast, the energy release with MOX fuel is greater and a containment vessel will undoubtedly be required. If a containment

vessel is included in the original design and construction of the reactor, either Metal or MOX may be used later. It should be noted that safety behavior of Metal Fuel becomes in some way more tricky when increasing the reactor power (> 1000 MWth).

Obtaining a supply of either Metal or MOX Fuel in the quantity and with the timing required to start up the ABTR does present a challenge. At present, the ability to fabricate Ternary Metal Fuel in the quantities required to support the startup on the ABTR does not exist. Both a facility capability and a timing problem may exist. While the AFCF does appear have the capability to fabricate Ternary Metal Fuel, it appears to be limited to lead assemblies and so does not have the required capacity.

Another metal fuel, Binary Metal with a composition of about 90wt%U-10wt%Zr, is also a possibility but suffers from the same lack of a fabrication facility. In this case, the uranium is enriched to about 25 to 30 percent, depending upon the requirements of the reactor. MOX is likewise a possibility but the logistics associated with obtaining it will require careful planning. There are four sources of a MOX fuel supply:

1. Use fuel previously fabricated for the Fast Flux Test Facility (FFTF), which was unused and which is currently stored at Hanford;
2. Fabricate new fuel in the plutonium facility TA-55 at the Los Alamos National Laboratory (LANL) from plutonium currently stored at LANL;
3. Use fuel previously fabricated by the Germans for their SNR-300 reactor, which is currently stored by British Nuclear Fuels at their Sellafield site; or
4. Use fuel previously fabricated by the French for Super-Phenix, which is currently stored at the Cadarache center.

The FFTF fuel supply is the smallest, and to obtain a full core load for the ABTR it may be necessary to combine this with some of the partially burned fuel from FFTF. The Super-Phenix supply is by far the largest (possibly 40 tons) and could provide fuel for the ABTR for many years.

If options 3 and 4 are used, it is possible that the MOX fuel pellets will have to be removed from the fuel pins as the fuel pins and assemblies were designed with a different reactor in mind. If this rework is required, the MOX pellets would be loaded into new fuel pins and the pins subsequently combined into new fuel assemblies. The most likely location for this work is the TA-55 facility at LANL.

It is possible that the Super-Phenix fuel assemblies could be used directly, without rework, if certain differences are taken into account during the design of the ABTR. The fuel would be used only for driver fuel and the mission of the reactor would be to test burner assemblies for use in later ABRs. With this approach, the following items would have to be considered during design. For

Super-Phenix, the active fuel height is one meter which is typical of all fast reactors, but there are axial blankets on each end of the active fuel. The design linear heat rate is about 16 kw/ft, which is typical of all fast reactors. But the fuel pellets are annular pellets and the gas plenum is located on the bottom of the fuel pin. While both of these designs were considered in the United States, they were not part of the standard fast reactor design approach in this country. They were part of standard design practice for fast reactors in other countries. The overall length of a Super-Phenix assembly is 5.4 meters in contrast to that in FFTF which was 3.8 meters. This difference would have to be taken into account during the design of the ABTR. Also the buildup of americium coming from plutonium after more than 20 years in storage would have to be considered. None of these concerns are insurmountable.

Using the Super-Phenix assemblies, with or without rework, could technically eliminate the fuel supply problem. It would, however, certainly require initial exploratory discussions between DOE and the CEA, and it would ultimately require an agreement that would involve a partnership relationship in some form, as yet to be determined.

As fast reactor fuel with multiple recycles will be employed, a fuel testing strategy for the ABTR will have to be developed. This will involve several items such as:

- Identifying the size of the test region or zone such that it is not dominated by edge effects;
- Determining the number of assemblies that must be tested for statistical significance;
- Determining the number of assemblies of first-recycle fuel, second-recycle fuel, etc., that must be tested;
- Determining whether these assemblies must be in the test zone together or can be tested in sequence separately.

