# Report of

# ADVANCED NUCLEAR TRANSFORMATION TECHNOLOGY SUBCOMMITTEE

# Of the

## NUCLEAR ENERGY RESEARCH ADVISORY COMMITTEE

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## 1. EXECUTIVE SUMMARY

The Global Nuclear Energy Partnership (GNEP) program is still evolving. Since our report of March 22, 2006 the DOE has sought to gauge industry interest in participation in the program from its very beginning. At the time the ANTT committee met, August 30-31, 2006, responses had not yet been received from industry to the DOE's request for Expressions of Interest. This report is based on the assumption that the program outlined recently, which does not include an Advanced Burner Test Reactor, is what will go forward.

As of the date of our meeting the integrated timeline for the program that we called for in our report of March 22, 2006 had not yet been generated. The advanced burner reactor (ABR), the first reactor facility called for in the new DOE program, is to be licensed by the Nuclear Regulatory Commission (NRC). It, therefore, has to be filled with uranium-plutonium fuel which is the only fast reactor fuel with which we have the necessary experience. The transuranic-based fuel (plutonium (Pu); neptunium (Np); americium (Am); curium (Cm); collectively called TRU) is not now qualified for reactor use and we see little likelihood that it can be qualified before the start of the ABR. There is a world shortage of fast neutron spectrum reactor test facilities to carry out this work.

In this case the TRU fuel will have to be tested and qualified in the ABR itself. The test will first be for a single fuel assembly and later for multiple assemblies filling a large fraction of the ABR core. In addition, the TRU fuel also needs to be qualified, perhaps separately, for each of the first few recycles. This process can easily take 10-20 years before a full demonstration of multiple recycling can be done.

A key question in the GNEP program is the "conversion ratio" of the fast reactor (FR). This is the ratio of the rate that TRU is produced to the rate that it is consumed in the reactor. Current technology will support a CR of about 0.5. The CR determines the number of FRs required to handle the LWR spent fuel. At a CR of 0.5, roughly 0.6 GW of FR are required for every 1 GW of LWR. If the nuclear power program remains dominated by LWRs for the long term a lower conversion ratio would clearly be desirable. This is an R&D issue.

Present planning by DOE assumes that all of the reactors built in this century, except for those required for transmutation, are LWRs. An alternate assumption, made for example by the French, is that a shortage of natural uranium fuel will force a switch to fast breeder reactors around the year 2050. The TRU from LWRs especially the Pu, will be needed as starter fuel for these breeders of the future. An analysis is needed as to how much of the LWR TRU one really wants to destroy in this scenario.

Since the ABR is to start with uranium-plutonium fuel and the US does not desire to use a process that involves separated plutonium, a co-extraction (COEX) process has been proposed by AREVA. COEX is a modification of the PUREX process so that plutonium and the same amount of uranium are co-extracted together initially and then are co-converted to the oxide, thus avoiding the presence of either pure plutonium aqueous or

oxide fractions at any time during the process. The Japanese plan to use a similar co-conversion step in an industrial reprocessing plant after adding the desired amount of a uranium solution to the Pu stream resulting from the PUREX process. This avoids the presence of a pure Pu oxide fraction. The COEX process is only a first step. The eventual goal is to deal with TRU-based fuel.

The UREX+ process and its variants which have been developed in the U.S. program are designed to keep the TRUs together. There has been an issue of contamination with the lanthanides in the final extraction steps. Recent work has shown that control of the acidity of the final solution allows separation of the lanthanides at the 99.9% level. This is a very nice piece of work.

We note in passing that the UREX+ Engineering Scale Demonstration Facility‘s required capacity has been reviewed by a panel of experts and the appropriate size determined to be 100 tons per year.

Pyroprocessing is an electrochemical process to separate the transuranics. It does not seem applicable to LWR spent fuel because the separated uranium stream is contaminated and cannot be treated as low-level waste. Pyroprocessing is most applicable to metallic fuels from fast reactors. The process is simple, compact, and radiation resistant. It continues to be of broad interest internationally. R&D should be pursued at about today’s level.

The development and qualification of transmutation fuel is a long term process and is on the critical path for the GNEP program. This development is hampered by a shortage of test facilities as we have said often in the past. The program is beginning to make progress with what is available. Test irradiations have been made at INL’s Advanced Test Reactor and a joint US-French program will soon begin to test small samples at France’s PHENIX reactor.

