Report of ADVANCED NUCLEAR TRANSFORMATION TECHNOLOGY SUBCOMMITTEE of the NUCLEAR ENERGY RESEARCH ADVISORY COMMITTEE

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I. INTRODUCTION AND SUMMARY

The committee met in Washington on September 16 and 17 to review progress in the program with respect to a changed set of mission priorities. Our last meeting took place in December 2002 after the reorganization that had placed the Advanced Fuel Cycle Initiative (AFCI) and the GEN IV program together in the Advanced Nuclear Research Office (AN-20). Since mission priorities have been evolving, the committee felt that it should wait until they have settled down before we met again. We have kept in touch during the process, the Chairman meeting several times with Bill Magwood and members of the committee attending the AFCI Semi-Annual Program Review, Santa Fe, New Mexico, August 26-28, 2003. Before reporting on the most recent meeting, it is useful to summarize where we were a year ago and our understanding of the new set of priorities.

In our report to NERAC of 15 April 2002, we gave an evaluation of the transmutation program which we described in terms of three phases. Phase I, completed at that time, defined the program goals, carried out exploratory R&D, and conducted system studies. This work showed that the program could, in principle, meet the four goals that had been set out for it.

1. Enhanced long-term public safety,
2. Provide benefits to the repository programs,
3. Reduce the proliferation risks from plutonium,
4. Improve the prospects for nuclear power.

We described a second phase of the program that would include focused R&D and testing on critical technologies, and the engineering and systems studies necessary to develop the reliable budgets for a large-scale third phase. The second phase program could have been done in five to six years and would have cost about $500 million in total.

A third phase that could follow on from the second phase would be the development of a scalable demonstration of a transmutation program. That effort was roughly estimated to take about 15 years at a total cost of several billion dollars. There was and still is broad international interest in transmutation and a potential for significant cost sharing.

As of a year ago, in spite of budget uncertainties, emphasis was on moving through this Phase II as rapidly as possible. Today this program has slowed and the first priority has shifted to studies of technologies that might affect the recommendation that the Secretary must make in the years between 2007 and 2010 on the need for a second repository. With this change in emphasis, the preliminary design and scoping study on a large-scale treatment facility has been postponed, the scope of UREX+ demonstration in the United States has been reduced, the investigation of other advanced treatment processes has been included, and the program has been tasked with more systems analysis. This has come about from a combined set of DOE needs, budget constraints, congressional language, and the recent MIT report on The Future of Nuclear Power, An Interdisciplinary MIT Study (2003).

The committee has not been asked to comment on the MIT report. We have reviewed the Nuclear Energy (NE) division paper commenting on various aspects of the report and made some suggestions. It is, however, appropriate to note at least one of the areas where we do disagree with the conclusions of the MIT report. That is in the cost of reprocessing. While no one has done a specific study of a full-scale transmutation program, there are two studies that have costed electricity from MOX fuel including capital costs of separation plants, fuel fabrication, operating costs, safety systems, etc. The French have estimated an increase of the cost of MOX-generated electricity of roughly 5%. Very recently, a draft Harvard study (*The Economics of Reprocessing versus Direct Disposal of Spent Nuclear Fuel*, M. Bunn, et. al., Belfer Center of the Kennedy School, July 2003) has estimated in the U.S. context an increase in the cost of electricity from reprocessing as 0.13 cents per kilowatt hour, or 2% to 3%, which is negligible compared to other uncertainties in the cost of energy.

Study of the technical performance and capacity of the repository under various spent-fuel treatment regimes is under way. The Office of Civilian Radioactive Waste Management (RW) is involved in developing revised inventory projections including waste from both civilian and military sources. RW will participate in reviewing options and, in some cases, fund R&D for treatment of spent fuel that might lead to significant volume reductions and/or removal of problem isotopes.

The legal question of the allowable limits to materials that can be stored in Yucca Mountain is not considered in this phase, although it will have to be considered eventually. Current law embodied in the Nuclear Waste Policy Act of 1982 prohibits "…emplacement in the first repository of a quantity of spent fuel containing more than 70,000 metric tons of heavy metal, or a quantity of solidified high-level radioactive waste resulting from the reprocessing of such a quantity of spent fuel, until such time as a second repository is in operation."

