23 September 2008

NEAC Technical Subcommittee

I Introduction

The technical subcommittee had two charges:
(1) Review the facilities available for nuclear energy programs starting from reports produced for DOE-NE.
(2) Recommend R&D programs to match the scenarios developed by the policy subcommittee.
This report does both and also identifies some issues relating to broader U.S. interests relating to nuclear matters.

II. Facilities Review

The subcommittee reviewed the following references:

1. *Nuclear Energy for the Future: Required Research and Development (R&D) Capabilities – An Industry Perspective* (September 2008)- An effort led by Battelle documenting input from over 30 industry and university representatives on the capabilities and types of facilities needed to further research and development in support of the domestic nuclear power industry over the next 20 years.

2. *Required Assets for a Nuclear Energy Applied R&D Program* (September 2008)- An Idaho National Laboratory (INL)-led effort documenting current assets in the US and overseas that could be used to meet the facilities and capabilities identified in the Reference 1 Battelle study. In addition to identifying various assets, the INL study provides information about the adequacy, accessibility, and availability of these assets to meet anticipated nuclear R&D requirements.

3. *Executive Recommendations for Nuclear R&D Capabilities* (July 28, 2008)- This Battelle-led effort documents recommendations developed by a team of executives from industry, national laboratories, and universities and the basis for these recommendations.

4. *A Sustainable Energy Future: The Essential Role of Nuclear Energy* (August 2008)- A position paper from the Directors of Department of Energy (DOE) national laboratories recommending near-term and long-term actions for developing the nuclear energy strategy in the U.S.

5. *Evaluation of Existing Department of Energy (DOE) Facilities to Support the Advanced Fuel Cycle Facility (AFCF) Mission* (August 2008)– A report issued by the GNEP program evaluating the capabilities and economics associated with using existing DOE hot cells for conducting an AFCF engineering-scale operation. Reference 2 incorporates input from various programs about facilities

needs and adequacy for various missions. Reference 5 estimates the costs for renovating facilities for this program.

The DOE-NE effort is not yet complete. DOE-NE intends to issue a report with a priority list of funding recommendations with respect to maintaining, modifying, and developing facilities required to support the R&D needed for nuclear energy to remain a viable option in the United States. DOE-NE indicated that the Office of Science document, "Facilities for the Future of Science: A Twenty Year Outlook," should be considered as a model for this DOE-NE effort.

This subcommittee believes that this effort is much needed and very ambitious (with respect to schedule and budget). The subcommittee recognizes that schedule limitations precluded obtaining input from some owners of applicable facilities. The subcommittee recommends that efforts be continued to include additional university, industry, and foreign facilities of interest. The subcommittee also recommends that this effort be expanded to recognize the impact of other DOE missions on these facilities and the need for DOE-NE facilities to support missions outside of DOE-NE, including NNSA, NR, SC, and RW. Although facility funding levels change each year, some indication of historical and current facility customers and required operating budgets should be examined as DOE-NE prioritizes facility funding allocations in their strategic plan.

All five references provide a list of recommendations for DOE-NE nuclear energy research (there are other areas of importance that are mentioned later). While there are some differences in the recommendations in the above five references, the prioritized goals listed in Reference 3 encompass the major components of the recommendations of all five.

- Further improve operations and extend the lifetime of the fleet of current and future light water reactors.
- Assure a well-qualified and trained workforce.
- Development and demonstration of Generation IV reactors, such as the Next Generation Nuclear Plant (NGNP), to extend the applications of nuclear energy.
- Upgrade domestic facilities and expand the collaborative use of international facilities for activities required to create a sustainable fuel cycle.
- Combine recognized fast reactor core competencies in critical areas with a robust program of international collaboration.
- Develop a modeling and simulation capability.
- Establish the Strategic Nuclear Energy Capability Initiative to assure that the proper resources are allocated to allow meeting the above objectives.

The majority of the subcommittee concurs with the above general recommendations as high priority capabilities for DOE-NE R&D investment (although some members disagreed with the prioritization of some items). The subcommittee has clarifications for several of these recommendations. For example, as discussed in Section IV of this report, the committee recommends strongly that the modeling and simulation capability be established adhering closely to the guidance stated in Reference 3 and the subcommittee's earlier preliminary report (initially developing the modeling and simulation capability by using existing capabilities procured by the Office of Science or NNSA and by demonstrating its worth with a pilot program that illustrates the economic benefit of this effort).