A review of US experience with metal and oxide uranium-plutonium fast reactor fuels indicates that either could be qualified for the ABR. However, this is not the case for TRU-based fuels. It is important to consider the cost implications of variations in the fuel fabrication system and we urge the DOE to carry out such a study, particularly because of NNSA’s new, evolving control standards for nuclear material.

The Technological Readiness Level (TRL) methodology has been used in parts of the Department’s program. It has shown itself to very useful in identifying the extent to which a technology has progressed along the development path. It can also be used to characterize the amount of R&D that remains to be done. The TRL methodology should be more broadly used throughout the program.

In our previous report we have emphasized the importance of an effective and expanded university program. This is not only because of the R&D that can be carried out at the universities, but because of the need to develop a new generation of nuclear scientists and engineers to carry out a large expansion of the nuclear energy program.

We urge NERAC to recommend that such a program be implemented. It may be appropriate for DOE to commission a study of workforce needs in an era of greatly expanded nuclear energy.

The Office of Science has recently conducted a series of workshops to identify science and technology issues that need fundamental R&D. The Office of Science intends to put funds behind calls for programs in the targeted areas in the coming fiscal year and NE needs to, at least, match the SC funding. We regard the advanced simulation program as of particular importance since most existing reactor simulation programs are not up to modern standards.

We have also mentioned the need for a high-level, coordinating committee that would link NE, RW, NNSA, and SC. There are many pair-wise links but there is no over-arching, coordinating program. We believe such a program is important. High-level people from each of these parts of DOE should be designated to sit on this coordinating committee, and it should be chaired by NE.

**Recommendations for NERAC Action**

The recommendations below include those from the March 22, 2006 report that are still relevant.

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 include the period through the demonstration of multiple transmutation recycles including the qualification of the required fuels.

3. The availability of the necessary test facilities should be reviewed with the view toward deciding if auxiliary facilities are needed.

4. The transmutation scenarios beyond 2050 should include the possibility that breeder reactors will be the main type of reactor deployed for power production.

5. The UREX+ and pyro-processing programs should both be supported for FR fuel reprocessing.

6. A comprehensive review of the appropriate scope of University programs should be done including as a factor the need to expand nuclear science and engineering personnel.

7. A high level coordinating committee should be created chaired by NE and including RW NNSA and SC.

## 2. DEPLOYMENT SCENARIOS

The Light Water Reactor (LWR) and the Once-Through cycle is the reference nuclear scenario in the United States today. The Global Nuclear Energy Partnership (GNEP) envisions a future in which transuranic elements, generated by the LWR, are destroyed in an Advanced Burner Reactor (ABR). In this scenario, the first ABR would begin operation about 2020. Although the size of the ABR has not yet been determined, the DOE's request for Expressions of Interest (EOI) from industry specifies a power in the range from 500 to 2000 Megawatts thermal (MWt).

Commensurate with this, the GNEP is requesting Expressions of Interest (EOI) from industrial suppliers for a Consolidated Fuel Treatment Center (CFTC). The CFTF will separate transuranic elements from LWR spent fuel and fabricate the fuel for the ABR. These facilities will form the initial basis for an infrastructure leading to a nuclear system containing both LWRs and ABRs that will destroy transuranic elements and ultimately reduce the need for additional geologic repositories.

The first ABR could be fueled with either metal or oxide fuel and will demonstrate the ability to burn transuranic elements. Since there is a world shortage of facilities in which TRU based fuel (Pu+Np+Am+Cm) can be tested, it is likely that this reactor will be fueled at first with standard U-Pu MOX or metallic fuel. If the initial core in the ABR is MOX fuel, as is likely since DOE's plans call for the facility to be licensed by the NRC, the transition to TRU fuel would depend on the initial operation date of the Advanced Fuel Cycle Facility (AFCF) as this is the facility that would fabricate the initial lead TRU test assemblies. The completion of the transition will depend upon the fuel fabrication rate of the AFCF.

The GNEP program is based on multiple recycles of TRU fuel in burner reactors. The testing program to qualify these multiple recycle fuels which are different from the fuel based on the first recycle from LWR fuel has not yet been thought through. This recycled fuel is to be fabricated at the CFTC. Qualification of the TRU fuel could require as little as a partial core loading if only fuel performance is at issue. On the other hand, if the passive safety response of a core loaded with TRU fuel is a concern, then qualification may require that most of the core be loaded with TRU fuel and also that passive safety testing be completed with this core loading. To predict the duration of this effort requires that three important parameters be specified, viz. the size of the ABR, the fabrication rate of the AFCF, and the fabrication rate of the CFTC, and these are not yet available.

