Readiness of the U.S. Nuclear Workforce for 21st Century Challenges

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Committee on Energy and Environment

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1. Introduction

The 21st century has brought a growing realization that it is time to reexamine the adequacy of the U.S. nuclear workforce and its ability to deal with many old and new challenges our nation faces. This report draws attention to critical shortages in the U.S. nuclear workforce and to problems in maintaining relevant educational modalities and facilities for training new people. This workforce comprises nuclear engineers, nuclear chemists, radiochemists, health physicists, nuclear physicists, nuclear technicians, and those from related disciplines. As a group they play critical roles in the nation's nuclear power industry, in its nuclear weapons complex, in its defense against nuclear and other forms of terrorism, and in several aspects of healthcare, industrial processing, and occupational health and safety. Each of these areas presents significantly more dramatic challenges than it did not very many years ago. Each is an important aspect of our national security.

<u>Nuclear Power: Past and Present</u>

Workforce shortages in the arena of commercial nuclear power, and the problem of maintaining modernized training facilities, mainly stem from the 30-year stasis in U.S. demand for new civilian nuclear power plants[1]. The number of operating civilian nuclear reactors in the U.S. has remained at about 100 during this time. Thus, U.S. vendors have been forced to look abroad for sales. Some have either ceased construction of new reactors entirely or else significantly scaled back business in this area. Their continuing, largely static, nuclear engineering workforce needs have been met through a combination of hiring those trained in university nuclear engineering programs and retraining others whose original expertise was in some other field (usually mechanical engineering). Retirees from the nuclear Navy also have played an important role.

A natural result of this stasis was for many years a greatly reduced interest among undergraduates in nuclear science and engineering programs[2]. In turn, this put great pressure on U.S. universities to scale back in these areas. Recently, however, the Federal government, through the Department of Energy (DOE), dramatically increased funding for these educational efforts. This played a major role in increasing undergraduate student enrollments in nuclear engineering from a low point of 480 in 1999 to 1,933 in 2007. Declaring the problem to be solved, DOE called for the termination of its university nuclear science and engineering programs for FY 2007. Congress in turn provided reduced funding for FY 2007 and transferred all the programs except reactor fuel services to the Nuclear Regulatory Commission (NRC) for FY 2008. These "feast or famine" gyrations have led to significant instabilities: the number of university nuclear engineering departments has decreased from 66 in the early 1980s to 30 today, and the number of university reactors has dwindled from 63 to 25 during essentially the same period.

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[1] Having begun construction in 1973 and commercial operation in 1996, the Watts Bar Unit 1 nuclear reactor of the Tennessee Valley Authority (TVA) is the Nation's last civilian nuclear power plant to be commissioned into service.

[2] In this report, nuclear science refers to nuclear chemistry, radiochemistry, health physics, and to a limited extent nuclear physics. Nuclear physics is only included to the extent that it pertains to nuclear fission and other radiological applications, which generally are not funded by DOE's Office of Science or the National Science Foundation.

Environment

Today there is increasing public concern about anthropogenic global warming and global climate change, and much public anxiety about future sources of abundant but clean (low "carbon footprint") energy. A 2003 Massachusetts Institute of Technology report[3] noted that there are few options in the near future to reduce greenhouse gas emissions from the production of energy: increased efficiency, increased reliance on renewable sources such as wind and solar power, capture and sequestering of carbon dioxide emissions, and increasing the contribution from nuclear reactors. About 20% of the electricity in the U.S. comes from its fleet of 104 commercial nuclear reactors, which annually displace hundreds of millions of metric tons of carbon emissions. These reactors currently account for approximately 70% of the non-carbon emitting electricity production in the U.S.

Given the contribution nuclear power makes to emissions reductions, some, including the American Physical Society, have argued that a balanced U.S. energy policy should maintain the nuclear energy option through the development and availability of nuclear plants and supporting infrastructure that can be built, operated, and eventually decommissioned in a safe, secure, environmentally sound and cost-effective manner[4].

Nuclear Power: Future

In light of the resurgence of interest in nuclear power, various scenarios of a U.S. nuclear future out to the year 2050 are being discussed, including (1) maintaining the current number of nuclear reactors without reprocessing (although some may be retired and replaced by new ones); (2) significantly increasing (doubling or even tripling) the number of reactors without reprocessing: and (3) significantly increasing the number of reactors while closing the fuel cycle by reprocessing and recycling spent fuel.