Although Reference 2 is still a draft, facility status information in this document clearly shows that many high priority facilities require moderate to significant investment before they could provide the capabilities needed by DOE-NE. (Reference 2 assessments of facility adequacy and costs to prepare for various missions were qualitative. As assessments similar to that documented in Reference 5 are conducted, required investments should be quantified). The subcommittee agrees that, independent of what it is called, a strategic initiative is needed to ensure that the required facilities are available and ready to support these missions (especially those identified for multiple DOE-NE missions). As noted in Reference 3, an integrated, time-phased and user-driven approach should be used for allocating funding for this initiative.

The subcommittee agrees on the importance of emphasizing international collaboration, especially with respect to longer-term, high cost R&D goals, such as in developing recycling and fast reactor dapabilities. As noted in Section VI of this paper, significant capabilities in these areas currently exist in other countries (e.g., such as the operating JOYO reactor in Japan and reprocessing capabilities in France and the United Kingdom). As the U.S. strives to regain its capabilities in these areas, the financial benefits associated with such collaborations should be explored to the fullest extent possible.

III. R&D Facilities

Reference 2 above assessed the state of all the significant facilities that are required to carry out a world class program. The assessment covered facilities needed for LWR development, irradiated fuel separation, advanced fuel development, and advanced reactor R&D.

A depressing story was revealed of decayed or decaying facilities that in most cases are not suited for their intended uses without significant and often expensive refurbishments. Although several superior facilities were identified, even these facilities were not as good as needed for conducting the missions assigned to the U.S.nuclear energy program. Neither DOE nor Congress has been willing to supply the necessary funds to maintain the R&D complex in good working condition.

The DOE’s nuclear facility needs have to be ultimately determined by the mission and the budget. The policy subcommittee has laid out three options for the expansion of nuclear energy in the U.S. ranging from no new power plants to many new plants between now and the year 2030. There also are advanced programs in progress related to GEN IV and GNEP. However, even if aggressive new power plant and advanced programs do not proceed, the United States needs a robust set of nuclear research facilities.

There are basic needs for R&D facilities in a country with 104 currently operating plants, a major high temperature gas cooled reactor program, thousands of tons of spent fuel to ultimately be disposed of, a vital interest in safeguards and security for nuclear plants all over the world, and an even more vital interest in limiting the proliferation potential from both the front and back ends of the nuclear fuel cycle. In addition there are issues relating to homeland security, space missions, and nuclear medicine that are independent of the projected growth of new nuclear power reactors. Current Department facilities to support all of these missions are in many cases inadequate without upgrades and refurbishments that will have significant costs. The lack of modern facilities also affects the ability to attract nuclear experts needed to support world class research.

The DOE needs to provide an analysis for the next administration that looks at the current status and suggests a multiyear program including facility upgrades and new facilities necessary for its several missions. The analysis should systematically examine which facilities need to be maintained, upgraded, abandoned, or built new. The goal would be to have the right mix of mission-driven modern facilities that can be kept up-to-date and operated safely.

IV Modeling and Simulation

Huge advances in computer power are available today that allow science to be incorporated in simulations at a scale from smallest to largest much greater than previously conceived. This is a potentially high value-added activity but there are obstacles to overcome to make effective use of the available computer power. Many of the existing codes are not written in a fashion that allows them to be run on the massively parallel computers that give the greatest increase in computer power. Also many of these codes have science gaps that are bridged by perturbation analyses that may not account properly for nonlinear effects that dominate in some applications.

Advanced simulation programs can benefit LWR programs for life extension as well as advanced new reactor programs by shortening design and testing processes. An example is what has happened in the last decade or two to aircraft design. As the computer codes have gotten better and have been tested against real world systems, aircraft design has gone from incremental steps followed by flight tests followed by more incremental improvements, etc., to a mode where most of the design is done in the computer and the final flight test verifies the design. Aircraft design times have been greatly shortened, and costs have been greatly reduced.

An advanced modelling and simulation effort can lead to better understanding of nuclear energy systems and has the potential to resolve long-standing uncertainties associated with the deployment of these systems. Among these long-standing problems are the uncertainty associated with plutonium recycle in United States LWRs[1], qualification of

[1] To date nearly 2000 t HM of MOX fuel have been fabricated for LWRs in Europe and over 150 t HM for FBRs in Europe, Japan and Russia. Irradiation experiments, experience in commercial reactors and post irradiation examinations all indicate that LWR MOX, despite being irradiated in reactor cores designed specifically for UO_2 fuel, not MOX, behaves as predicted and its performance can match that of the UO_2

new fuels, extending the burnup of existing fuels and the uncertainty associated with developing an unambiguously demonstrable economic Liquid Metal Reactor.