The proliferation resistance of any spent fuel treatment option will be an important consideration in the acceptability of any scheme. Our committee was briefed on preliminary conclusions of the "Blue Ribbon Panel" set up by the AFCI program. The panel's analysis compares partitioning and recycling to the "once-through" system, taking into account the transient nature of proliferation resistance (the spent-fuel standard) in the once-through system. The fission fragments that make the radiation barrier that protects the plutonium in the spent fuel dies away in roughly a hundred years, and so there is a short-term/long-term balance issue to consider. We will not comment further on this until we receive the final report of the committee.

In addition to the AFCI Blue Ribbon Panel, this committee has asked Dr. Paul Longworth, Deputy Administrator for Defense Nuclear Non-proliferation in NNSA, to analyze the proliferation resistance of the quite different isotopic mixes of plutonium at several stages in a possible transmutation scheme. We also note that both the GEN IV program and RW each have groups studying proliferation issues. It might be beneficial to consolidate these three programs.

In evaluating the effectiveness of various combinations of partitioning and transmutation, the technical limitations of the repository have to be considered. In both the short term and the long term, the main limit is heat. Tunnel walls must not go over 200°C and the point midway between adjacent tunnels must not go over the boiling point of water. In the early years, the tunnel walls are the limitation and the heat comes from fission fragments, particularly cesium and strontium. In the long term, the limit is the inter-tunnel temperature and the heat comes from the actinides. For example, removal of fission fragments to a separate, short-term, repository does nothing for the capacity of Yucca Mountain because of the inter-tunnel temperature limit and the presence of all of the actinides that would have been in an untreated fuel sample. On the other hand, removal of both the cesium and strontium to short-term storage and the plutonium and americium for transmutation increases the capacity of Yucca Mountain by a factor of sixty.

There are many variations to partitioning, storage and transmutation that need sorting out. An aggressive expansion of nuclear power as envisaged, for example, in the MIT study or the GEN IV study would require another Yucca Mountain in the United States every five to ten years. Clearly a method of greatly increasing the capacity of a single repository would be very beneficial. At present there are too many options to allow an in-depth study of any of them. It is to be hoped that the systems studies of this current fiscal year will narrow these options and give better focus to the program.

There are two other matters that we wish to highlight. We again note the absence of good, fast-spectrum test facilities in the United States. The final demise of the FFTF is to be regretted. We do point out the limitations of foreign facilities and the possibility of getting some capacity back home with upgrades to LANSCE, at Los Alamos, and ATR at INEEL.

We are concerned about the uncertainty in plans to do an engineering scale demonstration of the separation process. Such a test is needed to create confidence in the scalability of what has been done on a laboratory scale. AFCI program plans to do such a demonstration at INEEL have been cancelled because of budget limitations and costs. There are discussions involving NE, RW, and the French on a possible use of the COGEMA facility. In coming to a final decision, the impact on U.S. facilities and expertise should be considered.

II. SEPARATIONS TECHNOLOGY

Recently, there have been revisions in the AFCI mission and a shift in the program from early implementation of separation technologies to a focus on R&D designed to inform the Secretarial recommendation in 2007-2010 concerning the need for a second repository. There will be a single, integrated approach to the nuclear fuel cycle with intermediate and long-term replacing in the Series One and Series Two approaches. These changes have resulted in a strategy that will defer indefinitely any large-scale demonstrations of integrated separations processes, e.g., UREX+ and PYROX in the U.S., will reduce the scope of UREX+ engineering scale experiments, will investigate other advanced aqueous processes, and will place more emphasis on systems analysis and modeling.

Obviously, these changes have greatly affected the program to be pursued in the separations technology area. While the budget of about $30 million for separations appears large, AFCI (ANTT) separations technology now encompasses all of the following program elements:

- Advanced aqueous processing.
- Pyrochemical processing.
- Engineered product storage.
- Spent fuel treatment facility scoping study.
- GEN IV fuels processing.
- Advanced process development.
- EBR-II spent fuel treatment.