In the future, subsequent fast reactors could be either burner or breeder reactors as the need to burn additional transuranic elements or the need to offset a natural uranium shortage may dictate. A key design parameter that determines whether a fast reactor is primarily a burner or a breeder is the conversion ratio, or breeding ratio. These terms characterize the rate at which transuranic elements are produced divided by the rate at which they are destroyed. The term breeding ratio is generally used when the production rate is greater than the destruction rate. In this case the fast reactor will usually have both radial and axial blankets surrounding the core. The term conversion

ratio is generally used when the production rate is less than the destruction rate. To achieve this, the fast reactor will usually not have either radial or axial blankets, but only a reflector surrounding the core.

The most likely core conversion ratio for the burner reactor is in the 0.5 to 0.6 range because this is within the current technology base. Essentially all fast reactors in the world today, that use either enriched uranium or mixed uranium-plutonium oxide as a fuel, have a conversion ratio in this range when only the core of the reactor is considered and the blankets are neglected. Therefore the technological step required to obtain a burner reactor with this value for the conversion ratio is to simply replace the blankets with a reflector and to load fuel containing transuranic elements including the minor actinides.

Although lower conversion ratios, on the order of 0.25 have been explored, they are feasible largely in a reactor physics sense but present substantive engineering difficulties. For example, very low conversion ratios on the order of 0.25 require:

- Fuel enrichments on the order of 50% for which there is no fast reactor fabrication or irradiation experience, On the other hand, high fuel enrichments are not beyond the realm of consideration as the French did consider fuel enrichments as high as 45% for Super Phenix, but fabrication and irradiation were not completed due to the shutdown of the reactor;

- For smaller reactors, these high fuel enrichments produce significant reactivity swings during operating cycles, which in turn require a large number of control rods to manage this reactivity swing;

- The large number of control rods may produce a configuration in which essentially every fuel assembly is adjacent to a control rod, which in turn implies significant gradients in the neutron flux;

- This in turn implies that the fuel and therefore the coolant temperature vary from assembly to assembly and do so continuously throughout the core;

- This in turn implies significant differences in exit coolant temperatures between adjacent core locations, which in turn produces an effect called thermal striping, Thermal striping is a term used to characterize adjacent hot and cold sodium coolant steams leaving the core and impacting on the upper metal structures above the core;

- Small flow oscillations in these streams, which occur continuously in the radial and azimuthal directions, produce cyclical temperature changes in the metallic structures above the core and thereby subject them to thermal cycling and thermal fatigue.

In addition to the engineering considerations noted above, high enrichments on the order of 50% raise the Level of Attractiveness (proliferation risk) of the fuel and have the potential to lead to a fabrication facility that could be Category I, and thereby more expensive.

Nonetheless, low conversion ratios could prove important in a total nuclear system sense, in that they could reduce the total number of fast reactors required to burn the transuranic elements. If this should prove to be significant insofar as deployment scenarios are concerned, alternative core designs that do not contain these engineering impediments, or at lease avoid them to the extent possible, should be explored.

In summary, the development of nuclear power, as envisioned by the GNEP, will require burner reactors initially followed by breeder reactors at some uncertain time in the future. Core designs with conversion ratios on the order of 0.5 or 0.6 are feasible and capable of supporting the ABR and its mission, using either oxide or metal fuel. These core designs are within the technology base under development by the GNEP.

Current thinking seems to assume that LWRs will be the mainstay of the nuclear power production thorough the end of this century. In this model fast reactor deployment is done only to the extent that is required to handle the transuranics from the LWRs. There is another school of thinking where it is believed that a possible uranium shortage will require the switch to fast breeders beginning in mid-century. This scenario requires TRU as started fuel for the breeders, and so results in the need to preserve the necessary TRU starter fuel. It would be well for the DOE to examine the long term implications of this scenario.

With respect to technology development for GNEP, the Technology Readiness Level (TRL) concept and approach has been most useful for assessing: (a) the amount of research and development that has been performed to date, and (b) the amount remaining to be performed. This concept was originally developed by NASA to characterize the extent to which a concept had progressed along the development pathway. It consists of nine technological readiness levels with the lower levels characterized by basic principles identified and understood; intermediate levels characterized by component testing in a laboratory or in a relevant environment; and higher levels characterized by systems, or subsystems, tested in a prototypic environment. Some parts of the program use this approach, and when properly applied, it has identified the research and development needed as well as the basis for those needs. The Committee strongly recommends that the TRL approach be applied to all major technological areas of the GNEP.