The Energy Policy Act of 2005 (EPAct) was the first comprehensive energy legislation in the U.S. in over a decade. Among its many provisions, EPAct authorized the *Nuclear Power 2010* program[5], a joint government/industry endeavor to accomplish the following: (1) identify new nuclear reactor sites, (2) bring to market advanced standardized nuclear reactor designs; and (3) demonstrate improved regulatory licensing. It also authorized the implementation of Federal loan guarantees and other financial incentives. Spurred by this program, private industry has announced plans to develop combined construction and operating license applications for some thirty (30) new nuclear power plants. Several of these applications already have been submitted to the NRC.

In recent years, President George W. Bush proposed a new initiative[6], the *Global Nuclear Energy Partnership (GNEP)*, to spur the global growth of nuclear power while simultaneously reducing the threat of nuclear weapons proliferation. In particular, according to Clay Sell, Deputy Secretary of Energy[7]:

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[3] *The Future of Nuclear Power: An Interdisciplinary MIT Study*, ISBN 0-615-12420-8, 2003, http://web.mit.edu/nuclearpower/ **.**

[4] APS Panel on Public Affairs, *Nuclear Power and Proliferation Resistance: Securing Benefits, Limiting Risk*, May 2005, http://www.aps.org/policy/reports/popa-reports/index.cfm**.**

[5] See the DOE website http://www.ne.doe.gov/np2010/neNP2010a.html**.**

[6] See the DOE website http://www.gnep.energy.gov/gnepProgram.html.

[7] Foreign Press Center Briefing, Washington DC, Feb 16, 2006, http://fpc.state.gov/fpc/61808.htm**.**

> *"…The first element [of GNEP] is to expand dramatically the use of nuclear power here in the United States……. from a public policy standpoint we're shooting for 300 reactors in 2050; that's a significant increase. That's what we think would be appropriate to meet our energy needs as well as to manage our greenhouse gas emissions and that's going to require significant advances in technology."*

In order for the more ambitious of these ideas to have any chance of success, the nation will require a greatly enhanced nuclear workforce. On the international scene, the Organization for Economic Co-Operation and Development (OECD), through its Nuclear Energy Agency (NEA), also has voiced concern about maintaining an adequately trained nuclear workforce[8].

Homeland Security

The tragedy of September 11, 2001, has brought an intense focus on the issue of our national preparedness against terrorism of all varieties. For emergencies involving a terrorist action, or an accident at a nuclear reactor, experts must be ready to respond at all times. So it is very important to attend to the nuclear workforce needs of the Department of Homeland Security, the Department of Defense, the Nuclear Regulatory Commission, and specialized areas of the Department of Energy. An important example of the latter is the Nuclear Emergency Support Team from DOE's National Nuclear Security Administration that travels to the site of a suspected nuclear or radiological weapon to mitigate a situation of that kind. As for the NRC, it is the Nation's safety net for dealing with an accident involving a nuclear reactor.

The American Association for the Advancement of Science (AAAS) and the American Physical Society (APS) have prepared a report[9] on the status of nuclear forensics as a tool in the war against terror. Its major conclusions are that nuclear forensics is an essential weapon in the fight against nuclear terrorism, but the U.S. is severely under-prepared in this area for the post-9/11 world. That report makes recommendations for addressing this issue, as do other studies[10].

Nuclear Weapons Complex

One might expect that the reduced university-based training opportunities in nuclear science and engineering would have had a dramatic effect on the manpower levels in that sector. This does not appear to have been the case[11]. It is understandable from

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[8] Statement by the NEA Steering Committee for Nuclear Energy on a government role to ensure qualified human resources in the nuclear field, 2007: http://www.olis.oecd.org/olis/2007doc.nsf .

[9] *Nuclear Forensics: Role, State of the Art, Program Needs*, AAAS-APS Joint Report, February 2008, http://www.aps.org/policy/reports/popa-reports/index.cfm.

[10] See http://homeland.house.gov/SiteDocuments/20071010175138-84437.pdf (testimony of Dr. Carol Burns, LANL). Data have also been collected (in 2004) by the National Science and Technology Council (NSTC) Interagency Working Group on Critical Workforce Needs (data compiled by Dr. Beverly Berger, Director of University Partnerships at the National Nuclear Security Administration). See also the 2004 estimate provided by the DOE/NSF Nuclear Science Advisory Committee (NSAC) report: http://www.sc.doe.gov/np/nsac/docs/NSAC_CR_education_report_final.pdf. The NAS/NRC has also recently (early 2008) commenced a study of these issues.