However, the subcommittee believes that it is essential that the modelling and simulation program focus on major problems impeding the rapid deployment of advanced nuclear systems and concurs with the modelling and simulation recommendations suggested in the July 2008 version of Reference 3 and the September 2008 version of Reference 2. This effort should increase gradually, utilising existing advanced modelling and simulation capabilities at NNSA and the Office of Science, and focussing on a pilot program that emphasises areas where experiments are long and difficult to demonstrate the value that can be added by this effort. The modelling and simulation program has to be accompanied by an experimental program that can validate the codes. Without an experimental validation program, the modelling program will never be trusted, especially on safety issues

Some examples of important areas for consideration in this pilot program are:

- Extrapolating previous in-reactor fuel tests to higher burnup for those cases in which prototypic in-reactor tests are time-consuming, expensive, or no longer possible.
- Extrapolating results from existing small-scale separations tests to applications essential to the development of economical, proliferation-resistant, large-scale advanced separations systems.
- Developing designs and design configurations for lower-cost high- temperature nuclear steam system designs for advanced reactors using, for example, high-strength chromium-molybdenum steels.

To ensure a sound foundation, modeling and simulations must be tested against real reactor designs and experiments and be used to predict the results of tests to be run and already run using test and operating data gathered from separate effects and integral tests as well as data and other information gathered from earlier and current reactors, both foreign and domestic. While this may be called "postdiction" it is a necessary prelude to prediction.

It is recognized that data needs and gaps in data availability may very well emerge from the modeling and simulation effort, and the identification of such gaps is encouraged. Upon identification of such gaps, the information should be used to develop well-

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fuel along side it in the core. LWR MOX is able to meet the licensing and operational requirements of the large commercial stations. There are however, some constraints on the fraction of MOX fuel that can be loaded into an LWR core at any one time in order to avoid compromising original safety margins. Most European reactors licensed for MOX will use it as one third of the core loading but some reactors can load up to 50%. Designing a reactor for a whole MOX core is significantly easier than trying to adapt existing reactors types and recent evolutionary PWR and BWR designs now offer possible 100% MOX cores e.g. ABWR, System 80+, AP600/1000, EPR.
In 2007, the ESA reported, 8.6 tonnes of plutonium were loaded into European reactors in MOX fuel, displacing some 1035 tonnes of natural uranium and 690 tSWU. In total, 104 tonnes of plutonium has been used in MOX fuel in the EU since 1996.

designed experiments that clearly verify key physical and chemical mechanisms. If done successfully, confidence will be gained in using such simulations to reduce the need for empirical experimental data in NE systems and to focus those experimental efforts that must be undertaken.

Some staff in NE seem to be looking at a modeling and simulation program that moves to the $300-$500 million per year level within 5 or so years (the level of the NNSA Stockpile Stewardship program). The subcommittee believes this is too ambitious and too rapid a build up, considering the need to develop a programmatic focus on realistic problem solving and the state of reactor codes today. A more appropriate goal in that time frame is $50-$100 million per year. But even at this reduced level a detailed multi-year plan with specific experimental and simulation activities and objectives should be the basis for establishing the annual and long-term budget requirements.

V Problems that Inhibit DOE Nuclear Energy Programs

(1) Insufficient Internal DOE Couplings

Several DOE programs related to nuclear energy would benefit from stronger links between different parts of the DOE. Links to RW, NNSA, and SC are all important to maximize the effectiveness of work on various phases of the nuclear energy program.

Links between RW and NE would benefit both RW's and NE's programs. NE's work on advanced fuel cycles, at least in theory, can have a major impact on radioactive waste disposal. For example, an objective of the GNEP program is to change the required isolation time of the highly radioactive reactor waste stream from the hundreds of thousands of years characteristic of the once through fuel cycle to only a thousand years or so. Fuel elements from the High Temperature Gas-Cooled Reactor now under development can stand much higher temperatures than the fuel elements from our workhorse LWRs. Both of these could have significant impact on repository design.

NNSA is responsible for safeguards and security and proliferation prevention programs. Stronger coupling would benefit both programs. For example, as originally proposed the COEX process that NE is looking at for producing plutonium based fuel for thermal or fast spectrum systems had the plutonium-uranium mix set at 50% of each at the end of the reprocessing cycle. Closer interaction with NNSA would have led to an earlier change to a mix with less than about 10% to15% of plutonium. NNSA regards that mix as no more risky from a proliferation perspective than uranium enriched to less than 20% U-235. Closer coupling would have let NE start down a different road considerably earlier.

New fuel forms and new kinds of reactors will need more basic science input for such things as nuclear cross section determination and development of advanced materials. Much of this kind of work goes on in the Office of Science's programs. Coupling with SC is improving and this will help the energy mission.

Development of advanced nuclear energy programs with waste streams that are easier to handle and are more proliferation resistant would benefit from a system that included closer cooperation of all the parts of the DOE.