The identification and determinations will affect the requirement for arrival of lead-test assemblies at the ABTR. This will affect the fuel fabrication rate that is required and determine the requirements for the AFCF, if this is the facility supplying lead test assemblies.

Summary

The fuel supply problems for the ABTR are solvable and four possible solutions are identified and discussed in this paper. Each would involve a different approach. None would preclude the use of Metal Fuel in the longer term either as the driver fuel in the ABTR or as the reference fuel in the ABR.

IV. SEPARATIONS TECHNOLOGIES FOR SPENT NUCLEAR FUEL PROCESSING

Aqueous Processes

A suite of UREX+ processes has been developed for a variety of separation and partitioning options for LWR spent fuel. The main features of these are summarized in Table 2. These take advantage of the long experience with the traditional PUREX process at Savannah River and elsewhere. The fundamental difference between the UREX processes and PUREX is that there is no production of a separated plutonium stream. In contemporary PUREX processes which are used and planned for in Europe and Japan, the plutonium (Pu) is stripped from the initial extractant containing uranium (U) and Pu and used to fabricate MOX fuel. The U then goes to storage or recycles, and the higher actinides and fission products (FP) are vitrified and sent to a suitable repository.

Table 2.

ARGONNE NATIONAL LABORATORY

Suite of UREX+ Processes

Process	Prod #1	Prod #2	Prod #3	Prod #4	Prod #5	Prod #6	Prod #7
UREX+1	U	Tc	Cs/Sr	TRU+Ln	FP		
UREX+1a	U	Tc	Cs/Sr	TRU	All FP		
UREX+2	U	Tc	Cs/Sr	Pu+Np	Am+Cm+Ln	FP	
UREX+3	U	Tc	Cs/Sr	Pu+Np	Am+Cm	All FP	
UREX+4	U	Tc	Cs/Sr	Pu+Np	Am	Cm	All FP

Notes: (1) in all cases, iodine is removed as an off-gas from the dissolution process.
(2) processes are designed for the generation of no liquid high-level wastes

U: uranium (removed in order to reduce the mass and volume of high-level waste)
Tc: technetium (long-lived fission product, prime contributor to long-term dose at Yucca Mountain)
Cs/Sr: cesium and strontium (primary short-term heat generators; repository impact)
TRU: transuranic elements (Pu: plutonium, Np: neptunium, Am: americium, Cm: curium)
Ln: lanthanide (rare earth) fission products
FP: fission products other than cesium, strontium, technetium, iodine, and the lanthanides

In UREX, the U is removed in the initial extraction step and purified sufficiently so that it can be treated as low-level waste. This greatly reduces the mass and volume of high level waste (HLW) that must be sent to a geologic repository. In all scenarios, iodine (I) is removed as a gas during the original dissolution of the

LWR spent fuel. All of the UREX+ processes are designed with the goal of generating no liquid HLW, and technetium (Tc), cesium (Cs), and strontium (Sr) fractions are removed for subsequent storage or treatment. In UREX+1, the transuranium elements, TRU and the lanthanide fission products (Lns) are separated together and go to temporary storage, or further processing, while the remaining fission products constitute another product. In the UREX+1a option, the TRU fraction is separated from the Lns. The UREX+1a process has been chosen for LWR spent fuel treatment in the GNEP program.

A laboratory scale hot test of the UREX+1a process which is designed to produce a pure stream of TRUs suitable for recycle was conducted using a feed of actual spent LWR fuel (~0.46 kg irradiated ATM-105 fuel containing ~0.39 kg U) and a 24-stage centrifugal contactor array (2-cm diameter contactor rotors). The uranium product met the process goal for disposal as Class-C (or better) LLW. The TALSPEAK process, designed to separate lanthanides from the resulting transuranic stream prior to recycle in FBRs, was tested for the first time with Pu and Np in the feed. Although the TRU recovery goal of 99.9% was met, 11 wt% of the metal in the TRU product was Lns, primarily neodymium. It is not clear exactly what the limits on the various Ln concentrations in the TRU product for FBR recycle may be, but it appears that longer contact times will result in sufficient reduction of the Ln content and will be investigated during FY 2006. Note that this removal of the Lns could be deferred until just before fuel fabrication of the TRU product, thus making it self-protecting. A pyrochemical separation process and metal fuel fabrication might also be envisioned at this juncture since the large amount of U would already be removed.