[11] Testimony of Thomas Hunter, Director of Sandia National Laboratories, to the Senate Energy and Water Development Appropriations Subcommittee (2007): *"I think I'd be remiss if I did not note that few threats to this country's future loom as large as our chronic lack of investment in*

the point of view that the design and construction of nuclear weapons will never be a part of publicly available nuclear science and engineering curricula. In the past, many workforce members, especially at the technician levels, were trained on site by Ph. D.s who after earning their academic degrees then received relevant experience within the weapons complex. This may explain why the steady and precipitous 40-year decline in the number of Ph.D.'s granted each year in nuclear chemistry to the current low single digit numbers does not appear to have had a deleterious effect on our nuclear weapons programs. The recent downsizing and reconfiguring of the weapons laboratories, and uncertainties associated with the stockpile stewardship program have helped mask these effects. However, in the foreseeable future, the nation will need to produce a significant number of talented, well-trained nuclear scientists and engineers, nuclear physicists, nuclear chemists, radiochemists, health physicists, mathematicians, and computer scientists at the Ph. D. level in order to initiate new efforts in nuclear forensics and other parts of the Homeland Security portfolio, and to replace the many members of the weapons workforce trained a generation or more ago who have recently retired.

Manpower and Training

These manpower issues have been discussed for several decades, but almost exclusively from the perspective of university-based training programs. Thus, as these programs have waxed and waned – due to such factors as apparently static or diminishing workforce demand, retirements, less emphasis in the academic world, and highly variable Federal investments in nuclear science and engineering education – *de facto* "work-arounds" (essentially training their own personnel) have developed in industry and the national weapons laboratories. However, it seems very likely that this will not be sufficient in future years. Hence, because of their close linkage, the public, private, and defense-related manpower and training issues should ideally be viewed in a composite manner. Of course, national security concerns make this a difficult undertaking. But this report, the AAAS–APS document on Nuclear Forensics, and the work cited in footnote 10 are contributions to this exercise.

Purview and Logistics for This Study

To undertake this study, the Committee on Energy and Environment of the APS Panel on Public Affairs (POPA) established a working group (WG) of experts on issues facing the nuclear power industry (Appendix A). This group convened two workshops (on July 30-31, 2007, and November 5, 2007) to ascertain the current state of the civilian nuclear power workforce and related educational facilities, and to assess the nation's readiness to meet future civilian nuclear power workforce challenges. It also consulted many reports and analyses pertaining to other parts of the nuclear workforce. This report focuses primarily on nuclear scientists and engineers who have at least a Bachelor's degree. An assessment of the adequacy of the technician and construction workforces was not a primary goal of this study.

At the first workshop the WG heard presentations given by experts from government, universities, and private industry (Appendix B). Between the two workshops, members

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science and engineering and the education systems that support it……. One thing we find about these laboratories is they not only are places of excitement because of the work, but they're also places of values and character and they support the national interest, and that brings a lot of the right people to our laboratories. So I can report, basically, that we're able to get the people we generally need, but the national problem is one that's very significant and one I think all of us can do more to try to help."

of the WG conducted site visits to several university reactors (North Carolina State, MIT, and University of CA-Davis). In addition, a member of the WG visited the nuclear engineering program at South Carolina State University, one of the Historically Black Colleges and Universities (HBCU), which recently established an undergraduate degree program in nuclear engineering in collaboration with the University of Wisconsin-Madison (including distance learning activities using North Carolina State's reactor). The WG devoted the second workshop to analyzing the data received from the panel of experts, university nuclear engineering departments, administrators and faculty at the various university reactors, and the site visits.

Organization of Report

Using information from the study, this report provides the following: (1) a partial overview of Federal support for university nuclear science and engineering research and education; (2) a summary of past reports on these topics and on the closely-aligned fields of nuclear chemistry and radiochemistry, and on radiological health physics; (3) a discussion of the impacts of DOE's *Innovations in Nuclear Infrastructure and Education (INIE)* program; (4) the results of a survey of the needs of those facilities if they are to play a significant role in the U.S. nuclear future; (5) a discussion of the status of facilities for measuring fission and neutron-capture actinide cross sections, which are crucial for designing and implementing advanced nuclear reactor fuel cycles; (6) findings relative to the workforce and educational facilities, and their adequacy to meet both public and private future nuclear challenges; and (7) a summary and recommendations. Appendix C contains a list of common acronyms found throughout the report.

