Report of

ADVANCED NUCLEAR TRANSFORMATION TECHNOLOGY SUBCOMMITTEE

of the

NUCLEAR ENERGY ADVISORY COMMITTEE

06 April 2009

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1. Introduction and Summary

The ANTT Subcommittee of NEAC had its first meeting since the change of administration on February 18-19, 2009 in Washington. At the direction of Secretary of Energy Chu, the Advanced Fuel Cycle Initiative (AFCI) is in the midst of a major change in direction from one aimed at an early deployment of reprocessing and waste treatment technology, to one focused on a more measured pace emphasizing science-based technology development with later deployment as needed. The new program is a work in progress and will not be fully developed until more of the DOE leadership has been nominated and confirmed by the Senate. This meeting gave the subcommittee an opportunity to comment on the evolution of the new program.

We have commented many times before on the benefits to all of DOE's nuclear programs of closer coupling of Nuclear Energy (NE) with the National Nuclear Security Administration (NNSA), the Office of Science (SC), the Office of Civilian Radioactive Waste Management (RW), and the Office of Environmental Management (EM). We are pleased to see that NE-NNSA cooperation on advanced safeguards is happening. The goal is to build in real-time monitoring of all material flows in any reprocessing facility or actinide fuel fabrication facility.

Discussions between NE and SC have been happening at the staff level. There are measurements of various fission and capture cross-sections that need improvement, and the dynamics of many chemical processes are not well enough known. The new NE program on simulations would benefit from input from SC in areas of scientific interest to the SC community.

A serious discussion between NE and RW does not seem to have begun. There has been an understandable reluctance on the part of RW to do anything that might seem to lessen commitment of the government to the Yucca Mountain repository, but that situation is now changed. Secretary Chu has announced that alternative waste disposal, recycling, and storage options will be examined. Since strategies, site conditions, and waste forms are coupled, there is a need for better communications here. It is to be hoped that such discussions will begin in the near future.

The committee was briefed on all of the main elements of the program (the Appendix gives the meeting agenda). We have detailed comments on some parts of the program and they are given in subsequent sections of this report. Here we summarize the issues and our recommendations, noting again that the program is evolving and we expect there will changes over the coming months. In particular the new science-based orientation gives an opportunity to include some high-risk/high payoff elements in the program. However, as these efforts proceed, the subcommittee recommends that campaigns prioritize options in a manner that considers available resources and ensures that steady progress is made toward possible long term deployment.

NEAC itself in 2008 conducted a review of nuclear energy related facilities at the national laboratories and concluded that many were in poor condition. We recommend that the AFCI program review its needs in light of the new program orientation. It may be necessary to fund upgrades or replacement of obsolete facilities particularly those that handle radioactive materials. We encourage the use of some of these facilities by university research programs that might benefit from access to them.

There are two major facilities that are not now available in the U.S. and will be needed in the program; a fast neutron source and a transient fuel testing facility. There is an opportunity for international collaboration on funding and potential use of foreign facilities and NE should explore this option as well as developing purely U.S. facilities.

The AFCI program has been given responsibility for a large part of the U.S. GEN IV sodium fast spectrum reactor program in FY 2009. There is a natural relationship between future fast reactors for energy and a fuel cycle that uses fast reactors to simplify the waste disposal problem. However, the AFCI responsibilities for the program and its funding for the longer term do need clarification.

Accelerator driven systems (ADS) for transmutation were the original focus of transmutation studies. In ADS, a high power proton accelerator drives a spallation neutron source which in turn is coupled to a subcritical reactor. It was intended to transmute plutonium as well as all of the minor actinides. To be economical the system had to produce electricity for the power grid, but the frequency of accelerator trips made that impractical and the approach was abandoned. ADS R&D has continued elsewhere and we think it is worth revisiting here in a more limited role where the sale of electricity is not necessary.

Actinide recycle in a fast reactor is complicated by the need to include the minor actinides in the fuel, which requires that radioactive fuel be fabricated and qualified. Since the minor actinides make up a much smaller part of the spent fuel than plutonium, it may be that an economical system for transmutation of americium, curium, and neptunium can be done with ADS without requiring the income that comes with putting large amounts of electricity on the power grid. We recommend that a paper systems study be carried out to see if this might be a viable option.