The UREX+2 process is designed for thermal spectrum recycle and potentially could provide the following separation options: Pu + Np for recycle with separation of Am/Cm together for later transmutation in fast spectrum systems, or the Cm could be separated and stored for decay to Pu + Am and subsequent recycle of the Pu + Np + Am product. The process was demonstrated with actual LWR spent fuel in FY 2004 and showed the very high recovery efficiency of >99.7% with excellent product purity. The uranium was sufficiently decontaminated to qualify for disposal as low level waste (Class C) and the TRU streams met ASTM specs for MOX fuel. Pu + Np recovery was close to required levels, but there was some contamination from Tc, and a step to fix this problem will be tested in FY 2006. There was some Np in the Am/Cm fraction and this is being addressed.

A laboratory scale demo of the extraction of Pu and Np together was conducted in FY 2004 and has some interesting aspects inasmuch as the Np isotopes ^{237}Np (2×10^6 yrs.) and ^{239}Np (2.4 days) provide a method for monitoring the separation of Pu from Am and Np. Radiations from the 27-day ^{233}Pa daughter of ^{237}Np and the 2.4-day ^{239}Np which is the daughter of 7370-year ^{243}Am can be readily measured. If ^{233}Pa is not detected, then the Np has been removed and if ^{239}Np is absent the Am is gone from this product. Neutron spectrometry can be used to detect Cm.

A lab-scale test of UREX+3 in which Am + Cm are separated from all FP (including Lns) was conducted in FY 2003. UREX+4 is designed to also separate Am from Cm. Thus it appears that a wide variety of options is available and can be optimized to provide the desired products once it is decided what will be most beneficial for transmutation from the standpoints of economics, time scales, and safety/dose considerations and priorities have been established.

In FY 2007, planning for preparation of product storage and HLW forms is scheduled to begin. If irradiated MOX fuel is to be dissolved, the UREX+ processes will have to be modified accordingly, depending on the Pu content, to control potential criticality problems. If the MOX fuel is to be recycled in two or more passes, ROX fuel containing degraded Pu and minor actinides must be handled, and remote technology and hot cells will be required.

Summary

All of the UREX processes with the exception of UREX+4 have been demonstrated on the laboratory scale (~kg batch size) with actual spent fuel. In FY 2005, laboratory-scale hot tests of UREX+1 and 1a were conducted on actual spent LWR fuel using a 24-stage centrifugal contactor array and demonstrated that the uranium product met requirements for disposal as Class-C (or better) LLW or for unshielded storage. The TALSPEAK process for separation of lanthanides from the resulting transuranic stream prior to recycle in FBRs was tested for the first time with Pu and Np in the feed. The TRU recovery goal of 99.9% was met, but improvements to decrease the Ln content of the TRU recycle product will be made in FY 2006. Tc recovery efficiency was >99% and can be incorporated as metal in the metal waste form with cladding hulls forming the matrix. Cs and Sr recovery efficiency is >99.9 % and is intended for long-term decay storage and is sufficiently pure for disposal as LLW after the decay period. Pu recovery efficiency of >99.9% and Am/Np/Cm recovery efficiency of >99.9% greatly reduce the radiotoxicity of the eventual waste streams. Finally, no liquid HLW requiring long-term storage is generated.

UREX+2 and UREX+3 were demonstrated with actual LWR spent fuel in FY 2003 and 2004 and showed high recovery efficiencies and excellent product purity.