NE appears to be effectively involving the Office of Science. However, there are other offices that should be involved. An integrated program involving RW (waste forms and desirable characteristics for a repository), whether for long-term (once through) or shorter term (long-lived components destroyed in an ABR), would produce a stronger long-range plan.

NNSA is responsible for Safeguards and Security, and its input is needed as well to realize the NE vision of a solid 20-year plan.

(2) Programmatic Options

The subcommittee did not do a detailed review of NE's advanced fuel cycle programs but did a limited examination of facility needs if programs go forward. Therefore recommendations in this report should be read as conditional, i.e., if this program is pursued, then these are the subcommittee's recommendations on how facility needs might be met.

A NE near-term objective is to close the fuel cycle by using MOX in thermal reactors and the longer-term plan is to burn actinides in fast reactors. Both elements are controversial and have not received widespread support by the Congress or by outside review committees. Moreover, it is unclear whether the next administration will support these programs. A political-budgetary consensus to close the fuel cycle or launch a multi-decade effort to develop and deploy fast reactors for actinide burning does not exist today. Even if it did, it would be difficult to sustain the fast reactor development and deployment program over the multiple-decades and administrations needed to construct and commission actinide-burning reactors. Consequently, NE should broaden its assessment of nuclear infrastructure needs to include the once-through fuel cycle used by the current fleet of light water reactors and the likely improved versions of LWRs that will evolve from them.

The Draft GNEP Programmatic Environmental Impact Statement (PEIS) has not been released for public comment, and consequently there is no Final GNEP PEIS record of decision (ROD). The NE Staff is moving forward on GNEP as if the ROD will adopt the proposed program, NE also should have a base R&D program option that assumes that the US will continue to rely for the foreseeable future on the open fuel cycle use by the current fleet of LWRs for power production, such as the LWR Sustainability effort proposed by industry and DOE-NE.

One member of the subcommittee indicated that relative to the existing open fuel cycle the closed cycle for MOX use in thermal reactors is more costly, less safe, leads to greater routine releases of radioactivity into the environment, greater worker exposures to radiation, greater proliferation risks, larger inventories of nuclear waste that must be managed and does not appreciably reduce the geologic repository requirements. Some members do not agree with all of these statements and other members believe that one reason to advocate a closed cycle is that in the long term Pu and other higher actinides dominate the radiotoxicity in a repository and that, on sustainability grounds, failure to recycle a valuable energy resource is not really sustainable.[2]

However, all members of the subcommittee agreed that, if GNEP is to be pursued, it makes sense to develop or identify an existing fast reactor for fuel testing.

(3) Down selections

DOE-NE should emphasize the need to expedite technical decisions and down-selections so that funding can be wisely allocated. Specific examples include: pebble-bed versus prismatic fuel for the HTR and oxide versus metallic fuel for the FSTR (which in turn may allow GNEP/AFCI to down-select to only aqueous processing). Although the lack of these down-selections is partially due to the fact that industries preparing responses to RFPs are considering both options, DOE-NE should find a way to accelerate these down-selections so that R&D costs can be reduced.

VI International Collaboration

International collaborations should be increased, especially in the current climate of stringent budgets.

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[2] Dissenting Opinion by committee member Dr. Thomas Cochran

The GNEP vision of reducing repository requirement and risk by recycling selected actinides in fast reactors requires that a substantial fraction of the operating reactor fleet be fast reactors. One member of the subcommittee, who does not support a large R&D effort to close the fuel cycle and develop fast reactors for actinide burning offers the following dissenting view:

“Large numbers of fast reactors for actinide burning is unlikely to occur because—to borrow observations made by Admiral Hyman G. Rickover more than 50 years ago— fast reactors have proven to be more costly to build, more complex to operate, susceptible to prolong shutdown as a result of even minor malfunctions, and difficult and time-consuming to repair. Plutonium is a valuable resource for weapons, but is not for energy production. It has a negative economic value for this purpose and there is little prospect that this will change in the foreseeable future because there is no evidence that uranium resources are likely to become scarce in the world, or even in those countries that are closely allied with the United States. Plutonium recycle and the introduction of fast reactors will contribute nothing toward the de-carbonization of global electricity supplies for many decades, while consuming valuable capital resources better spent on less costly and more practical energy alternatives for climate change mitigation.
The GNEP R&D effort could encourage the development of hot cells and reprocessing R&D centers in non-weapon states of concern, as well as the training of cadres of experts in plutonium chemistry and metallurgy, all of which pose a serious proliferation risk. Moreover, were NE to pursue less risky open fuel cycle alternatives, all of the large, costly facilities in NE’s current or recently proposed program, namely, the Advanced Burner Reactor (ABR), Advanced Recycle Reactor (ARR) prototype, Interim Fast Spectrum Reactor (FSR), the Advanced Fuel Cycle Facility (AFCF), and commercial reprocessing and MOX plants, would be entirely unnecessary or, at a minimum, could be deferred indefinitely.”