Most of the budget has gone toward EBR-II spent-fuel treatment as the DOE is committed to removing this fuel from Idaho by 2035, leaving about $7 million for the remaining program elements. However, the electrometallurgical processing technology used for EBR-II spent fuel provides technology for new waste forms potentially relevant for GEN IV fuel treatment processes and Tc and I disposal, and provides an avenue for development of future pyrochemical processes.

The AFCI Separations Overview given by National Technical Director Jim Laidler emphasized the potential significant benefits to the repository from partitioning of spent LWR fuel followed by subsequent transformation of the transuranics. The first steps of UREX+ would remove the uranium which could then be decontaminated and presumably disposed of as Class C waste, or be recycled, rather than going to “expensive storage” in Yucca Mountain, thus increasing the capacity of the repository. There may be a question of whether the uranium could meet Class C waste requirements because of higher alpha activity which might result from the potential buildup of U-234 and U-236.

Removal of transuranics (Np, Pu, Am), the heat generators Cs and Sr, and mobile nuclides (Tc, I) would decrease the heat loading and dose rate in the repository and should reduce costs and hazards related to transport and disposal of the wastes or some might be converted to suitable waste forms and stored elsewhere. The annual volume of high-level waste could be reduced by more than a factor of ten. The amount of post-transmutation residual Pu sent to the repository could, in principle, be reduced from ~17,000 kg/y to <75 kg/y.

A dramatic new direction was proposed subsequent to the decision not to go ahead with plans for any large-scale demonstration of UREX+ and/or PYROX in the U.S. A planned demonstration of the UREX+ process at the INEEL TAN-607 facility (2 tons per year for 3 years) was reported to cost nearly $200 million, and the project was abandoned. This has prompted discussions by NE and RW with CEA of France of the possibilities for conducting such demonstrations in France and options are currently being investigated. Apparently, there is a window of opportunity when the COGEMA facility would be available. However, adjustments to the existing plant might be required and there will be many legal issues to negotiate such as intellectual property and patent rights. Joint sponsorship by NE and OCRWM and others might be envisioned. A downside to the plan is that then there will be no facility in the U.S. for large-scale demonstrations and training of personnel in the intervening years until a commercial-scale facility for LWR spent-fuel processing in the U.S. could be designed and built. An undesirable erosion of the entire capability in the U.S. might result. In any event, process chemistry must still be investigated in the U.S. prior to conducting a full-scale demonstration at COGEMA.

Progress to date with UREX+ process development includes:

- Successful separation of pure U on the laboratory scale with irradiated fuel at Savannah River in 2002.
- Laboratory-scale demonstrations of flow-sheet with irradiated fuel and of U/Pu/Np co-extractions are in progress.

- Laboratory-scale demonstrations of fuel dissolution and UREX+ flow sheet using simulant solution have been completed with a 24 stage 2-cm contactor in a hot cell, and results will be reported soon.
- Experiments with some specialized processes such as U crystallization, improved Am/Cm separations, and voloxidation processes have begun with nominal funding.

Many variations and alternatives in the UREX+ process have been proposed for consideration. These can be narrowed down once additional laboratory scale and pilot scale experiments have been performed and the primary goals and criteria are clearly known. It is strongly urged that laboratory investigations be conducted on the stability and kinetics of the critical reagents involved, such as AHA or other redox or complexing agents, under the conditions to be encountered in the actual processes.

Vertical dry-cask storage designs for spent fuel were investigated and vertical storage casks have been approved which will reduce the storage area required. For example, assuming current NRC standards (30 kW per cask), 100 years' production of fission product Cs/Sr can be accommodated in an equivalent space of two-to-five football fields, and 30 years' production of Am/Cm would occupy less than one. Other storage issues were also addressed.

Proposed future directions include development of:

- Advanced aqueous or hybrid processing methods for LWR spent fuel that reduce cost to $400/ kg and still meet separations criteria.
- Methods for process simulation, including safeguards systems and near real-time accountability.
- A reduced-cost substitute for large-scale demonstration.
- Advanced pyroprocessing methods for GEN IV spent fuel treatment.
- Process technology for future aqueous and pyrochemical processes.