The question of scale-up of the UREX+ processes from laboratory to industrial scale has been considered. Construction of an intermediate facility, the EDS, is being proposed to give confidence that scale-up can be accomplished with the necessary separation efficiency and purity.

The real leap forward will be in handling irradiated commercial-size LWR fuel assemblies, chopping the fuel rods for dissolution, designing feed and storage tanks, etc., and extensive industrial experience must be relied upon.

Regardless of the ultimate mix of thermal and fast spectrum reactors, it is clear that LWR spent fuel processing capability will be required (as well as a fuel fabrication facility). There are currently no suitable facilities for processing at this scale in either the U.S. or abroad.

Pyrochemical Processing

The pyrochemical process (PYROX), although still at an early stage of development, seems to have inherent limitations which will preclude its choice for the treatment of LWR fuel for recycling in the near future. Among the problems are the scale-up required to deal with the large amounts of uranium in LWR spent fuel. Even if the dissolution of the large quantities of oxide fuel can be accomplished in the traditional manner, it will still have to be prepared for subsequent pyroprocessing. It has not been shown that U can be separated at purity levels that would permit non-shielded storage as has been done for the aqueous processes. If PYROX is to be operated for processing LWR spent fuel to provide metallic fuel for fast reactors, a huge excess of U which is of no use would have to be laboriously treated. The incomplete removal of high neutron absorption Ln fission products may constitute a problem even for FR recycle. At this stage of the PYROX R&D program it is not possible to say whether it will work.

V. SEPARATIONS AND PARTITIONING OF FUELS IN FAST REACTOR RECYCLE

The scheme for dissolution of fast reactor fuel, and subsequent separation, partitioning, and preparation of feed for recycle depends on the type of fast reactor system and fuel that are selected for transmutation. Since the sodium fast reactor has been selected for the GNEP program, the fuel could be either MOX containing minor actinides, or metal alloy, probably containing Zr. Nitride and carbide fuels will not be discussed here, but present some special problems. Some pros and cons of the aqueous and pyrochemical processes are given below.

Aqueous processes

Metal fuel will contain a high initial content of TRUs (30-50%) and Zr (~10%) with a discharge fissile content of ~15% and will require dilution of the dissolver solution and strict design requirements for criticality control. The Zr can also be a problem, especially at higher concentrations, because it forms complexes with the TBP extractant and reduces the efficiency of the initial extraction. However, there are various steps that can be taken to solve this problem and to remove bond sodium.

Oxide fuel: Requires the same criticality precautions. The PuO_2 in high burn up fuel is more difficult to dissolve and may require treatment with hydrofluoric acid (HF) to obtain the desired recovery efficiency.

Pyrochemical process

Regardless of fuel type, the pyrochemical processes have inherent safety issues due to the inhomogeneous distribution of fuel material in the process vessels. Techniques for in-process monitoring of fissile content in this system need to be developed.

Although the fast spectrum reactor can accommodate impurities in metal fuel (except for some Lns), recovery efficiency and throughput may still be problems. Earlier (1989) lab-scale tests of segments of an INL spent ternary fuel (10% Zr) showed actinide dissolution efficiencies of >99.9 wt% and electrochemical dissolution tests will be performed in a lab scale electro-refiner this year. Small-scale tests for TRU recovery using a liquid-cadmium cathode (LCC) have been performed and indicate the feasibility of using LCC to recover TRU metals from electro-refiner salt. Some “engineering-scale” tests for TRU recovery using LCC were conducted but need further interpretation. Much effort has focused on process improvements supporting timely treatment plans for EBR-II fuel. Technology development activities associated with EBR-II fuel treatment may be helpful in demonstrating the feasibility of pyrochemical processing and fabrication of metal fuels for recycle when the next generation FBRs are commissioned and operating.