1) Interim Fast Spectrum Test Reactor (FSTR)

The subcommittee is skeptical that the GNEP program can achieve its long-range goals without an FSTR before the proposed ARR prototype is available. Thus, if GNEP is pursued, the U.S. will need the services of a fast spectrum test reactor; hence, NE should investigate a shared funding model to support work at a foreign facility until the ARR prototype is commissioned.

There is no FSTR in the United States and few in the world. Currently, Phoenix in France is scheduled to begin decommissioning in summer 2009. There are plans to construct a new demo fast reactor probably in Marcoule during the 2020s, with a decision on the path forward by 2012. JOYO in Japan currently is shut down but scheduled to restart around 2011. After being shut down in 1995 due to a leak in its secondary cooling system, Japan's Monju reactor is scheduled to restart in February 2009. Russia has two operating fast reactors, BOR-60 and BN-600. BOR-60 is old and politically and functionally challenging for the U.S. to use. However, both Japan's Monju and Russia's BN-600 are power reactors and are not designed to accommodate efficiently extensive testing of fuels and materials. Thus, Joyo appears to offer the most likely opportunity for conversion to an international FSTR user facility, to irradiate fuel elements and other materials, in partnership with a limited set of countries, including France, Japan, and the UK.

If existing or currently planned facilities are not adequate or not available a new international FSTR should be constructed, based upon such international models as ITER and CERN's Large Hadron Collider (LHC). In both of these examples an international consortium contributes to both construction and operating costs. The experimental program of the fast reactor user facility would be best determined by an international committee of the participating nations.

2) International Reprocessing Facility

Rather than launching an expensive program to construct an engineering scale AFCF immediately, it may be faster and less costly to demonstrate UREX reprocessing technologies on an engineering scale at a foreign facility such as AREVA's LaHague facility in France or the THORP facility in the U.K.[3] Also, there may be some interest in Japan to convert its Recycle Equipment Test Facility (RETF), which was designed to reprocess spent fuel from the JOYO and Monju reactors, to an international reprocessing user facility. Since RETF is currently under construction, this is an excellent time to explore this idea. However, if the decision is made for the US to pursue a closed nuclear fuel cycle, eventually the U.S. should construct its own reprocessing facility along the lines of the Advanced Fuel Cycle Facility.

[3] Any proposal would be subject to both availability of the plant and the willingness of the UK or French government to support such an initiative.

Based upon R&D needs, AFCF's program priorities should be established among the different modules (aqueous, electrochemical, fuel fabrication, waste form) leading to a phasing of buildings. Consideration should be given to using existing foreign facilities, looking at some complementary capabilities between such facilities and AFCF. In particular, throughput should be studied carefully.

4) AFCF if International Engineering Demo is Possible.

A recent study on the use of the AFCF identified engineering scale, or production scale, throughput as a key development parameter necessary to provide a sound engineering basis for larger future facilities. The preferred throughput rate for establishing an engineering scale process in the facility was 25 tonnes/year of heavy metal, which is equivalent to a product output of four Lead Test Assemblies (LTA) per year. As a possible means for reducing the capital cost of the facility, an alternative case based on 4 tonnes of heavy metal per year and a product output of one LTA per year was also examined. In either case, the authors found that it is difficult to fit the entire capability into a single existing facility in the DOE complex and a Greenfield facility would be the best-fit possibility.

Given the current budget situation, it appears unlikely that funding sufficient to build a Greenfield facility at either the higher or lower rates is likely to be available. Therefore it behoves the program to change the assumption basis and to determine what use can be made of those existing large facilities within the complex. With this as the assumption basis, it is unlikely that full capability can be established in a single facility at the preferred throughput levels.

A full demonstration at the laboratory scale of the UREX process has not yet been done; though all pieces have been done separately. The possibility of a single Integrated End-to-End demonstration, that is, all process steps from receiving to final production of the product carried out by a single operating organization in a single facility at a lower throughput rate should not be dismissed. Given this starting point, it may be possible that the entire process can be demonstrated in an Integrated End-to-End manner with some of the key process steps at the engineering scale. The subcommittee believes that this possibility should be examined as it may be the only means of carrying out the AFCF program in a reduced budget scenario.

5) Possibility of User Facility Based in the U.S.