Technology developments needed in a future spent-fuel treatment facility include:

- Improved methods for analyzing composition of feed material to a spent fuel treatment facility.
- Precise rapid on-line chemical analytical instrumentation, such as mass spectrometers, gamma-scanners, neutron emission analyzers, tank liquid volume and mass measurements.
- Real-time use of alpha spectrometry.
- Improved process models for detecting secondary indications of diversion, e.g., changes in reagent concentrations, product stream compositions, isotopics, etc.

A group separation of TRUs that could improve the perceived proliferation resistance of the UREX+ process is currently being studied. The U plus Tc and I are extracted first followed by Cs/Sr. Then all TRUs are stored in the same way as proposed for Am/Cm. This product would be self-protecting for 60 years or more because of the dose from

Pu-241 and Eu-154, but a change in storage geometry and addition of neutron absorbers would be required due to criticality issues.

III. TRANSMUTATION SCIENCE AND ENGINEERING

Under the Advanced Fuels Cycle Initiative, Transmutation Science and Engineering is divided into four subprograms: Physics, Structural Materials, Materials Coolant Technology, and Accelerator Driven Systems (ADS). Both at the August 2003 DOE-NE AFCI's Semi-Annual Meeting and at the September 2003 Meeting of NERAC's Advanced Nuclear Transformation Technology Subcommittee, the AFCI National Technical Directors and their colleagues gave extensive presentations on activities for FY '03 and future plans. The highlights of those presentations are as follows.

Physics: There is a continuing and urgent need for more nuclear cross-section data to bolster the statistical and deterministic computer software models of the transmutation process. Sensitivity studies will continue to focus on which cross section uncertainties will have the greatest impact on transmuting the transuranics. Much theoretical work has been done on system parameters. Notable among the theories is the so-called Generalized Perturbation Theory (GPT) to assess system performance. However, in the end, real data must be obtained to properly assess the accuracy of such theoretical models. Although more thermal and epithermal data will be important, especially regarding uncertainties, there is a dearth of data in the fast-spectrum region. The main problem is the lack of adequate facilities for providing a source of fast neutrons.

Structural Materials: The major issue here is the choice and characterization of materials under intense irradiation and high temperatures. Pinpointing the lifetime to failure of materials under harsh reactor environments is of extreme importance. Notable work has been done on helium gas production in irradiated materials. Recent experiments have shown the necessity of benchmarking theoretical models and codes with real data. LANSCE researchers have analyzed and published data on neutron-induced helium production from nickel. The experimental results differ markedly from the theoretical predictions above 50 MeV.

There has been considerable atomic modeling of helium production in a body-centered cubic-iron matrix, studying the influence of defects and temperature on gas bubble evolution. Researchers have studied the evolution of gas bubbles, employing data from molecular static and dynamic calculations. Soon, there will be measurements on both iron and chromium. Clearly, there is a much more theoretical, computational, and experimental work that needs to be done in this area.

The LANSCE facility at LANL could prove to be an important facility for AFCI activities, especially for materials testing. There is a roughly $18 million proposal to establish a Materials Test Station (MTS) at LANSCE to use its 800 MeV proton beam operating at about 1.1 milliAmperes of current to produce intense fast-spectrum neutrons for performing small sample materials irradiations. Fast neutron fluxes up to 1.1×10^{15} neutrons/cm^2/sec could be achieved, although the irradiation volume could be as low as 1 liter. Activities could include materials validation of simulations and codes through experimental measurements. Another possibility for obtaining fast neutrons is the roughly $15 million proposed addition of a Flux Booster to INEEL's 250 MW Advanced Test Reactor (ATR). There, fast neutron fluxes up to about 5×10^{14} neutrons/cm^2/sec could be achieved. Both possible sources of fast neutrons could be operational within three (3) years, but the problem now is the funding. Although both facilities could make major contributions to the improvement of alloys and even the definition of data needs, they are far from the large-scale test facility that will eventually be needed.

With facilities like the MTS at LANSCE and Flux Booster at the ATR, structural materials testing could be done to determine the effect of high-energy proton and neutron irradiation on mechanical properties under prototypical conditions: temperatures in the range 400°-600° C, with total fluencies up to 200 dpa. Materials to be tested will include T91, HT-9, EP 823, and 316L. The mechanical test data for such materials will help to determine the structural design parameters for transmutation materials. Finally, the data will be published in Revision 4 of the research team's *Materials Handbook*.

