Report of the Fuel Cycle Subcommittee of NEAC

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I. Introduction and Summary

The Fuel Cycle subcommittee of NEAC met April 25-26 in Albuquerque, New Mexico. The main topics of discussion were the Used Nuclear Fuel (UNF) disposal program, the System Study Program's methodology that is to be used to set priorities for R&D on advanced fuel cycles, and the University Programs. In addition to these, we were briefed on the budget, but have no comments other than a hope for a good outcome and restrict ourselves to general advice until more is known.

A current complication in the design of the Fuel Cycle R&D FCRD program is the Blue Ribbon Commission (BRC) which has been created to address the issues involved in long term disposal of used nuclear fuel (UNF) and any of the highly radioactive materials that are created with any possible treatment of that material. A summary of the draft findings of the BRC has been made public, but the final version of their report will not be available until later this year. NE has adopted the sensible procedure of focusing on generic issues that must be addressed irrespective of the final system while waiting for the BRC report before getting back to the specific issues relating to different choices on long term issues.

In this section of our report we summarize the issues we see in the three areas and collect all of our recommendations at the end of this section. Details are in subsequent sections.

UNF Program: With the decision to terminate the Yucca Mountain repository project, the Office of Civilian Radioactive Waste Management was dissolved and responsibility for R&D related to treatment and disposition of UNF was transferred to NE along with a much reduced budget and staff.

It is clear that a new repository cannot be opened for at least 20 to 30 years considering the time it will take to chose a site, validate its viability and license it. The oldest UNF is already 50 years old so whatever the BRC recommends, the disposal program will have to deal with fuel that is, at a minimum, 70 to 80 years older than when it was removed from a reactor, a period far longer than contemplated originally in the spent fuel management program. There are issues of fuel integrity during long-term storage, and issues in transporting such fuel from a reactor site to any interim or final repository, and it is a priority to carry out the R&D to assure that we have the proper methods for storing and transporting the material. These issues are discussed in Section II of this report, and the focus of today's R&D in the area is on these issues.

The direction of future repository related R&D will have to await the final report of the BRC. Interim storage issues are already being addressed and there will probably be geological and chemical issues related to the type of long term storage that may need to be addressed in order to make a repository siting decision.

We also note that the Nuclear Waste Technical Review Board (NWTRB) was established by the Nuclear Waste Policy Act as amended (1987). Its members are appointed by the President, and its charter is to advise Congress and the Administration on technical issues related to implementing the Act. The NWTRB issues periodic reports and a particularly interesting one is their 2009 report comparing various national programs for disposing of high level waste.

(http://brc.gov/e-mails/June10/nwtrb%2020sept%202009.pdf).

Recommendation: Since NE will have responsibilities in the UNF disposition program, the roles and responsibilities of the NWTRB and NEAC and its subcommittees need to be clarified.

Systems Engineering and the Fuel Cycle Research and Development (FCRD) Program: There are many possible options for advanced fuel cycles that can improve performance of nuclear reactors for energy production. The FCRD program is developing a method to systematically evaluate and prioritize options to help select those that seem most promising when measured against a realistic set of effectiveness criteria that span the entire fuel cycle. The work includes input from the reactor technologies part of NE. The system is evolving and this first effort has shown where further work is required.

Nine criteria were used in this first attempt: (1) Nuclear waste management, (2) Safety attributes, (3) Environmental impacts, (4) Fuel resource utilization, (5) Overall security risk, (6) Nuclear Regulatory (NRC) familiarity, (7) Overall proliferation risk, (8) First-of-a Kind investment, and (9) Compatibility with existing infrastructure. One obvious criterion, cost of electricity, was not included at this stage because considerable engineering work would be required to determine it even approximately. It will have to be included in later versions. Other criteria, NRC familiarity, for example, are not really appropriate for advanced systems and innovative technologies that are not close to deployment, while still others, proliferation risk, for example, are not well defined. In view of this, we think that great care is required in applying the model to innovative technologies in the early stages of concept development because little is known about them at this stage and a strict application of the model's criteria could easily rule them out prematurely. Nevertheless, the overall exercise is an excellent beginning.

The initial evaluation was conducted by a group of laboratory people, followed by a peer review process by a group that included lab insiders and outsiders, an excellent procedure. After the process is further tuned up, it will need the involvement of more outsiders from both the university community and industry. We note that results are sensitive to the relative weighting of criteria. The relative weights are sometimes more a policy issue than a technical one. Senior DOE officials need to be involved, though this is not easy since policy can vary from administration to administration.