Audience

This study is intended for use by the Executive Branch of the Federal government and members of Congress, state governors and legislators, university administrators and faculty, and the physics community at large.

2. Federal Support for University Nuclear Science and Engineering Research and Education

Funding for U.S. university nuclear science and engineering research and education is heavily dependent upon a single source for the vast majority of support: previously DOE and now the NRC. Therefore, it is no accident that the vitality of the nation's university nuclear science and engineering education and infrastructure program closely tracked funding support provided by DOE over the last 15 years.

As shown in Fig. 2.1, as DOE's funding increased in the decade 1997 through 2007, undergraduate student enrollment in nuclear engineering increased in concert – quadrupling from a low point of 480 students in 1999 to a high of 1,933 in 2007. For nuclear engineering students registered at minority-serving institutions, DOE support created opportunities where none had existed before. While other factors[12] contributed also to this dramatic increase in undergraduate enrollments, responses received from the WG's survey clearly showed that increases in Federal funding were an important factor.

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[12] e.g. growing public concern about global warming, positive Presidential and Congressional statements in support of nuclear energy, more aggressive recruiting, broadening the names and academic emphases of many departments, and recently increased salaries and job opportunities for nuclear engineers.

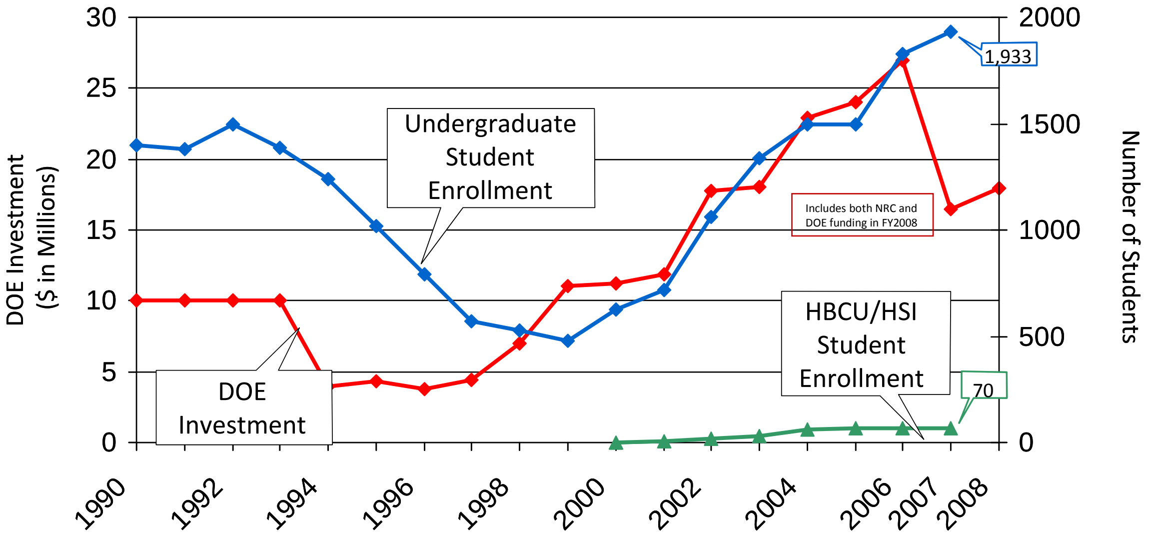

Fig. 2.1. Past DOE investments in university programs and undergraduate enrollments in nuclear engineering[13]. In FY 2007 the DOE university budget was $16.5 million. For FY 2008, aside from $ 2.9 million remaining at DOE for university reactor fuel services, Congress transferred $15 million for the remaining university programs to the NRC.

2.1. Background and History

In the aftermath of the accidents at Three Mile Island in 1979 and Chernobyl in 1986, DOE support for nuclear science and engineering education declined precipitously as industry construction of new plants ceased and student interest and career opportunities declined. In 1997, the President's Committee of Advisors on Science and Technology (PCAST) issued a report that urged President Clinton to reinvest in university nuclear science and engineering research and education[14]. PCAST also urged him to establish the Nuclear Energy Research Advisory Committee (NERAC) to provide advice to DOE on this reinvestment. In the mid-1990s, the Clinton Administration recognized the potential for a resurgence in nuclear technology, and constituted NERAC in 1998 to advise DOE as it began reinvesting both funds and management attention to rebuilding the educational infrastructure for nuclear engineering, health physics, and to a more limited degree, nuclear chemistry and radiochemistry. This support was implemented by creating a powerful suite of 11 targeted programs (see Appendix D).