Materials Coolant Technology: This subprogram currently is concentrating on lead-bismuth eutectic (LBE) coolant, sensor technology, and corrosion mitigation for fast reactors and Accelerator-Driven Systems (ADS). The LBE studies are centered at Los Alamos National Laboratory's DELTA Loop (DEvelopment of Lead-Bismuth Target Applications Loop). The goals of this program are the study of long-term corrosive effects of liquid lead-bismuth on structural materials at extreme reactor environment temperatures; creation and maintenance of natural convection flow in a liquid lead-bismuth system; the study of the design and operation of oxygen control systems in the lead-bismuth flow; and the study of lead-bismuth thermo-hydraulic properties of materials for different flow geometries.

The DELTA Loop gives researchers the possibility of taking materials samples previously irradiated in reactors or accelerators and emplacing them in the Loop to study the effects of irradiation on corrosion. Thus, the DELTA Loop, with its removable test sections, will be an excellent test bed for the development of transmutation components, whether for fast reactors or ADS. The University of Nevada-Las Vegas (UNLV), which has some thirty-seven (37) graduate students and roughly thirty (30) faculty involved in AFCI-related research, is a major contributor to the DELTA Loop research effort.

Accelerator-Driven Systems: The main issues here continue to be accelerator reliability, target technology, coupling of an accelerator to a sub-critical reactor, and operation and safety. Two initiatives being pursued are the cyclotron-TRIGA reactor coupling experiment in Italy called TRADE and the Idaho State/University of Texas/Texas A&M collaboration to couple an electron accelerator to a TRIGA reactor.

The usefulness of studying an electron accelerator coupled to a reactor is said to lie in the similarity of spallation neutron spectra up to 20-25 MeV for 600 MeV proton and 50 MeV electron beams. However, the neutron flux is small.

Even though studies of ADS will continue as part of the AFCI portfolio, DOE deems it to be of lower priority than the other subprograms. We agree.

International Collaborations: Under the Transmutation Science and Engineering Program, there have been a number of international collaborations that have saved millions of dollars over the cost of doing the research here in the United States. A sampling of such collaborations is as follows:

TRADE:	Coupled cyclotron to TRIGA reactor in Italy
MUSE:	Coupled external sources to fast reactor criticality facility (CEA-Cadarache)
PROFIL:	Small sample irradiation experiments at the PHENIX fast reactor
CEA-Saclay:	Advanced Cavity Development
JPARC:	Target Test Station and low power Subcritical Multiplier in accelerator complex
MEGAPIE:	Megawatt scale spallation source at PSI

In the MEGAPIE project, a major U.S. interest will be in the post-irradiation examination of materials. Finally, it was noted that Euratom, the European Atomic Energy Community, will become the eleventh member of the GEN IV International Forum.

With the regrettable recent decision to shut down permanently the Fast Flux Test Facility at DOE's Hanford Site in the State of Washington and the fact that France's PHENIX fast reactor probably will shut down permanently after around 2006, few fast-neutron spectrum test reactors will be available for research and development purposes. There is still Russia's 60 MW BOR-60 experimental fast reactor located in Dimitrovgrad; however, relations between the United States and Russia are strained at the moment because of international issues, mainly concerning Iraq and Iran. Thus, the work of the AFCI program, with its emphasis on GEN IV and nuclear waste partitioning and transmutation, will be greatly hampered. Even though there is the possibility of creating small volume fast-neutron test facilities at ATR and LANSCE as noted above, the lack of funding has delayed those efforts.

Fortunately, several old samples that were irradiated in the FFTF (HT-9, MA 957, 10Cr-1Mo, AISI 422, F82H, have been found that would have cost some $20-30 million to reproduce today. Those samples were irradiated up to 200 dpa and currently are being prioritized for structural materials studies. After the studies, the new data for the FFTF samples will be incorporated in Revision 4 of the *Materials Handbook*.