The modeling includes proliferation characteristics as attributes of a technology (criterion 7). As we have said in previous reports, a uniform and consistent set of nonproliferation metrics has not yet been developed and is needed. There have been at least two previous attempts to do so. Neither report has been reviewed nor accepted. We recommend that NE, in cooperation with NNSA, try again to address the issue taking into account the views of the international community that collectively has many more nuclear power plants than does the US, and their views will be influential in determining what can be accepted on a global scale. NE and NNSA must find a way to develop a concrete set of metrics that can be used in the type of analysis being carried out. It is complicated because at least part of such a study will have to be classified. Without some agreed on analysis, proliferation risk will remain only a matter of opinion.

It is the Subcommittee's opinion that this Systems Engineering model can become a useful tool or framework that may eventually provide a structured way to compare different alternatives, and allow NE to quickly evaluate the impact of policy changes on priorities in its current program**.**

Recommendations: **1)** NE leadership should be involved in reviewing the weighting of criteria used in the systems studies since some of these are policy dependent and the weightings can strongly affect the relative scores of various options.

2) NE and NNSA should try again to agree on criteria to be used in evaluating proliferation resistance of fuel cycle and reactor technologies.

University Programs: The university R&D component of the NE budget has gone through extreme excursions falling to zero in 1998 and rising to 20% of the NE R&D budget in recent years. In the years up to about FY 2008 it was Congress that pressed DOE to support the universities, giving funds to the NRC and NNSA as well as to DOE. More recently DOE decided that 20% of the NE R&D program would be a target for funding for what is now called the NE University Programs (NEUP). This is in addition to a Congressional appropriation of $5 million for university scholarships and fellowships. The NEUP budget was $53 million in FY 2009, $58 million in FY2010, and was targeted for $80 million in FY 2011.

The program has been working well in its important dimensions, supporting the R&D goals of NE, supporting upgrades to university research reactors and laboratory equipment, as well as developing the next generation of nuclear energy professionals. Some fields of importance have had a particularly hard time in maintaining personnel and an example is nuclear chemistry and radiochemistry, which nearly disappeared during the low budget years and now seems to be making a much needed, though still precarious, comeback.

We have two concerns regarding FY 2012 NEUP funding. First, the budget submission has eliminated the $5 million for university scholarships and fellowships with a statement that the nuclear industry will pick up the program. A senior official at the Nuclear Energy Institute indicated that there have been no discussions with industry on the matter that they know of, and thus it is not likely that industry will pick up the program immediately, if ever.

Second, the uncertainty in the total NE budget for the next fiscal year is much larger than usual and, therefore, so is the uncertainty in the NEUP budget. It is important to keep in mind that the people and information developed through NEUP is, in the long run, as important as that developed in the laboratories.

Recommendation: An appropriate balance between NEUP and laboratory funding needs to be maintained bearing in mind that sharp cutbacks in university programs can have a long-term effect on the attractiveness of the nuclear field.

Summary of Recommendations

Since NE will have responsibilities in the UNF disposition program, the roles and responsibilities of the NWTRB and NEAC and its subcommittees need to be clarified.

NE leadership should be involved in reviewing the weighting of criteria used in the systems studies since some of these are policy dependent and the weightings can strongly affect the relative scores of various options.

NE and NNSA should develop a procedure to try again to agree on criteria to be used in evaluating proliferation resistance of fuel cycle and reactor technologies.

An appropriate balance between NEUP and laboratory funding needs to be maintained, bearing in mind that sharp cutbacks in university programs can have a long-term effect on the attractiveness of the nuclear field.

II. Used Fuel Disposition Campaign

With the decision by the Administration to end work at the potential Yucca Mountain repository site, responsibility for the conduct of R&D activities related to storage, transportation and disposal of UNF and high level nuclear waste (HLW) was transferred to NE and within NE to the Fuel Cycle R&D program where the Used Fuel Disposition Campaign (UFDC) has been established. The Mission of the UFDC is [1]

> *To identify alternatives and conduct scientific research and technology development to enable storage, transportation and disposal of used nuclear fuel and wastes generated by existing and future nuclear fuel cycles*.