DOE developed, refined, and optimized these programs over the course of a decade and made significant contributions to the impressive resurgence currently underway in nuclear science and engineering education programs across the United States. Perhaps the most influential of these programs was the *Innovations in Nuclear Infrastructure and Education (INIE)* program, which encouraged the development of strategic consortia among the universities, the DOE national laboratories, and industry, and the leveraging of resources made available by the partners.

2.2. A Reversal of Policy

When DOE released its FY2007 budget request, it announced that it had completed its mission in the area of nuclear science and engineering education and made plans to

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[13] Data source: DOE.

[14] http://www.ostp.gov/cs/report_to_the_president_on_federal_energy_research_and_development

terminate the program. DOE proposed essentially zero funding for nuclear technology education for both FY2007 and FY2008. This signaled a significant reversal of fortune for U.S. nuclear technology education not seen since the early 1990s. DOE proposed to return to the practice of those years by providing only basic fuel services for university research reactors under a new infrastructure program.

In FY2007, Congress rejected DOE's proposal to terminate the program and instead provided $16.5 million – far less than the $27 million the program received in FY2006 (see Fig. 2.1). In FY2008, Congress again rejected ending the program and allocated $17.9 million in the FY2008 Consolidated Appropriations Act. Of this amount, $2.9 million remained at DOE for university reactor fuel services, and Congress transferred to the NRC $15 million for the rest of the programs. While these funds will defer to some extent the erosion of nuclear science and engineering education in the U.S., they are not sufficient to maintain vital elements of the nation's programs, particularly the highly successful INIE program. It was last funded in FY2006.

3. Summary of Past Reports Related to U.S. Nuclear Workforce Readiness

Given the evident Federal interest in expanding nuclear power, safeguarding its nuclear weapons complex, defending against nuclear and other forms of terrorism, providing adequate healthcare, and promoting excellent occupational health and safety, it is important to evaluate the readiness of the nation's nuclear workforce and its educational facilities for future possibly significant expansions. In the following subsections we summarize the findings of several reports issued over the years on this issue.

3.1. Nuclear Science and Engineering Education

Over the past two decades, a number of reports have highlighted the challenges facing both nuclear science and engineering education and university-based research and training reactors. Appendix E lists some of the most influential ones. The major conclusions are as follows:

- **There will be a continuing, long-term, significant need for nuclear scientists and engineers in industry, government, and academia, across a wide range of disciplines.** As an example, a recent report from the American Nuclear Society (ANS) states, "*It is clear that the growing problems associated with the interface between nuclear weapons and nuclear power will increasingly require innovative technical and policy solutions and people who are literate, trained, and educated in nuclear processes.*"[15]

- **Some agency of the Federal government must be in a stewardship position with respect to nuclear science and engineering education, and the designated agency must have the resources necessary to support the widespread needs for the development and maintenance of human resources, facilities, and basic and applied research.** A recent National Academies study[16] emphasized that university nuclear science and engineering

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[15] *Nuclear's Human Element,* Special Committee on Federal Investment in Nuclear Education, American Nuclear Society, Dec. 2006. http://www.ans.org/pi/fine/docs/finereport.pdf

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

infrastructure support should receive a high priority from its steward agency, which at the time was DOE's Office of Nuclear Energy, Science and Technology (DOE-NE) and now is the NRC.

- **Federal support for the nuclear science and engineering disciplines has been extremely effective in improving the quantity and quality of our nuclear technology expertise and expanding the university infrastructure for nuclear research and training.** Previous reports recommended a variety of programs and practices that were either implemented by DOE or had the potential for implementation and success. These reports urged Congress to retain a separate funding line for nuclear science and engineering university programs in future appropriations bills. The recent National Academies report also concluded that the Federal government should include university infrastructure support in its budget at the levels authorized by the Energy Policy Act of 2005[17].