Fuels and materials are an area where the time allowed by the new program orientation may be beneficial. There are new materials that show promise in a radiation environment, and there should be a part of the program that assesses their potential.

Within the NE budget, 20% of the 2009 NE R&D funds are to go toward university-based R&D. We applaud this move. To carry out the mandate, NE has crafted a unique proposal review system administered by the Center for Advanced Energy Studies (CAES). CAES is a partnership of industry, Idaho National Laboratory and the three Idaho public universities (University of Idaho, Boise State University, and Idaho State University). We know of no other peer review system like it and recommend that NE have its performance reviewed in about a year to see if it is functioning as it should. There is a potential for conflict of interest here.

We note also that the university fellowship program supported by NE has been moved to the CAES program. We are glad to see the recent announcement of funds for fellowships and scholarships, considering the need for more young people to move into the nuclear area. The administration of this program too should be evaluated in about a year.

We requested and received a briefing on uranium availability because the move toward fast spectrum reactors is driven by both their potential for simplifying waste disposal and by their potential to breed nuclear fuel from U-238 if the supply of U-235 begins to get tight. According to the "Red Book" on uranium availability there is thought to be about 16 million tonnes of natural uranium available at a "reasonable" price. There are 435 power reactors operating in the world today and a large increase in that number might strain the uranium supply. A one gigawatt-electric reactor needs about 200 tonnes of natural uranium per year. Over their 60 year lifetime 1000 1-GWe reactors will need 12 million tonnes of natural uranium, getting uncomfortably close to the available supply. Of course there is much more uranium and the issue is its extraction at a reasonable cost. The largest reservoir is seawater which has a low concentration of uranium but a huge amount of it. If such uranium can be extracted at a reasonable cost, the need for fast spectrum breeder reactors is delayed and fast spectrum systems would then be needed mainly for fuel treatment. The leader in R&D on extracting uranium from seawater is Japan. We suggest that NE review the situation to see if the U.S. should get involved.

Summary of Recommendations

- Improve the coupling of the NE program to RW, EM, and SC as well as NNSA. Now that new repository sites are being considered, a close collaboration with RW is particularly important.
- Include some high-risk, high-payoff elements in the campaigns.
- Review facility requirements in the light of the new program direction. Some facilities should be designated as user facilities where university programs could have access.
- Explore the potential of an international collaboration to develop and use a fast neutron source and a transient test facility, both of which will eventually be needed for the program.

- Clarify the AFCI responsibilities for sodium fast spectrum GEN IV reactor development.
- Reevaluate accelerator driven systems for minor actinide transmutation.
- Assess the potential of new materials for fuels, reprocessing, and reactors as an element of the new science based program.
- Evaluate the effectiveness of the CAES program in about one year.
- Investigate the potential of extracting uranium from sea water, perhaps in collaboration with Japan

2. Facility Needs

The subcommittee applauds the initial efforts by the program to refocus the program as a long-term research and development program, reconsidering options that were initially eliminated due to schedule constraints in the previous early-deployment oriented program. As these efforts proceed, the subcommittee recommends that campaigns include some high-risk/high-payoff research efforts that could result in dramatic improvements in closing the fuel cycle.

In light of the new science-based AFCI program, the subcommittee recommends that there be a comprehensive review of facility requirements to carry out its revised mission. Members of this ANTT subcommittee participated in the 2008 NEAC comprehensive review of the state of R&D facilities in the nuclear complex. The NEAC report indicated that many of the existing facilities at DOE laboratories are in poor shape and need upgrades and even replacement in some cases. If the AFCI program is to succeed in its new mission, certain facilities will be required, and it is not clear that what is needed exists in good working order. It is recommended that the facility status be reassessed to determine what additional upgrades and facilities are needed to support a science-based program.

Based on our understanding of the new directions of the program, the subcommittee believes that in addition to the standard R&D facilities for fuel development, handling, and analysis, two additional facilities are needed to support US AFC efforts: a facility capable of producing a prototypic fast neutron spectrum and a transient fuel testing facility. It should be noted that international fuel cycle and fast reactor research programs could also benefit from these facilities, and it may be possible to arrange an international collaboration to fund and operate major facilities that do not now exist or exist outside the U.S. The Office of Science has such collaborations on the LHC accelerator at the CERN laboratory in Europe, and on the ITER fusion project.