During our April 2011 meeting, we learned about various initiatives in the UFDC. With respect to funding, approximately half of their $37.2 M funding is devoted to areas that are not storage-option specific and would have been required if there had not been a recent change in the US policy related to Yucca mountain (e.g., transportation, cask certification, etc.); such research activities are needed no matter which fuel disposition approach the U.S. ultimately selects. The remaining funding is devoted to alternative options for used fuel storage, such as an alternate repository location. As noted below, the UFDC has completed a gap analysis to identify and prioritize research needs.

It should be noted that since this was our first opportunity to learn about this program, we are limiting our comments to insights that we gained from the presentations made to us and from the referenced documents[2-5]. In addition, we note that as part of the Nuclear Waste Policy Act as amended (1987), the U.S. Nuclear Waste Technical Review Board (NWTRB) is tasked to independently evaluate U. S. Department of Energy (DOE) technical activities for managing and disposing of UNF and high-level radioactive waste. It appears that there is duplication in efforts by our subcommittee and the NWTRB, and guidance is needed with respect to the scope of each advisory group.

Storage and Transportation

It is not known when the UNF that is currently stored at commercial nuclear power plant sites will be transported to other locations. Research is needed to understand how long used fuel can be stored in either wet pools or dry casks before the fuel or the storage system components degrade to the point that they are no longer able to meet regulatory requirements for continued storage or for transport to an interim storage facility, a final repository, or for a processing facility.

Storage

When fuel is transferred to dry storage, it must be dried because residual water that remains affects subsequent internal degradation processes. The vacuum-drying heat cycles can change the nature of the hydrogen in the cladding and stress the fuel. The fuel, the dry-storage system components (canister, cask, etc.), and the concrete foundation pad may all degrade during dry storage. Some degradation mechanisms may be active during the early years of dry storage, while different mechanisms may be active at the lower temperatures that would be expected during extended storage. The most significant potential degradation mechanisms affecting the fuel cladding during extended storage are expected to be those related to hydriding, creep, and stress corrosion cracking. These mechanisms and their interactions are not well understood. There are limited data related to the low- burnup fuel currently used by the existing LWR fleet and no data for high-burnup fuel or new cladding materials proposed for use with high-burnup fuel. Hence, it is not possible for reliable predictions to be made of degradation processes or potential releases that may occur as a result of accidents during handling and transportation.

One of the main deterrents to corrosion of the fuel cladding and the canister or metal cask internals during extended dry storage is the presence of helium. If the helium leaks and air (and any moisture present in the air) enters the canister or cask, it can result in corrosion of the fuel cladding, the canister, and the cask. Although provision is made to monitor the pressure of the helium during extended storage in bolted canisters, there is currently no means of confirming the presence of helium in welded containers or casks, nor is there a requirement for periodically inspecting the integrity of the closure welds for defects. If these storage systems were periodically inspected for weld defects and/or tested for helium, this would allow welded containers and casks with leaks to be repaired and refilled with helium. During extended dry storage, degradation mechanisms also act on the outside of canisters, on storage casks (concrete or steel), and on modular concrete facilities as well as on the storage pads. The effect of these degradation mechanisms depend on the environmental conditions at the storage location.

Data are needed to accurately predict the degradation of dry-storage canisters, casks, or concrete structures during ex tended storage. Presentations given to the Subcommittee indicate that the UFCD is aware of the current challenges associated with used fuel storage. On-going research tasks have been identified and prioritized to address such issues.

Transportation

Used fuel eventually must be moved from the reactor sites, either to off-site interim storage facilities or to used-fuel processing facilities for recycling or for management of waste. Transportation regulations are largely focused on the integrity of the transportation casks which contain the used fuel, and on maintaining the fuel in a subcritical condition. The primary goal is to ensure that the cask does not fail in the event of a transportation accident, with the potential for release of radioactive materials. The regulations require that under both normal and accident conditions, the transportation cask and its contents are capable of meeting stringent performance specifications that include maintaining geometric configuration of the fuel to certain limits, largely for criticality control, and to address concerns about external radiation levels.

If the fuel degrades during extended storage, it could be susceptible to damage from the vibration and shocks encountered during transport operations. The consequences may include release of fission-product gases into the canister or the cask interior, which must be contained during a transportation accident.

Upon reaching the interim storage location, the repository site, or other processing facility, the used fuel may have to be handled, which requires that the casks and used-fuel canisters be opened and the fuel removed. Before this is done, consideration will need to be given to the condition of the fuel, and a means will need to be available for determining if the fuel isolation has failed.