It is not sufficient for the U.S. to use facilities in other countries without establishing a reciprocal international user facility at home. There are many possibilities. One is a transient test reactor of the ilk of the Transient Reactor Test Facility (TREAT), which is a large air-cooled thermal test reactor that was constructed in the late 1950s at Idaho National Laboratory and operated for almost 40 years until 1994. There continues to be a need for a TREAT-type reactor that is capable of studying the transient response of materials to severe reactor conditions.

It must be demonstrated that restarting TREAT is the best path forward for getting a state-of-the-art facility for transient testing. Since 1994 it has been in standby mode and the cost for a restart is estimated to be on the order of $100 Million. The subcommittee, however, cautions that independent verification is needed to ensure that all the required upgrades to obtain an appropriate state-of-the-art facility are included in this cost estimate. A TREAT upgrade may be the way to proceed. However, the main point here is that there are important, unique facilities that could be built on U.S. soil as its contribution to the set of international user facilities.

6) Fuel Development

It takes a very long time to develop and supply a sufficient amount of stable, reliable, and licensed reactor fuel. Furthermore, the amount of fuel now needed for an HTR is limited. (It also would move the program forward if the HTR program had a clear mission.) Therefore, it is recommended to find ways to develop the fuel jointly between the US and Japan, including industrial cooperation. Japan is the only country that has fabricated a large amount of HTR fuel and successfully operated it at very high temperatures. The US might save in development costs by working with Japan, although the licensing requirements for US fuel may be more stringent than the Japanese requirements (run to failure). NE also should explore possible joint work with South Africa, related to the work on the PBMR, and with China, which has an operating HTR.

France, Japan and the United States should make a survey of available and useful hot laboratories, and setup a joint program based on cost sharing. For example, the potential for using JAEA's RETF (Recycle Equipment Test Facility) should be explored for wet type LWR fuel reprocessing technology. This survey should include the brand new UK facilities which are pending full commissioning and the labs of the European Commission, e.g., the Institute for Transuranium Elements in Karlrsruhe Germany

VII Scenarios

The policy subcommittee considers three scenarios: no new builds, about 17 Gwe new nuclear reactors by 2030, the EIA base case, and about 45 Gwe new nuclear reactors by 2030. In all three scenarios, current reactors operate for a lifetime of 60 years.

This subcommittee concludes that some R&D programs would be the same for all three scenarios:

- R&D to keep current plants running well and avoid any surprises. This R&D will include aging phenomenon.
- R&D to encourage a new cadre of engineers and scientists to become involved in nuclear energy..
- R&D on waste management.
- R&D to maintain the US as a major participant in international nuclear power discussions.

For both the 17 Gwe and 45 Gwe scenarios, R&D will be necessary to address issues related to new builds, including manufacturing and inspection. Also required will be R&D on separations chemistry and scaleup and on possible transmutation options.

For the third scenario, which is the most aggressive, particular R&D should address new reactor concepts, GEN IV and advanced LWRs, and the testing and design work necessary for these concepts.

To end at 2030 in planning will be a serious mistake. New concepts can take many decades to go through lab scale and engineering scale development before getting to commercial scale. In particular, if the closed fuel cycle is to be pursued, with new concepts for (recycling, reprocessing, regeneration), ten years of lab work, ten years of engineering work, and ten years of further testing will be necessary, leading to the conclusion that 2030 is too short a time horizon for a healthy R&D program.[4]

Unless the United States government aggressively changes its policy of neglect, a review in the future may find what is described in a recent UK report:

"[T]he current crisis of skills in the area of nuclear engineering, and the uncertainty regarding the UK's capacity to forge ahead with a new generation of nuclear new-build, could have been avoided if a nuclear strategy had been put in place 10 years ago. The need is now pressing for a strategic Government policy on nuclear engineering." [5]

"It would be wholly unrealistic to consider the possibility of sustaining a new nuclear power programme in the UK without UK expertise and engineers. Whilst the design of a new build will be procured from overseas vendors, its deployment will be local, requiring UK engineers to complete detailed design and site specific works, regulate, build, commission, operate, maintain and support a fleet of new nuclear power plants over their projected 60 year lifetimes."[6]

VIII Nuclear Education and University Programs

Regardless of whether the scenario for utilization of nuclear energy involves the status quo, modest growth, or an ambitious and enhanced program that includes developing recycling, transmutation, and new reactor and fuel technologies, university programs will be essential in educating and supplying the required next generation of scientists and engineers. Even in a status quo scenario, our preeminence in frontier nuclear science areas[7] has earned us a "place at the table" in international discussions.