For the neutron source, in the long run a fast test-reactor would be best suited to meet fuel development and materials research testing needs in the U.S. and abroad. The US no longer has an operating fast test reactor, and the future of foreign test reactors that have historically been available for international research is uncertain. The French PHENIX reactor will be permanently shutdown this year. Japanese efforts to restart the JOYO test reactor are financially constrained as they focus on restarting the MONJU reactor, a commercial reactor that will not available for research. Although fast test reactors exist or are under construction in several other countries (e.g., Russia, India, and China), experience indicates that these facilities would be extremely difficult to access for the required AFC testing. Other options, such as the Materials Test Station at Los Alamos and the fast test loops in thermal test reactors, such as ORNL's HFIR and INL's ATR, were also discussed. These could be very useful in the early stages of the program, but their spectra are not ideal for fuel testing and in the case of the MTS, there is concern about NNSA being willing to refurbish this older facility (a prerequisite for this facility to be usable).

A transient test facility will also be needed to evaluate the performance of new fuels for AFC and other DOE programs. The TREAT facility (Transient REActor Test facility) appears to be the least expensive option for meeting these needs. If TREAT were restarted, it would also give the US a unique facility that could be used by foreign organizations as part of international research.

As it adds to, modifies, or rehabilitates its facilities, NE should strive to make these facilities, hot-cells for example, available to the broader R&D community, especially the universities. Other parts of the DOE, especially in the Office of Science, designate some facilities as User Facilities where groups from outside the laboratory system can apply for a share of use time. This kind of program could make the university programs even more effective.

3. Reactor Campaign

In the international GEN IV program, the US is involved in both the High Temperature Gas Reactor and the Sodium-cooled Fast Reactor (SFR). Some responsibility for the SFR program has now been placed in the ACFI program office, a natural evolution since a fast spectrum reactor is necessary to close the fuel cycle. Among the fast reactor systems, the technical basis for the SFR is currently the most comprehensive based on experience gained nationally and internationally from operating research, demonstration, and commercial-size reactors. The technological basis gained from these reactors includes key elements of the overall reactor design (pool- or loop-type), large-core design, fuel types (metal, oxide, carbide, nitride), safety, and fuel cycling.

Valuable new options for SFR should be studied in order to reduce the dominant capital cost and to improve the safety of these reactors. Among others, the subcommittee recommends that the main issues to be addressed should include: design simplification (e.g., suppression of the intermediate sodium circuit, replacement of the water-cycle by innovative high-efficiency cycles), increase of Na temperature for better efficiency, improvement of in-service inspection and repair, mitigation of the hypothetical re-criticality severe accident, use of innovative advanced materials for structure and cladding such as Oxide-Dispersion-Strengthened (ODS) ferritic steels, and use of innovative fuel allowing grouped-actinide separation for minimizing the high-level waste production and enhancing proliferation resistance within a closed fuel cycle.

None of these issues appear unsolvable, especially if the program is refocused as a long-term (15+ years) more fundamental science-based R&D program.

The subcommittee was briefed on the Gas-cooled Fast Reactor (GFR), and the Lead-cooled Fast Reactor (LFR), both of which are of interest for the future though not major parts of the US GEN IV program. There are some different issues in fuel development for each of the fast systems. For now, the AFCI program is focusing on SFR fuels which seems appropriate. However, the emphasis to be placed on closing the fuel cycle and GEN IV energy production needs clarification. An SFR needs minor actinide bearing fuels if it is to be used to close the fuel cycle, while simple power production needs only plutonium-based fuel.

At the very beginnings of the work on transmutation to simplify the waste disposal problem, accelerator driven systems (ADS) were the focus. These are high power proton accelerators diving spallation targets coupled to subcritical reactor facilities. They were found to be impractical for the entire job of transmuting all of the actinides. To be affordable, the ADS had to produce electricity to be fed to the power grid, but the stability of accelerators and the frequency of trips make that impractical. ADS may be practical if their use is limited to the minor actinides which are a small percentage of the totality of long-lived components in spent fuel. If, for example, the minor actinide output of ten or more power reactors can be handled by one ADS, the economics change and it would not be necessary to sell electricity. The plutonium could then be used in fast reactors, and the fuel cycle would be closed. It is worth a look by the systems analysis group to see if this is worth pursuing further.