Presentations given to the Subcommittee indicate that the UFDC is aware of the current challenges associated with used fuel transportation and handling after reaching interim storage, repository, or processing facilities. On-going research tasks have been identified and prioritized to address such issues.

Roadmap and Gap Analysis

In March 2011, the UFDC issued a roadmap [1], that is an initial evaluation and prioritization of R&D opportunities that could be pursued by the campaign. Independently, at the direction of the President, the Secretary established the BRC on America's Nuclear Future to conduct a comprehensive review of policies for managing the back end of the nuclear fuel cycle, including all alternatives for the storage, processing, and disposal of civilian and defense used nuclear fuel, high-level waste, and materials derived from nuclear activities. The BRC is to provide advice, evaluate alternatives, and make recommendations for a new plan to address issues, including several of particular importance to the UFDC Disposal Research and Development Roadmap:

- Evaluation of existing fuel cycle technologies and R&D programs;
- Options for permanent disposal of used fuel and/or high-level nuclear waste, including deep geological disposal; and
- Options to ensure that decisions on management of used nuclear fuel and nuclear waste are open and transparent, with broad participation.

The UFDC R&D Roadmap is an evolving document that will ensure that the technical information needed to implement new national policy for managing the back end of the nuclear fuel cycle is available when decisions are made to move forward. Initially, it focuses on generic research and development work undertaken today that will support future site-specific work; a prudent strategy. The research and development is focused on finding solutions to difficult issues related to nuclear waste repository siting. The UFDC is conducting its R&D in collaboration with university, industrial, and international collaborators.

The roadmap focuses on identifying knowledge gaps and opportunities where research and development have the greatest potential to contribute to advancing the understanding of technical issues regarding the deep geologic disposal of nuclear waste. The proposed research is designed to help to maintain U.S. expertise in repository sciences, both within the U.S. National Laboratories and university system (through NEUP). The UFDC will also collaborate, where appropriate, with other countries that are pursing the geologic disposal of spent nuclear fuel and high level radioactive waste.

Presentations given to the Subcommittee indicate that the Roadmap is an appropriate initial tool to assess what tasks should be addressed by the UFDC. We applaud them for assessing the state-of-the-art, including input from US and international research and industry organizations. In particular, we concur with their efforts to identify gaps in the current knowledge base and to prioritize activities (e.g., analyses, tests) to obtain the required information. For example, a Spent Fuel Demonstration Test Facility is proposed to evaluate if fuel can be shipped after 5 years and if fuel can be safely stored for 60 years or longer. Data obtained from this facility could be used to support changes in the current regulations related to cask certification and storage facility licensing. We also appreciated their efforts to identify various options that could be used to overcome current limitations with respect to storage and transportation. For each option, actions were identified (in addition to analyses or tests) that could overcome these limitations.

Analyses Opportunities

Although our Subcommittee did not hear any presentations about current opportunities for advanced computing that could be used in the UFDC, we were informed of the

Advanced Simulation Capability for Environmental Management (ASCEM) effort. ASCEM was formed to develop transformational, high performance computer modeling capabilities to better meet the challenge of waste disposal and cleanup left over from the creation of the US nuclear stockpile decades ago. We suggest that the UFCD explore opportunities to collaborate in the effort to improve analysis opportunities.

Summary:

At this point, the nuclear waste management policy of the United States is unclear, and the result is that UNF will be stored at reactor sites for longer than originally foreseen. It is thus essential that the appropriate research and development programs and monitoring and inspection programs are implemented as a matter of priority to demonstrate that UNF can be stored safely for extended periods and then transported and handled as part of a future waste management program.

We recommend that 'generic' activities not specific to any final repository decision be continued. When the US formulates a credible scheme for the ultimate disposition of used fuel, then repository-specific activities should be resumed.

III. Systems Engineering and the Fuel Cycle Research and Development (FCRD) Program

A detailed description of the development of a Systems Engineering (SE) model for evaluation of alternative fuel cycle options and prioritization of R&D for the Fuel Cycle Technology (FCT) program was presented to our Subcommittee. This (NE-5) initiative was undertaken together with input from Nuclear Reactor Technologies (NE-7) so both the fuel cycle and the reactor system are considered together. The system is still evolving and this first effort has shown where further work is required.