3.2. Nuclear Chemistry and Radiochemistry

Nuclear chemistry and radiochemistry are two fields that overlap in many ways and often are grouped together. Simply put, radiochemistry is the study of radioactive elements using chemical techniques, focusing on their radioactive characteristics. Nuclear chemistry is the study of the fundamental properties of nuclei, both radioactive and non-radioactive, using chemical techniques. It is quite close to the field of nuclear physics. To be more specific, experts often group Ph.D. nuclear chemists and radiochemists into six categories according to the following research interests:

(1) Fundamental nuclear chemistry
(2) Chemistry of radioactive elements
(3) Analytical applications
(4) Nuclear probes for chemical studies
(5) Tracer techniques and labeled compounds
(6) Nuclear medicine and radiopharmaceuticals.

Over the past three decades, various groups have reported on the status of nuclear chemistry and radiochemistry (see Appendix F). The Division of Nuclear Chemistry and Technology (DNCT) of the American Chemical Society (ACS) initiated a study in 1977 on the status of the training of nuclear chemists and radiochemists and published its findings in 1979. This was probably the first such study and was due to members' concerns that *"the vigor and magnitude of academic training in nuclear and radiochemistry were declining due to shrinkage in faculty, students, and research funding"*[18]. Those fears were confirmed, and although 68 Ph.D.s (24 in nuclear chemistry and 44 in radiochemistry) were awarded in 1976, it was estimated that only 30 (total for both fields) would be awarded in 1980-81, a decrease of more than a factor of two! They warned that these numbers were inadequate and would be in serious imbalance with the nation's needs by 1988. More recent studies have also warned of impending shortages, and even the ultimate demise of fundamental nuclear chemistry education in the U.S. In addition, we have witnessed the absorption of various aspects of radiochemistry into other disciplines. The major conclusions from past reports are the following:

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[17] The Energy Policy Act of 2005 authorized $50.1 million in FY2008 and $56 million in FY2009.
[18] See Reference 1 in Appendix F.

- **There has been a continuing dramatic decrease in the number of Ph.D.s earned annually in nuclear chemistry, as shown in Fig. 3.1.** It reflects the fact that only a handful of U.S. university chemistry departments currently have professors with active research programs in nuclear chemistry. They are needed to train the next generation of Ph.D.s in fundamental nuclear chemistry. **Thus, advanced education in nuclear chemistry education is all but extinct in the United States.**

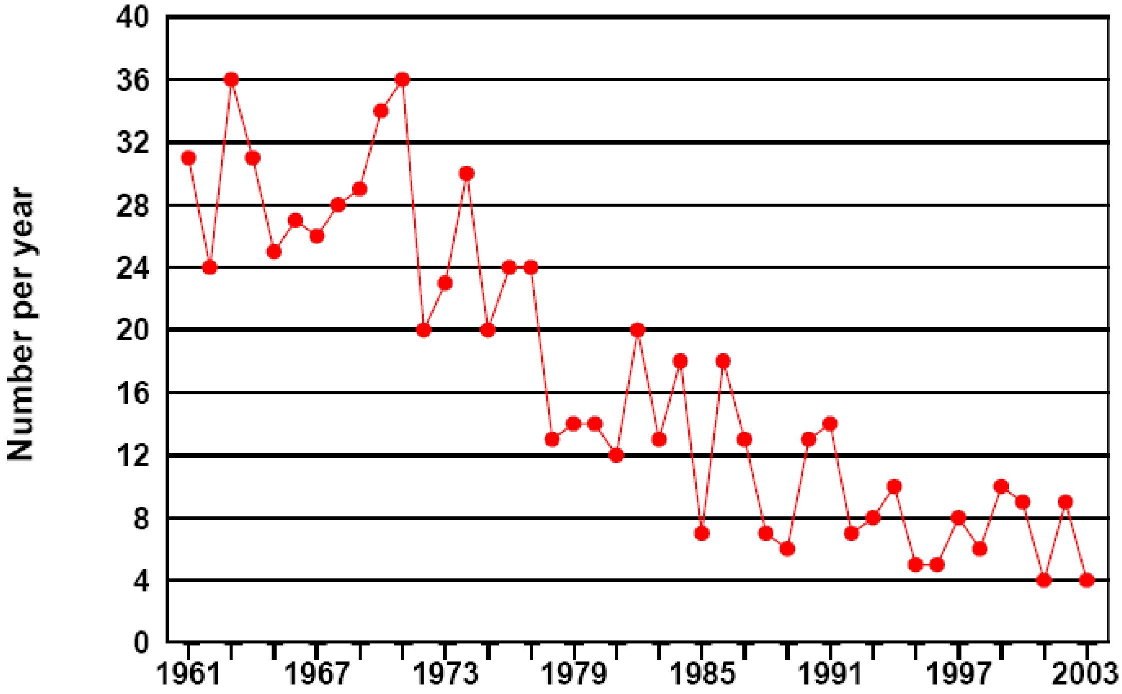

Fig. 3.1 Numbers of nuclear chemistry Ph.D.s earned at U.S. universtities: 1961-2003[19].