## 3. Separations Technologies

### A. Aqueous Processing

Our report of March 2006 included a summary of the status of the aqueous processes for spent nuclear fuel processing and recycling that were described at our February 28-

March 1, 2006 meeting in Washington, DC. The described suite of UREX+ processes offered a variety of separation and partitioning options for LWR spent fuel. However, in light of the requests for EOI from organizations interested in building facilities for processing and "conditioning" of fuel for burning or recycling in reactors, it is worthwhile to review the fundamental differences between UREX+ and the traditional PUREX process that was operated at Savannah River and elsewhere. In the original PUREX process both the uranium (U) and plutonium (Pu) are extracted into the organic phase in the first step leaving most of the fission product activities in the aqueous phase. Plutonium as Pu (III) is then removed by contact with an aqueous phase containing a reducing agent and the U is then removed from the TBP with dilute acid. Pu and U can be subsequently cleaned to the desired purity and the U stored or disposed as LLW if desired.

Currently, in variations of PUREX processes used and planned for in Europe and Japan, the Pu is stripped from the initial extractant containing both U and Pu and used to fabricate MOX fuel. Excess U then goes to storage or is recycled and the higher actinides and fission products (FP) are vitrified and sent to a suitable repository.

In the AREVA version of the PUREX process, the Pu is removed from the U after the original extraction, converted to oxide and used in MOX fuel fabrication. Np, Am, Cm, and other remaining fission products (including lanthanides (Lns)) are vitrified and incorporated in the HLW form.

In a planned Japanese version of the PUREX process, an equal amount of U solution is added to the aqueous Pu stream from the PUREX process. Then the U and Pu are co-converted to prepare MOX fuel directly without ever producing a pure Pu oxide fraction at any time during the entire process. In the COEX process as proposed by AREVA, a mixture of equal amounts of U and Pu is extracted initially and would be sent directly to MOX fuel fabrication without ever producing pure liquid or oxide Pu fractions

In the COEX process as proposed by AREVA, a mixture of equal amounts of U and Pu would be sent directly to MOX fuel fabrication without ever producing a pure Pu fraction. Again, the Np, Am, Cm, and remaining fission products (including Lns) go to the HLW product.

In UREX, the U is removed in the initial extraction step and purified to the extent that it can be treated as low-level (Class B or C) waste. Thus, it is not necessary to send it to a repository which should greatly reduce the mass and volume of high level waste (HLW) that must be sent to a geological repository. It can be stored or disposed as LLW.

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; technetium (Tc) is removed during the UREX process and incorporated in the HLW form destined for the repository. Cesium (Cs) and strontium (Sr) fractions are removed for subsequent storage or treatment.

In UREX+1, the TRU plus any potential higher actinides; 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, a further step is added and the TRU fraction is separated from the Lns. This process was proposed for LWR spent fuel treatment in the GNEP program.

A laboratory scale hot test on actual spent LWR fuel of the UREX+1a option using the TALSPEAK process to remove the Lns from the TRU stream so it could subsequently be incorporated in fuel to be used for recycle was described at our last meeting. Although 99.9% of the TRUs were recovered, a considerable quantity of the Lns remained with the TRU stream and it appeared that additional research was necessary to sufficiently reduce the Ln content. (It was noted that final separation of the Lns could be deferred until just before fuel fabrication, presumable making it more “self-protecting” thereby increasing proliferation resistance.) A pyrochemical separation process followed by metal fuel fabrication might also be envisioned at this juncture since the large amount of U would already have been removed and the initial dissolution of the oxide fuel has already been performed.

During the current meeting the results of recent research to improve the performance of the TALSPEAK process were described. This is based on a solvent extraction with hydrogen di(2-ethylhexyl) orthophosphoric acid, HDEHP. Detailed studies of the variations in distribution ratios for the individual Lns as a function of pH and contact times were performed. It was shown that a pH could be selected which gave high extraction yields with reasonable contact times for all of the relevant Lns. A lactate buffer was used to control the pH within the limits required to accomplish this group extraction with high decontamination factors. The TALSPEAK Demonstration Results-FY-06 (250 g/L U with added high burnup fuel) were summarized and showed that the TRU stream (raffinate) contains >99.99% of the TRUs and <0.05% of the Eu and total Lns. The Ln fission product fraction which contains <0.01 of the Pu, Np, and Am, and <0.001 of the Cm can be incorporated in the high level waste or otherwise stored as desired.