Nine criteria were used in this first attempt; (1) Nuclear waste management, (2) Safety attributes, (3) Environmental impacts (4) Fuel resource utilization, (5) Overall security risk, (6) NRC familiarity, (7) Overall proliferation risk, (8) First-of -a Kind investment, and (9) Compatibility with existing infrastructure.

One obvious criterion, cost of electricity, was not included at this stage because considerable engineering work would be required to determine it even approximately. It will have to be included in later versions. Other criteria, NRC familiarity, for example, are not really appropriate for advanced systems and innovative technologies that are not close to deployment, while still others, proliferation risk, for example, are not well defined. Nevertheless, the exercise is an excellent beginning.

The initial evaluation was conducted by a group of national laboratory experts. It was followed by a peer review process by a group that included laboratory insiders and outsiders, an excellent procedure. After the process gets further tuned up, it will need the involvement of more outsiders from both the university community and industry. We also note that results are sensitive to the relative weighting of criteria. The relative weights are sometimes more a policy issue than a technical one, and senior DOE officials need to be involved.

It is the Subcommittee's opinion that this Systems Engineering model provides a useful tool or framework that will eventually: (1) provide a structured consideration of different alternatives, (2) allow NE to evaluate and provide a timely response to proposed alternatives, and (3) allow NE to quickly evaluate and articulate the impact of policy changes upon its current program**.**

On the other hand, we advise caution in several areas. A mechanistic model such as this may not be as useful in assessing new and innovative technologies for which less is known. The modelers indicated that they attempted to divide fuel cycle technologies into three broad categories: (1) promising, (2) not enough known, and (3) not worthwhile to pursue. They aim to provide transparent, traceable, and reproducible documentation of early screening decisions, and the methodology demonstration to support future screenings and down-selections.

But a new innovative fuel technology can easily fall into both the “promising” and “not enough known” (at present) category. Therefore, the Subcommittee strongly urges caution to ensure that new technologies such as innovative fuel concepts and/or Small Modular Reactor (SMR) concepts are not ruled out prematurely.

In our view, the metrics used as well as the weights must be carefully examined. In addition, it is important to avoid getting caught up in the machinery and intricacies of the model as the purpose is to generate an understanding of basic cause and effect relationships rather than to simply generate instantaneous results.

The presenters noted that the model includes non-proliferation characteristics as attributes of a technology. As we have said in previous reports, a uniform and consistent set of nonproliferation metrics has not yet been developed and is needed. The developers of the models recognize this. Two earlier reports provide source material for such development -- the Waltar report[6] and the Bathke[7] report.

In the first study, DOE constituted a committee of internationally recognized professionals in the field to study proliferation risks associated with closing the fuel cycle, assess nonproliferation attributes, and provide input to the ANTT subcommittee of NERAC (now the Fuel Cycle Subcommittee of NEAC). The committee including experts from Great Britain, USA, Japan, and France, was chaired by Dr. Alan Waltar (PNNL) and has come to be known as the “Waltar Report.” Two key conclusions emerged from the study and are in the report. The first was that there is no completely proliferation-proof technology or silver bullet, and the second was that the proliferation risks associated with the front end of the fuel cycle (enrichment) are likely to be equal to those associated with the back end (reprocessing).