- **This is a crisis situation that must be addressed promptly. If nuclear chemistry and radiochemistry education programs are not reinvigorated, the U.S. will lack the expertise required to pursue promising advanced research and development (R&D) in a myriad of disciplines**. In addition to processing both fresh and spent fuel for nuclear reactors, including basic research on spent fuel separations and transmutation technologies, nuclear chemistry and radiochemistry are also extremely important to the nation's security and health in the following cross-cutting roles: (1) nuclear weapons stockpile stewardship, (2) nuclear forensics and surveillance of clandestine nuclear activities, (3) monitoring of radioactive elements in the environment, (4) production of radioisotopes, and (5) preparation of radiopharmaceuticals for therapeutic and diagnostic medical applications. (See Ref. 6 in Appendix F.)

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[19] Source: NSF Survey of Earned Doctorates. Nuclear chemistry was dropped from the NSF database in 2004 when fewer than 2 Ph.D.s were earned. These data are consistent with those compiled by the National Opinion Research Center at the University of Chicago. Data do not include radiochemistry Ph.D.s.

- **Many students have been attracted to careers in nuclear chemistry and radiochemistry by the two ACS-DNCT sponsored 6-week summer schools for undergraduate students.** Supported in part by DOE, the number of applicants was more than 100 in 2004, indicating the interest among undergraduates in these fields. The recent, comprehensive DOE/NSF report on *Education in Nuclear Science* by Cerny *et al.* (see Ref. 5 in Appendix F) recommended establishment of a third summer school at a new site and a nationwide Center for Nuclear Science Outreach. Unfortunately, many who want to pursue Ph.D.s in these fields cannot find university programs with qualified faculty to advise them. Retiring faculty are not being replaced. The scarcity of tenure-track faculty and programs in nuclear chemistry and radiochemistry at U.S. universities is indeed in a disastrous state of affairs.

- **The Federal government must take an active role in helping to reinvigorate the fields of nuclear chemistry and radiochemistry, primarily by providing incentives for universities to add tenure-track faculty positions, allocating funding for university research and student scholarships and fellowships, and encouraging effective means of outreach to the general public. A funding "home" for such activities needs to be designated.**

Thus, in 2008, after the many recommendations and warnings issued in these and other reports have gone unheeded for so many years, nuclear chemistry education appears to be nearly extinct in U.S. universities. In addition, retirements and workforce downsizing are taking a significant toll in the expert workforce available at the national laboratories for training specialists in the nuclear science relevant to our nuclear weapons and nuclear forensics programs, and other aspects of our Homeland Security efforts.

3.3. Health Physics

As for any large-scale enterprise involving radioactivity, the status of the health physics (HP) workforce and its training facilities must be considered when studying U.S. future nuclear readiness. For occupational safety and the protection of the public, HP professionals are employed in many sectors, including the commercial nuclear power industry, DOE's national laboratories, homeland security, the NRC, the military, and medical facilities.

Recent reports and surveys have examined the health physics workforce needs and arrived at the following conclusions:

- **The nation's health physics capabilities will be impacted negatively over the next decade due to the number of expected retirements coupled with inadequate numbers of graduates entering the field.** Fig. 3.2 provides the combined total (as well as breakdown by degree) of undergraduate and graduate students graduating from HP programs. On the other hand, the 2004 retirement rate in the U.S. was about 167 per year[20]. Assuming that an equal percentage of individuals retire over a forty-year working lifetime, the number of existing health physics program graduates, approximately 130-200 per year (2004-2007 data below), does not allow for much increase in the demand for their services.

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[20] *Human Capital Crisis Task Force Report*, Health Physics Society, July 2004, http://hps.org/documents/ManpowerTaskForceReport.pdf.