University Programs: ANTT is pleased to see DOE's investment in university research programs, such as those at UNLV, Idaho State, University of Texas, and Texas A&M and encourages it to continue along this route. ~~Although there will be no new Nuclear~~

~~Energy Research Initiative grants, ANTT is pleased about the new FY04 university program called the Nuclear University Research Initiative ("NURI" is a temporary placeholder until a final name is chosen). Under this program, which will solicit fresh new approaches to solving problems of interest to the AFCI program, awards will be made through university faculty with an eye towards research leading to student theses.~~

In Transmutation Science and Engineering the Committee would like to see progress in the following.

- A source of fast neutrons for cross-section measurements and the irradiation of materials for structural testing and analyses is needed. The newly proposed Materials Test Station at LANSCE and the Flux Booster proposed at INEEL's Advanced Test Reactor could play a major role. Moreover, if and when the political tensions ease between the United States and Russia, DOE should move swiftly to collaborate on fast neutron studies at Russia's BOR-60 reactor.
- The AFCI research team should push harder to benchmark theoretical and computational modeling with real data. New data on helium gas production in samples shows vividly how far models can stray from reality.
- The National Directors of the AFCI programs should ensure that all its researchers see the big picture of the overall AFCI program and keep the whole team focused on the main objectives of the program.
- AFCI researchers re-examine the idea that coupling an electron accelerator to a reactor is useful for learning what to expect when one couples a proton accelerator to a reactor. There was some concern that students may be training at Idaho State University on possibly irrelevant systems.
- DOE should be cautious about directing too many of the limited AFCI dollars to the lead fast reactor (LFR) program at this point. ANTT appreciates this new thrust of DOE, but it is concerned too many options are being pursued for the funds available.

IV. FUEL DEVELOPMENT

The revised mission of the AFCI program has resulted in a significant reorientation of the fuel program. Previously, the program clearly focused on deployment of non-proliferant plutonium-containing fuel and the long-term development of innovative fuels for transmutation in fast spectrum reactors. The decisions to abandon any intermediate-term, scalability demonstration, and to introduce in AFCI the development of new, advanced, reactor fuels disrupts the coherency of the transmutation fuel program, jumbles the main objective to be reached, and creates new conflicts of priorities. Fuel development requires some program stability as it takes about 15-20 years to qualify and to license any new fuel concept.

A review of proliferation risk is in progress (the Blue Ribbon Committee). Any fuel cycle (direct disposal as well as waste recycle) has some proliferation risk. Spent fuel, the standard of proliferation resistance, actually provides a radiological barrier only over roughly 100 years, so that long-term proliferation resistance is not ensured. A partition and transmutation scenario restores the radiation barrier by the fuel re-irradiation in a reactor but offers a window of vulnerability, however limited in time, during the reprocessing and re-fabrication steps. Such vulnerability can be safely managed with appropriate safeguard measures, as it is already demonstrated in European countries. Separated and stored uranium, curium and americium have little proliferation risk. Introduction of neptunium into the fuel allows the degradation of the plutonium isotopic vector from one cycle to the next and significantly decreases the long-term proliferation risk. Analysis seems to show that MOX fuel containing Np is a long-term proliferation resistant fuel.

Concerning innovative fuels containing high fraction of transuranics, successful fabrication of nitride and metal fuels containing americium have been carried out in LANL and ANL laboratories at the laboratory scale. Fuel samples have already or soon will be irradiated in ATR, and information on their behaviour under irradiation will be available as soon as the end of this year. Process difficulties have been clearly identified; the americium volatility will be a major challenge at the industrial stage when processes minimizing Am losses will be required. As regard to TRU-fuel fabrication, it has been noticed from the lab-scale tests that the Am volatility, mastered by applying rapid heat treatment on very small batches or by repeating heat treatments as many times as necessary, becomes a major issue at a larger scale.

Regarding MOX-Np fuel, a small-scale fabrication of pellets containing weapon-and reactor-grade Pu have been successfully achieved meeting the fuel specification for an irradiation test in ATR starting in December 2003.

The AFCI mission of technology demonstration is indefinitely delayed. The program has been reoriented toward lab-scale feasibility demonstration. This is clearly insufficient to achieve in the U.S. program alone a complete technical and economical assessment of transmutation and will require a heavy reliance on international data and experiments.