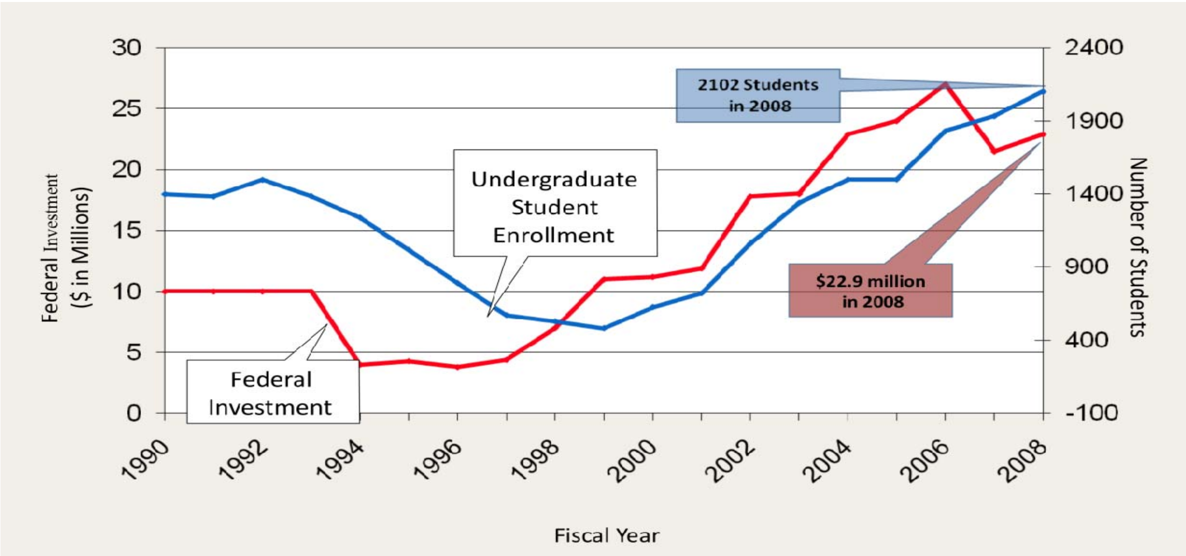
In the second report, Bathke et al. define Figures of Merit (FOMs) and considers “attractiveness” of different materials to various entities with different capabilities and motivations. These range from an individual suicide terrorist to nation states. Although the approach taken by Bathke was quite different from that taken by Waltar, the conclusion that is there is no completely proliferation resistant technology is the same. However, neither report, although useful in scoping the issue of proliferation risk, provides a comprehensive framework for quantifiable "risk" that would be useful in the context of the systems study being undertaken by NE-FCRD.

A realistic look at proliferation resistance criteria needs to be developed, reviewed, and used in this kind of exercise. It is important to remember that the US is not alone in the world of users of nuclear energy and a comprehensive risk assessment will have to have input from others if its conclusions are to be influential on the world stage.

IV. University Programs

The Subcommittee is quite concerned about maintaining DOE's commitment to university programs in its FY2012 budget request. A recent report by the American Physical Society highlighted the sensitivity of nuclear science and engineering enrollments and degrees to federal funding.[8] Fig. 1 slightly updated from that report, shows how undergraduate nuclear engineering enrollments closely tracked federal university funding over nearly two decades. Communications between the APS panel

Figure 1: Federal Investment & Undergraduate Enrollments in Nuclear Engineering



that prepared the report and both the heads of nuclear engineering departments and directors of university research reactors indicated the same cause and effect between funding and enrollments. Another telling indicator is the decline in the number of PhD degrees awarded in nuclear chemistry over four decades, according to the National Science Foundation database. The numbers dipped so low that NSF dropped nuclear chemistry from its database starting in 2004.

The very genesis of NEAC itself is derived from the 1997 advice of the President's Committee of Advisors on Science and Technology (PCAST), which urged the establishment of a committee to advise DOE on reinvesting in university education. This was in light of the fact that in 1994, federal support for nuclear science and engineering education was essentially zero and the small amount allocated was for fuel assistance to university research and training reactors.

Fig.1 clearly shows the benefits of the Clinton Administration's attention to this problem, with input from the Nuclear Energy Research Advisory Committee (NERAC), the original name of NEAC. The first two university programs to be established were the Nuclear Energy Research Initiative (NERI), with an emphasis on research not tied to national lab programs, and Innovations in Nuclear Infrastructure and Education (INIE), which played an important role in saving a number of university research reactors. With the demonstrated increase in undergraduate nuclear engineering enrollments, for FY 2007 DOE-NE attempted to zero out its funding for university programs. However Congress rejected the idea, although the funding for FY 2007 was less than that for FY 2006. For FY 2008, DOE-NE again tried to zero out university funding, and Congress again rejected the idea. However, this time it transferred the bulk of the funding (~$15 million) to the NRC, except that about $3 million remained at DOE for fuel services to university reactors.

Since 2008, Congressional appropriators have instituted an "Integrated Universities Program (IUP)" in the funding bills which provides the Universities somewhat more protection from funding disruptions and fluctuations that have plagued it in the last 20 years. In order to provide more stability to the University nuclear programs, the IUP authorized $15M in each of three agencies: DOE, NRC, and NNSA. The stated objective was to operate a collaborative program to attract the brightest minds to study and teach nuclear engineering in the U.S. A $5M amount of the IUP at DOE is dedicated specifically to scholarships and fellowships awarded competitively to undergraduate and graduate students through the designated calls for proposals.