4. Fuels and Materials Irradiation Testing

Irradiation testing of fuels and materials should focus on areas where technological breakthroughs are possible and where it is possible to establish a fundamental scientific understanding of the performance of fuel, targets, and materials. The program should not spend scarce resources attempting to perform prototypic testing in areas previously explored and where irradiation test data already exists, but rather should perform testing of fuel features in promising new areas.

Examples of areas with promise that should be investigated are the effect of target materials on deep-burn actinide destruction, particularly as it may relate to the efficiency or effectiveness of selected target materials to burn selected, or a selected suite of, actinides. An example of materials testing is exploring the ability of new materials to operate at high temperatures and a very high fluence, or displacements per atom. One example of such a material is Oxide Dispersion Strengthened (ODS) cladding which could provide a technological breakthrough allowing operation of a Liquid Metal Reactor (LMR) at very high Carnot efficiencies. Irradiation testing of coupons and pressured capsule (indicating material performance under biaxial stress) at high temperatures and to a high fluence are examples where a fundamental scientific understanding of material behavior is possible. In addition, the possibility of improving fundamental understanding using new analytical modeling methods combined with coupon and capsule data should not be neglected. Other examples are possible, but the ones above provide an indication of program direction that could extend the scientific basis for a dramatically improved LMR, prior to any subsequent deployment decision.

5. Separation and Waste Forms Campaign

Over the past 6 years several aqueous separation technologies have been developed and tested at laboratory-scale (the various UREX+ processes) using spent fuel. Flow sheets were developed and tested for group actinide separations and U/Pu separation followed by minor actinide separation as well as a variety of other options. Electrochemical processing of oxide fuels is also being investigated. Current investigations are in progress on oxide reduction and scale-up and studies of various cathode designs to improve actinide recovery and product recovery, and processing for salt recovery and EBR-II spent fuel treatment. The waste and separations campaigns were combined in FY-09 with an emphasis on near-term heterogeneous recycle and process simplification to reduce cost and number of waste forms. There was some research on off-gas capture in initial dissolution steps and some additional research on iodine and other waste forms.

Secretary Chu's change in emphasis to long-term, science-based research rather than near-term deployment or demonstration will present many opportunities as well as challenges. As near-term activities ramp down, there should be time and resources to carefully document and assess previous results from both aqueous and electrochemical processing. A science-based approach can be initiated to gain a fundamental understanding of the underlying separations chemistry, including thermodynamics and kinetics, as well as to understand some of the special phenomena involved in the engineering processes. Comparison with existing simulations, and theories, development of new models, and even some small-scale laboratory experiments may be required.

In addition, innovative high-risk options should be explored; but with limited resources these options must be chosen very carefully. The resources should be concentrated on the steps where a technological breakthrough would make the most difference. Both aqueous and electrochemical processing could be evaluated to determine where technological breakthroughs would have the most impact under two different scenarios: 1) Recycle in LWRS only, and 2) Recycle with a breeder-burner reactor. Effects of aqueous and electrochemical processing on different fuel types may also need to be investigated

As suggested, utilization of the AFCI university research program to help investigate innovative new technologies is important. If any appear to be promising, collaborations with the appropriate national laboratories should be encouraged. (*For example, there are several strong university programs investigating behaviors in a variety of geologic environments of waste forms synthesized to be similar to stable natural minerals or homologues.)*

The efforts described to initiate a multi-lab team to focus on a common "grand challenge" should certainly be encouraged and perhaps expanded, assuming the midyear review is positive. The proposed defining of safety and regulatory requirements for a future fuel recycle facility are laudable as is working with regulators to develop appropriate risk-based regulations.

The most difficult challenge in the whole area of Separations, Waste Form, and Engineering Development is to remain focused and not spread limited resources so thinly that nothing is accomplished. A continuing, very careful review of priorities to ascertain which directions appear most promising will certainly be required!