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[4] "The deployment of a new nuclear option takes a long time: 30 to 40 years…." Electricite de France presentation by J-M. Delbecq/J-L. Rouyer, Micanet Meeting, April 7, 2005.
[5] *Nuclear Engineering*, The Royal Academy of Engineering, March 2008, p. 1.
[6] *Ibid.*, p. 2.
[7] *The Future of U. S. Chemistry Research: Benchmarks and Challenges 2007,* Committee on Benchmarking the Research Competitiveness of the United States in Chemistry, Board on Chemical Sciences and Technology, Division of Earth and Life Studies, National Research Council of the National Academies, The National Academy Press, Washington, D.C.

Nuclear science and engineering personnel are urgently needed, not only for utilization of nuclear energy, but for other aspects of the nation's security and well-being in the broadest sense. These include homeland security, nuclear forensics, production of radioisotopes for nuclear medicine and other applications, minimization and safe storage of nuclear waste, environmental monitoring, defense programs, and sectors of government responsible for regulation, safety, or emergency response, to name but a few. Currently, the pipeline in the U.S. is insufficient to furnish the required personnel for all these areas, especially with the increased emphasis on homeland security, detection and assessment of terrorist activities, and other radiological threats.

A recent APS study[8] of nuclear workforce needs considered the following three scenarios for nuclear power: (1) maintaining the current number of nuclear reactors (about 100) without reprocessing their nuclear fuel; (2) doubling the number of reactors without reprocessing fuel; (3) doubling the number of reactors and closing the fuel cycle by reprocessing and recycling spent fuel. The report drew attention to "critical shortages in the U.S. nuclear workforce and to problems in maintaining relevant educational modalities and facilities for training new people".

The sub-disciplines of nuclear chemistry, radiochemistry, and actinide chemistry were found to be in a crisis situation, with nuclear chemistry on the verge of extinction. University chemistry departments have not replaced retiring professors and fewer than two Ph.D.s in nuclear chemistry were awarded in 2004. Even though there is strong student interest, there are only a few remaining universities with programs awarding Ph.D.s in nuclear chemistry. The situation is exacerbated by the absence of a single funding home for the three related sub-disciplines of nuclear chemistry, radiochemistry and actinide chemistry as each must seek support from a different, or even multiple funding agencies[9].

The APS Panel recommended that a cross-cutting workforce initiative to address the needs for trained nuclear chemistry and radiochemistry personnel, including fellowships and scholarships, should be established. It also concluded that prestigious faculty fellowships (such as awarded by NSF) for new professors in these areas and increased research funding would demonstrate that significant opportunities existed and would help convince university chemistry departments to consider hiring new faculty.

The "feast or famine" DOE support for nuclear engineering programs and university reactors has led to considerable uncertainty and has resulted in more than a factor of two

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[8] *Readiness of the U. S. Nuclear Workforce for 21st Century Challenges*, Report of APS Panel on Public Affairs, June 2008: http://www.aps.org/policy/reports/popa-reports/index.cfm.

[9] In 1978 when the DOE Division of Nuclear Science was eliminated, portions of the program went to Chemical Sciences and other portions to the Office of High Energy and Nuclear Physics. Nuclear chemistry went to nuclear physics, actinide chemistry to Chemical Sciences and Radiochemistry was left to try to attain funding from various applied programs such as in RW, Nuclear Medicine, etc. None of these subfields could apply to NSF for funding due to prior agreements that DOE was responsible for all nuclear and energy related activities. Only recently has this ban been lifted!

decrease in the numbers of nuclear engineering departments and university reactors between the 1980s and the present. The current university funding is too tightly tied to the existing NE programs. A funding program for universities similar to the earlier Nuclear Energy Research Initiative (NERI), should be established. As recommended by PCAST (President's Committee of Advisors on Science and Technology), DOE established NERI to provide research funding not necessarily tied to ongoing R&D at the national laboratories. Thus, any new program should use caution in appointing members of any committee that reviews university funding proposals to ensure that they are not too heavily weighted toward national laboratory R&D interests.

Another recommendation of the APS Panel[5] was that the federal government should assume significant responsibility for education of the next generation of nuclear scientists and engineers by naming a single Federal agency to act as steward for an ongoing, robust university-based nuclear and chemical science and engineering education program. This subcommittee has not discussed this recommendation and takes no position on it. In the short term, while the pipeline from the universities is being refilled, nuclear technician training programs and retraining programs at community colleges or at reactor sites should be established. Collaborative programs and internships with nuclear industry and national laboratories also should be implemented.