Independently, the DOE/NE made a commitment to allot up to 20% of its total R&D program to University research, with the funds competitively awarded in response to a set of targeted calls for proposals. The strategic goal here was, in part, to provide mission-related funding to the University community that would sustain the imperatives of a vibrant faculty research program in the Nation’s nuclear engineering programs. This would more directly support a larger number of PhD graduates from these programs, guaranteeing the availability of future nuclear engineering faculty. Nuclear Engineering departments are now struggling to find qualified junior faculty candidates in this environment. Although metrics for gauging health of nuclear University programs typically show the number of B.S. degrees awarded, this may be a “lagging indicator” of the educational enterprise. The number of PhD degrees awarded from the nuclear programs nationwide has remained constant since 1998, generally less than 100. Arguably, this metric would be a more direct, or “leading indicator” of a sustainable nuclear education “system.” Curtailing University-based nuclear research would endanger the entire workforce pipeline, and create an unintended, but nuanced drive away from “innovation” and more in the direction of “training” in research-starved educational programs. The system response would not support the visionary goals of a vibrant, sustainable nuclear energy industry in the United States.

Thus, the NEUP program is critical for the life extension of the current nuclear fleet, successful deployment of advanced nuclear reactors including small modular reactors that will uniquely reinvigorate US domestic nuclear industry, and the development of proliferation-resistant recycling techniques that reduce the volume of radioactive waste. In the 2012 President’s Budget, the subject R&D funds are in three major categories: Reactor Concepts Research, Development, and Demonstration ($125M), Fuel Cycle R&D ($155M), and Nuclear Energy Enabling Technologies ($97.3M).

Nuclear Chemistry is a special problem within the university programs of importance to NE. The number of Ph. D. degrees in nuclear chemistry awarded per year in the U. S. over the past few decades declined until by 2004 the number became so small that nuclear chemistry was dropped as a separate category in the NSF data base. As of 2008 only the following U. S. university chemistry departments offered advanced degree programs in nuclear chemistry, radiochemistry and/or nuclear medicine (numbers of professors associated with each program are given in parentheses): Indiana U. (1); Michigan State U. (1); Oregon State U. (1); Texas A&M, College Station (position posted); U. California, Berkeley (3); U. Kentucky (1); U. Maryland (1); U. Missouri, Columbia (2); U. Missouri, St. Louis (1); U. Nevada, Las Vegas (2); U. Rochester (1), State U. New York (1); Wash. State U (3). [Auburn and Clemson offered programs in Nuclear & Environmental Eng (2)].

Fewer than 10 PhDs were awarded in radiochemistry/nuclear-chemistry/nuclear medicine per year out of ~1,800 PhDs awarded in chemistry, although PhDs in Nuclear Physics per year remained nearly constant at ~70 or so out of ~1,400 PhDs in physics per year.

Since 2008, some improvement appears to have been achieved, primarily due to funding received for PhD and postdoctoral programs relevant to nuclear forensics, homeland security, and environmental monitoring and remediation from sources such as various special programs within DOE, Department of Defense (DOD)/Defense Threat Reduction Agency (DTRA), Department of Homeland Security, and NNSA Stockpile Stewardship.

Recent anecdotal information indicates that the number of faculty in Nuclear Chemistry/ Radiochemistry and/or Nuclear Medicine at the following universities increased as follows: Michigan State University (+3); Oregon State University (+2); University of Missouri, Columbia, (+1); University of Nevada, Las Vegas, (+2); Texas A&M, College Station, (+2 & recruiting for 2); Washington State University (+3); Washington University, St. Louis, (+2). Presumably, the number of M. S. and PhD degrees per year should show a commensurate increase, but it is still too early to forecast these numbers. It remains to be seen if these gains can be sustained.

We strongly recommend that, in order to train the next generation of nuclear scientists and engineers, every effort be made to continue both the $5 million support for scholarships and fellowships provided by the IUP, as well as to support the current "up to 20%" of NE R&D funding in the NEUP account. Ultimately, this translates to support for the $377.3M for DOE Office of Nuclear Energy research and development programs. The U.S. nuclear industry is in no way prepared to take over the $5 million support for scholarships and fellowships, contrary to the professed arguments made by the OMB. DOE should continue this program for the time being until the industry has made provisions to take it over.

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