In the AREVA COEX and PUREX processes described briefly above, the Pu or Pu/U stream may need to be further purified from the Lns, and the Lns may also have to be separated from the minor actinides (MA) before possible subsequent transmutation steps. This separation could be done by TALSPEAK or by the SAMEX-DIANEX process used by the CEA in France.

In summary, it appears that if a TRU stream or MA product free of Ln fission products is advantageous for preparing recycle fuel for a burner reactor it can be added to the process as required. Provision for adding such additional processing steps if necessary should be considered in the original designs of proposed processing plants.

### B. Pyrochemical Processing

A review of the current status of pyrochemical processes was presented. The work on pyrochemical processing has focused on treatment of metal or fast reactor fuel rather than LWR fuel. Recoveries of greater than 99.7 % were reported in processing metallic fuels. However, it is much more difficult to get high recoveries from oxide fuels and it appears that pyro-methods are most applicable to metal fuels or processing after an aqueous head end procedure as discussed above, while the aqueous methods are best for the oxide fuels. The resistance to radiation effects and potential compactness may make it advantageous to co-locate pyroprocessing facilities with proposed ABRs for metallic fuels. Recent data indicate that it may be possible to perform actinide/lanthanide separations and this will be investigated.

Progress in developing alternative crucible materials for the cathode processor for U was reported and appears promising. Some oxide reduction tests with BR-3 spent fuel (LWR) fuel were discussed and tests with irradiated MOX fuel will be performed in FY-07.

There is considerable international interest in pyroprocessing as evidenced by the INL hosted conference held in August 2006 that included papers by attendees from South Korea Japan, France, UK, India, and Russia.

## 4. Transmutation Fuel Development Program:

Efforts to fabricate, characterize, and evaluate the performance of candidate transmutation fuels continue. Currently, the program is considering both metal and oxide candidate first generation fuels and nitride and dispersion candidate fuels for later generations. Note that for the long term the program is only considering transmutation fuels that contain multiple elements (e.g., U, Pu, Np, Am, and Cm).

Fuels research is addressing several key issues: the need to quantify fuel material properties; the impact of lanthanide carryover after separation; the impact of helium production from Am during irradiation; remote fabrication processes; and the need to qualify the fuel for a variable range of compositions and burnups. Evaluation of these candidate fuels requires irradiation testing in a fast neutron flux. However, there are limited facilities available in the world for such testing. Currently, the program plans to perform irradiations using available domestic facilities, such as INL's Advanced Test Reactor (ATR) thermal reactor and transient testing in SNL's Annular Core Research Reactor (ACRR) of smaller-sized samples. In addition, it is planned to utilize foreign fast reactors, such as PHENIX, JOYO, MONJU, or BOR60. Note that PHENIX is scheduled to close in 2009. Russia is rumored to be considering closing BOR60 around 2010. Joyo is to close soon. The availability of FR test reactors may become a serious limitation on progress until the ABR itself is ready.

If available, the program will also utilize proposed fast irradiation facilities, such as the Materials Test Station proposed by LANL or the Fast Flux Gas Test Loop proposed by

INL (although there are limitations associated with the applicability of either of these facilities, even if they were to be constructed). Last, the program plans to conduct irradiation tests in INL's TREAT reactor, which is required for transient testing of full-sized fuel pins. Note that the unavailability of foreign test reactors or the inability to restart the TREAT reactor would hinder the ability to complete the planned transmutation development and evaluation efforts.

Since the last time that this subcommittee reviewed this program, the fuels development and evaluation effort has focused on the following tasks:

- Fabrication of metal and nitride fuel rodlets, so they could be shipped to France, where they will be irradiated in Phénix with four oxide samples produced by CEA.

- Post-irradiation examinations of LWR transmutation fuels irradiated in the ATR.

- Fuel Cladding Chemical Interaction (FCCI) studies on metal fuels that were clad with AIM-1 cladding (AIM-1 is the material used for Phénix reactor fuel. Test results indicate that iron in AIM-1 cladding migrates into zirconium metal fuel, allowing an iron/zirconium eutectic to form that melts at lower temperatures).