High-level waste forms have been developed as an integral part of pyrochemical processing and have been qualified and officially classified as high-level waste forms in DOE orders and can be sent directly to HLW disposal sites. The development of planar electrode configurations and poroplate materials appears promising and might help increase the throughputs and purity of product in electro-refining.

With oxide fuel **t**here are severe corrosion problems in the oxide reduction step and reducing the fuel to small size particles poses extreme off-gas handling problems. The U. S. currently has no fast reactors and international collaboration might provide an opportunity to expedite R&D on the appropriate reprocessing technology for these fuels.

Summary

Pyroprocessing appears to be most applicable to the fabrication and processing of the metal fuels which may be used (although oxide or other fuels could be used) when large numbers of Fast Burner Reactors (FBR) become operational sometime in middle of this century.

VI. UNIVERSITY PROGRAMS

We have great concerns about the apparent major cutback in University and student support in the GNEP program from that provided by its predecessors, the AFCI and GEN IV programs. If nuclear energy is to undergo an expansion during the next decades, an adequate supply of students in the pipeline must be maintained.

NERAC Chair, William F. Martin, in his letter to Secretary Bodman of 7 March 2006 has expressed NERAC's concern about the effect of cutbacks in the University Reactor Fuel Assistance and Support Program on nuclear engineering educational programs. However, NE has been supporting university programs in many ways and it is the totality of them that is the university support base. We cannot tell from the budget information available what is happening to all of them.

NE programs have been supporting university research and providing a fellowship program to encourage students to study nuclear engineering and radiochemistry. For example, it continues to support a significant R&D program at the University of Nevada, Las Vegas (UNLV), including studies on metallic fuel pins, modeling and testing of corrosion in steels for lead bismuth eutectic (LBE) coolant systems, and developing a sensing system for oxygen concentration in LBE coolant. UNLV researchers performed the major experimental portion of the LBE studies at Los Alamos National Laboratory, in collaboration with researchers at that laboratory.

AFCI also sponsors a large collaboration involving six universities: Idaho State University (ISU), the University of Texas – Austin, Texas A&M, University of Michigan, North Carolina State University, and UNLV – a program called the Reactor-Accelerator Coupling Experiments (RACE) Project. The purpose of the project is to conduct subcritical nuclear experiments using particle accelerators and heavy metal targets in order to study the coupling between accelerator targets and subcritical systems.

The University Research Alliance (URA), located in Canyon, Texas, is a consortium of Texas universities that manages the AFCI University Fellowship Program, which has been existence for five years. Out of 110 applicants for FY 2004, the program awarded nine new Masters-degree fellowships, with eight students accepting the awards. Notably, last year the program funded its first radiochemistry student. Overall, the number of students supported in FY 2004 is as follows:

UNLV Research Program	68 (13 Ph.D., 44 M.S., 11 Undergrads)
ISU-IAC Research Program	35 (13 Ph.D., 19 M.S., 3 UGs)
Lab Directed Univ. Research Program	14 (6 Ph.D., 6 M.S., 2 UGs)
University Fellowship Program	9 (all M.S.).

Both the UNLV and ISU-IAC programs are funded under Congressional earmarks.

Counting all its programs, AFCI funded nineteen (19) universities in FY 2004, including Ben-Gurion University in Israel.

With AFCI assistance, UNLV recently established a Master of Science degree in materials and nuclear engineering and a doctoral degree in radiochemistry. The latter is of extreme importance, since the educational infrastructure for the training of students in radiochemistry has been on a downward spiral over the past twenty-five (25) years. According to the report, *Assessment of the Teaching and Applications in Radiochemistry*, a June 2002 IAEA report of a technical meeting held in Antalya, Turkey, the number of departments at U.S. universities that offer courses in radiochemistry has dropped from about 50 to 20 between 1979 and 2002. During the same period, the number of faculty who taught such courses dropped from about 120 to 20. Thus, it is no wonder that the report, *Status of Graduate Programs in Radiochemistry and Nuclear Chemistry*, prepared for DOE by Gregory Choppin, Professor of Chemistry at Florida State University, states that the number of viable radiochemistry programs in the United States in 1992 was probably eight (8) and that the number of doctoral degrees granted by all programs averaged fewer than eight (8) annually during the period 1989-1992, with even fewer Master's degrees awarded during the same period.