Generally speaking, statistical assessment based on large-scale irradiations of pin bundles in representative conditions is required to qualify and validate fuel performance. Such a program cannot be envisioned without a fast-spectrum test reactor. The JOYO, MONJU and/or BOR 60 test reactors might be used in bilateral or multilateral collaboration for scoping tests. However, it seems unlikely that a complete demonstration program can be done in these reactors because of their limited availability and fuel transportation issues. The recurrent issue of fast-spectrum test reactor availability in the near future is not yet solved. The fast-flux booster in ATR will offer a small irradiation volume. The French Phenix reactor will not be available long enough to demonstrate the ability to achieve high burn-up. The Japanese reactors are overbooked and will not able to carry out the irradiation program required to qualify innovative fuels. A Russian cooperation in BOR60 or BN600 seems difficult to consider.

Fuel transportation across countries is furthermore more and more difficult to organize. This problem may be the limiting issue for fast-reactor fuel development.

The AFCI program is faced with managing a growing variety of fuels for GEN II, GEN III and GEN IV reactors. While grouping of all fuel programs within the AFCI program tends to favour synergy between them, specific development of each is required to take into account their differences. For GEN II and GEN III reactors, transmutation fuels will have to adapt to reactor design through the development of minor actinide targets or fuels containing low content of minor actinides. For GEN IV, reactors can be designed to accommodate transmutation fuels, i.e., low-fertile or fertile-free fuels. Prioritization is required to limit the options, taking into account the different time horizons of the programs and the need of transmutation to begin in Gen II reactors.

V. SYSTEMS ANALYSIS

The Systems Analysis program has been tasked with activities that support near-term AFCI and longer term GEN IV program objectives. Specific tasks conducted and/or planned to support near-term AFCI program objectives include:

- Quantifying the impact of various waste management strategies (separations, transmutation, etc.) on the inventories, costs, and proliferation resistance associated with SNF disposal.
- Analyses that provide insights about optimizing and/or down-selecting proposed processes/concepts (separation flow sheets, recycling strategies, transmuter designs, etc.)
- Assessing readiness levels of technologies to provide guidance for prioritizing various technology needs.

Although the deployment timeframe for the GEN IV program is long (e.g., 2030), there are AFCI tasks of importance to GEN IV systems studies such as assessments to optimize waste management of proposed GEN IV concepts and studies assessing the viability of proposed GEN IV concepts as transmuters.

During the last year, AFCI system analyses have focused on assessments of various transmutation and separations options for LWRs, such as extended burn-up, repeated recycles, varied recycle (curium removal, MIX concept, CORAIL concept etc.). Calculations were begun to assess the impact of possible separation and fuel-cycle options on the repository's performance. Several repository performance measures were considered – waste mass/volume, heat load, and doses/radiotoxicity. With the existing nuclear power reactors, the legislated mass limit for storage in Yucca Mountain would be reached by spent-fuel produced by 2010. The mass of waste stored in Yucca Mountain would be greatly reduced if the uranium is separated from spent fuel and treated as low-level waste. However, some of the transuranics or fission products must also be removed from the remaining waste in order to remain below thermal limits of the repository. At least in theory the separation and subsequent decay and/or transmutation of certain elements can substantially benefit the design and operation of the Yucca Mountain repository.

The systems analysis group also held an expert workshop this year to conduct a detailed assessment of the current reference separation worksheet. The objective of this workshop, which included experts from separation and transmutation areas, was to establish technical criteria for each operation in selected advanced nuclear transformation fuel cycles (e.g., recovery efficiency, decontamination factors, losses, waste form characteristics, etc.). Criteria considered included technical feasibility, cost/performance tradeoffs, expected benefits, and dynamic effects. During the workshop, recommendations were developed for key issues associated with transmutation (e.g., separations criteria, cesium and strontium recovery, curium storage or recycle, uranium disposal, etc.). These recommendations provided an important basis for future tasks performed in the systems analyses, separations, fuels, and transmutations areas.

Unfortunately, efforts to complete planned FY03 system analyses activities were hampered by funding delays and reductions. Clearly, a stable supply of increased levels of funding is required to complete all of the broad and detailed assessments proposed by this group for FY04 and subsequent years.