- Comprehensive review of the U.S. metal and oxide fast reactor fuel experience.

Results from the latter task suggest that there is adequate US experience with metal or oxide fuel to allow either of these fuels to be qualified as driver fuel for the ABR. At the time of the Subcommittee review meeting, the program assumed that the driver fuel type will be selected and qualified by the vendor (including any interactions required for NRC licensing).

Key issues to be addressed by the program in the upcoming year include:

- Quantifying the allowable amount of Lns that can remain in high burnup fuel without leading to cladding embrittlement. Note that results from this quantification will impact the separation efficiencies specified for lanthanides.

- Completion of ATR irradiations of metal and nitride transmutation fuels. Post-Irradiation Examination (PIE) to characterize the effect of irradiation on fuel thermal and mechanical properties; fission gas formation, behavior and releases; materials dimensional stability due to restructuring, densification, growth, creep and swelling; species diffusion; fuel-clad chemical interactions; and phase diagram development.

- An updated version of the Transmutation Fuels Handbook with associated analytical support to allow available metal and oxide fuel data to be incorporated into this handbook.

- Definition of candidate remote fabrication design concepts and required research to determine the viability of various concepts. Proliferation resistant fuels containing transuranic elements require that they be fabricated remotely in a hot cell. Some of the requirements for fabricating the transuranic fuels must be tested and optimized at bench-scale before implementation in a larger engineering-scale at AFCF.

With respect to the latter task, the subcommittee recommends that a comprehensive analysis be completed to assess the impact of including TRUs in the transmutation fuel. The analyses should consider the impact on fuel fabrication costs and system complexity, proliferation risk (or costs to mitigate such risks), and ultimate waste disposal costs for recycled fuel. The Subcommittee notes that this evaluation will require that DOE-NE continue to work with NNSA to fully understand the impact of the new graded safeguards approach that NNSA is considering.

## 5. OTHER ISSUES

### A. University Programs

The GNEP program has introduced new directions in the U.S. nuclear energy program. It moves the development of the technology for reprocessing and transmutation of spent fuel high up on the DOE priority list. The low conversion ratio reactors required to burn transuranic based fuel have never been built before. In addition, the GNEP program will require advanced materials, new directions in chemistry, more precise cross sections from the nuclear physicists, advanced computer programs for modern simulation tools, etc. Since nuclear power has been out of favor until recently, there is a shortage of younger scientists required to carry this evolving program for the long term. Universities and the national laboratories both have roles to play. University programs in many areas of science and engineering are important to train students while the labs and the universities are both important in training the post-docs that will become leaders the program in the future. It may be appropriate for DOE to commission a study of workforce readiness considering the planned large expansion of nuclear energy.

Our report of 22 March 2006 called attention to the dangers of cutbacks that were planned at that time in the university programs funded by NE. The pace of the program has speeded up since then, and we again urge NERAC to advocate the development of a long-range plan to fund universities' programs on a scale that will make a difference.

### B. Office of Science

We applaud the recent series of workshops that the Office of Science (SC) has held to identify the science and technology issues that need fundamental R&D. The Office of Science intends to put funds behind calls for proposals in targeted areas in the coming fiscal year. NE needs to, at the very least, match the SC funding.

An area of particular importance is simulation. Most, perhaps all, of the reactor design codes are old, heuristic, one-dimensional, and constituted so they cannot work efficiently on today's highly parallel big computers. A teraflop of computing power these days is not very expensive but efficient use of this compute power lies in having large numbers of processors working together on a problem and programs have to be designed to use these systems. SC and NE plan to invest in this important effort and here both the universities and the laboratories can contribute.

### C. DOE Coordination

Also in our 22 March 2006 report we urged formation of a high-level coordinating committee that would link NE, RW, NNSA, and SC. What we see today is pair-wise links between NE and each of the other three. We do not see, as yet, the integrated oversight that this program requires. For example, RW's requirements affect thermal properties, waste forms, and long-term storage needs. NNSA's non-proliferation mission leads them place limit on fuel processes and outputs. SC's R&D is targeted at the needs on NE but those needs are affected by the needs of other parts of the DOE. An understanding of the issues critical to each of the parts of the nuclear energy program has the potential to simplify the system. We believe it is even more important in the new two-track program that NERAC should recommend the establishment of a coordinating committee at a high level to be chaired by NE.