As suggested by the recent National Academies report[10], DOE-NE should fund nuclear science and engineering education at the levels authorized by the Energy Policy Act of 2005, namely $56 million for FY2009. This would support the development of the needed workforce to address the large wave of retirements in government, national laboratories, and industry and the additional workforce needs for homeland security, detection and attribution of nuclear events, and nuclear forensics to combat nuclear and other forms of radiological terrorism. As part of the educational funding, there should be adequate support for university training and research reactors, such as was provided previously by DOE's Innovations in Nuclear Infrastructure and Education (INIE), a program last funded at $9.41 million for FY 2006 that encouraged partnerships among the university reactors, national laboratories, and industry.

Quoting from the *July 2008 letter of Executive Team member James Duderstadt to Paul Kearns of Battelle*, "Long ago DOE (AEC-ERDA) was assigned the primary responsibility for developing the engineers and scientists necessary to sustain the nation's nuclear energy capabilities. Yet DOE's support of these educational programs has been at a token level for years – actually amounting to less than 10% per student or faculty member of other areas such as nuclear physics and high energy physics." Although individual program leaders have sometimes tried to eke out some support for various student training programs, significant amounts of money for faculty grants and student training never seem to materialize.

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[10] *Review of DOE's Nuclear Energy Research and Development Program*, National Research Council, National Academies Press, Washington, DC, October 2007.

The recent reports generated by Battelle and INL have listed Workforce Issues and Nuclear Education and related facilities among their top priorities, but it is not yet clear what the funding mechanisms will be for university faculty and student research and training support.

Lessons to be Learned

Lessons can be learned from past foreign situations both in a negative way (decline of the nuclear sector as in the UK) and in a positive way (world leadership of nuclear research and industry as in France and Japan).

The UK presents a case history of relevance to the US in terms of rapid decline of skills supporting the nuclear sector in the absence of a coherent policy from the Departments of Government which should have recognized the need for them to be nurtured.

During the late 1980's and early 1990's successive privatizations of parts of the UKAEA and CEGB (Central Electricity Generating Board) led to a catastrophic fall in R+D supporting the nuclear sector. Most of the major laboratories of the CEGB closed and R+D associated with new nuclear systems ceased to be funded by the then Department of Energy with the Department of Trade and Industry. Some 8000 technical posts were lost to the sector. This in turn had a catastrophic effect on the University base which had supported UK and international nuclear endeavors. The UK had only ever had one course in Nuclear Engineering and this was at Masters level. The supply of graduates historically came from nuclear modules within mainstream science and engineering degrees and it was these which disappeared as students failed to take an interest in an industry perceived to be in decline and experienced academic staff retired. Absent government funding it was almost impossible to encourage new academic appointments. By the mid 1990's the only investment of any significance was being made by BNFL through four targeted research alliances with top UK universities. This encouraged leveraged investment by the UK's main research council as Government realized it needed to have a science base capable of 'keeping the nuclear option open'. It took nearly a decade to regain internationally competitive research groups targeted at the nuclear sector and a resurgence of taught modules at undergraduate and masters level. Failure to sustain an active program over the last 5years has made it almost impossible to sustain the UK's knowledge base in fast reactors. A Generation's valuable work has been consigned to an archive but valuable know how of relevance to the systems still under consideration internationally has probably been lost.

An additional unforeseen consequence of reduced funding for R-D and no coherent plan to sustain nuclear competence was an increasing shortage of trained technicians and top end blue collar skills required to service a sector over the coming two decades of existing plants and very significant shortages in skilled personnel available to join the nuclear regulator.

In the former case in 2007 the UK Government launched a National Nuclear Skills Academy to provide training of technicians and modules up to foundation degree level but recognizes it will take over a decade to remedy the situation.

In the latter case the under resourcing of the regulator is of significant concern to the Industry trying to engage in a new build endeavor with internationally available designs and to the UK Government who now want a new generation of reactors deployed by the end of the second decade of the 21C.

The Royal Academy of Engineering (the UK's equivalent of the US National Academy of Engineering) has strongly recommended that the UK Government fund a targeted research program.

The UK through BNFL invested $400M in new active R+D facilities at Sellafield to enable 21C fuel cycles to be explored and underpinned. These have yet to be exploited but the capital investment has at least been made.

On the other hand, countries like France and Japan have succeeded in the past to develop world class Nuclear R&D facilities, and to upgrade them constantly at the needed level up to a point where ageing can no longer be overcome for technical or safety reasons. Even if long lasting and difficult, a time-phased approach as used in these counties to anticipate shut down of ageing facilities allows making decisions to build new and adapted R&D capabilities. For example, in France nuclear hot cells built in the Paris area in the sixties have been shut down, while the new Atalante facility was progressively built in Marcoule in 1990-2000. This facility is now recognized as a leading world class laboratory for supporting reprocessing and waste form studies.
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