6. University Programs

We continue to be concerned about the health of university programs in nuclear science and engineering. DOE has directed that fully 20% of the AFCI budget be directed to university programs. Most R&D gives incremental improvements, but some is revolutionary and may not be in the directions now pursued by the laboratories.

The university program is now administered by the Center for Advanced Energy Studies (CAES), which is a partnership comprised of private industry; Idaho National Laboratory; and the three Idaho public universities, Idaho State, Boise State and the University of Idaho. Through the CAES management, DOE-NE currently is executing Phase II of its 2009 Nuclear Energy University Programs (NEUP) R&D solicitation process. In the recently completed Phase I, approximately 400 pre-applications were submitted, evaluated, and selections made for submittal of full proposals in response to the Phase II Request for Proposals. Support in the range of $13 - 50 million is expected to be available in FY 2009 for new R&D awards under this RFP.

The CAES system is unusual for peer review of government funded programs. The Subcommittee did not receive sufficient information to comment on the effectiveness of the organization and administration of the program, but recommends that DOE have the program evaluated after a year. There is a potential for serious conflict of interest in this administrative arrangement.

Responsibility for the fellowship program has also been transferred to CAES. We are glad to learn that an announcement of funds availability has been made (April 2009, after our meeting).. The shortage of young people entering critical areas, nuclear chemistry for example, was elucidated in a recent report from the American Physical Society[1]. Funding research in universities allows faculty and students to play an important role in pursuing new research directions, and fellowships in nuclear science and engineering form an indispensable component in attracting and educating the next generation of the nuclear workforce. Here, too, the method of award is unusual and this program's administration should also be evaluated after one year.

In general, there are many opportunities to do fundamental nuclear science research in the AFCI Program. Examples include such things as measurements of actinide fission and neutron capture cross sections at appropriate energies where some cross sections remaining to be measured require innovative techniques and are fertile ground for Ph.D. theses, and development of improved fundamental theoretical physics models that better inform experimentalists and system designers when predicting the behavior of one actinide based upon what is known about others. A better understanding of the fundamental nuclear physics and nuclear chemistry would help to close the loop of theory-experimentation-simulation-system design-theory. A new Under-Secretary for Science should be confirmed soon, and DOE-Nuclear Energy should enlist the resources of DOE-Office of Science to assist it in its mission.

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[1] *Readiness of the U.S. Nuclear Workforce for 21st Century Challenges*, A Report from the APS Panel on Public Affairs, Committee on Energy and Environment, see http://www.aps.org/policy/reports/popa-reports/index.cfm.

Appendix

Agenda

ANTT Meeting

Washington, DC

INL/ANL Conference Room, 6th floor L'Enfant Plaza North

February 18-19, 2009

February 18

8:30 – 8:45	Welcome	Shane Johnson, DOE
8:45 – 9:15	DOE AFCI Program Status & Strategy	Paul Lisowski, DOE
9:15– 9:30	GNEP Programmatic EIS Status	Buzz Savage, DOE
9:30 – 10:30	Fuel Cycle Options and Current Status	Phillip Finck (INL)
10:30 – 10:45	Break	
10:45 – 12:00	Transmutation Fuels: Status and Path Forward	Kemal Pasamehmetoglu (INL)
12:00 – 1:00	Lunch	
1:00 – 2:00	Safeguards: Status and Path Forward	Mike Miller (LANL)
2:00 – 3:00	Fast Reactor: Status and Path Forward	Bob Hill (ANL)
3:00 – 3:15	Break	
3:15 – 4:15	Separations and Waste Forms: Status and Path Forward	Terry Todd (INL)
4:15 – 5:00	Advanced Modeling & Simulation	Alex Larzelere, DOE

6:00	Dinner	

February 19

8:30 – 9:30	Status of Systems Analysis and Path Forward	Kathy McCarthy (INL)
9:30 – 10:15	Uranium Resource Discussion	Eric Schneider (UT Austin)
10:15 – 10:30	Break	
10:30 – 11:30	Answers to specific ANTT Questions	Roald Wigeland(INL)
		Kathy McCarthy (INL)
11:30 – 12:00	General Discussion	All
12:00 – 1:00	Lunch	
1:00 – 3:00	Subcommittee Executive Session	ANTT, DOE