Despite the excellent record in recent years of DOE's support for university programs, the FY 2007 Budget Request is cause for great concern, as can be seen from the following:

Budget Summary for University Infrastructure and Educational Assistance ($ in Millions)

Program Element	FY 2006 Adjusted Approp.	FY 2007 Request
University Nuclear Infrastructure	14.1	0.0*
Matching Grants	1.0	0.0
Fellowships/Scholarships	2.3	0.0
Health Physics Fellowships and Scholarships	0.3	0.0
Nuclear Engineering Research Grants	5.0	0.0
Nuclear Engineering Educational Opportunities	0.6	0.0
Radiochemistry Awards	0.7	0.0
University Nuclear Education Infrastructure and Assistance	2.7	0.0
Total	**26.7**	**0.0**

*2.9 M for fuel is requested in the Radiological Facilities Management budget under Research Reactor Infrastructure.

The University Nuclear Infrastructure Program is called *Innovations in Nuclear Infrastructure and Education (INIE)*. That program was established in response to a NERAC study that found that the number of university reactors declined from some 63 in 1979 to 27 in 2001, about the time that INIE began. Around the year 2001, several of the highest power university reactors were on the verge of being decommissioned, including those located at the Massachusetts Institute of Technology, the University of Michigan, and Cornell University. The university administrations had grown tired of subsidizing the operations of such expensive research tools when they were being underutilized. Several of the reactors, including those at Michigan and Cornell, indeed were ordered to be decommissioned. A NERAC study concluded that the underutilization was due to the universities' inability to generate the necessary funds to maintain state-of-

the-art instrumentation and sufficient technical support for the reactor users. Thus, the INIE program was born with funding on the order of $100K-$2M/yr. Now the rug is being pulled from under that program.

Part of the Education Assistance Program that is being terminated is the Nuclear Engineering Education Research (NEER) Award Program. These awards had a second rebirth around 1998. They provide research grants to faculty and financial support for students to pursue nuclear energy-related research and education. Approximately, $1,600,000 in federal funds is expected to be available for the NEER program in FY 2006, and DOE anticipates making approximately 15 new awards ranging from one to three years at a recommended budget of $100,000 per year. Besides NEER, several other grant, scholarship, and fellowship programs were terminated as well.

There is another source of research support to universities called the Nuclear Energy Research Initiative (NERI). During President Clinton's administration, the President's Committee of Advisors on Science and Technology urged him to create a new kind of nuclear energy research award program that would spur innovative ideas, and not force researchers toward the national laboratory-based, programmatic research directions that are mandated from DOE headquarters. There was a sense that there was too much of the "standard thing" going on in nuclear energy research. In 1998, NERAC endorsed PCAST's recommendation and strengthened it with its own reports, which can be found at http://neri.ne.doe.gov. Thus, DOE established the NERI Program to fund bold, new, creative ideas. Recently, the NERI Program has morphed into one that funds research at universities that is integrated into the national laboratory programs. Hence, it appears that the PCAST and NERAC recommendations for a NERI program to fund research of the blue-sky, creative type have taken a back seat to explicit DOE Gen IV goals.

In summary, it is difficult to analyze the NE university support budget at the present stage. It appears to have major cutbacks, and we are greatly concerned that cutbacks in support for work at the universities will have negative impact on the program by curtailing the flow of students into nuclear energy related areas, and reducing the work carried out by some of the most innovative people in the field.

We understand that support for existing programs at the universities will continue for the short term, but our analysis based on the information currently available leads us to feel that may be insufficient. We recommend that a robust university program including student support be maintained for the long term as an essential part of the GNEP program.