- **In the near term, it will become increasingly difficult to find an adequate number of technical level radiation protection professionals for the nuclear energy enterprise[21].** According to the Health Physics Society's Task Force Report, operational nuclear power plants employ 2,940 permanent radiation protection staff, with 12% of the positions having a minimum Bachelor's degree in health physics or a related field; DOE contractors and national laboratories employ 403 full-time radiation protection staff, with practically all having a Bachelor's degree; and the NRC employs 177 health physicists. Thus, nuclear energy employers will have to compete with these and diverse other career options for health physicists, not the least of which are options involving homeland security or the thousands of hospitals that have diagnostic or therapeutic, radioisotope or radiation treatment facilities[22].

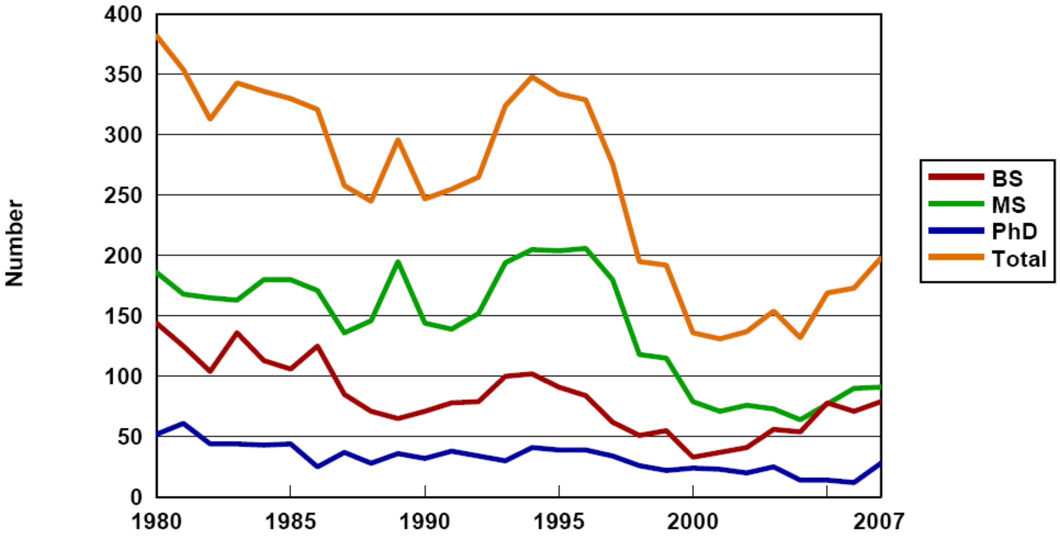

Fig. 3.2 Number of students graduating from health physics programs, including Bachelor's, Master's, and Ph.D. degrees[23], 1980-2007.

4. Research and Training Reactors and INIE University Consortia

Appendix E lists several reports that document the status of university research and training reactors. Their number has decreased from 63 in the late 1970's to 25 today. Recently a number of them have been decommissioned, including those at Cornell University and the University of Michigan. During FY2006, DOE's INIE Program provided $9.41 million to six consortia consisting of both the higher power – usually 1 MW and above – research reactors as well as the lower power – usually less than 1 MW – training reactors. Research reactors perform state-of-the-art experiments in a

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[21] *NEI Annual Survey 2003*, Nuclear Energy Institute, Washington, D.C., 2004.

[22] *AHA Hospital Statistics 2003*, American Hospital Association, http://www.ahastatistics.org.

[23] Source: Oak Ridge Institute for Science and Education, under contract with DOE, annual surveys of enrollments and degrees in academic programs with majors or programs equivalent to a major in health physics. Other ORISE data indicate that the number of institutions with health physics programs decreased from 60 to 29 between 1991 and 2007.

variety of disciplines, including nuclear engineering, materials science, physics, and medicine. They also provide irradiation services for private industry and other researchers. Training reactors provide hands-on experiences for students, including both nuclear engineering and health physics students, as well as reactor technicians, and are an indispensable component of the nuclear science and engineering infrastructure.

The WG surveyed the INIE consortia listed in Appendix G to ascertain the effectiveness of the INIE program in stabilizing and enhancing their operations. However, the WG recognized that decommissioning any particular reactor is an inherently local decision.

Appendix H contains four tables that display results from the survey, including: (Table 1) each reactor's power and whether it is under threat for decommissioning; (Table 2) the most important reactor needs; (Table 3) the minimum one-time funding required to bring the reactor systems up to an acceptable level of modernization and the annual funding required to maintain that level; and (Table 4) the average annual funding received since 2000 from governmental, industrial, and other private sources. Based on the survey, as well as site visits to select locations, the WG concluded the following:

- **The INIE consortium program had numerous significant successes. It has:**
  (1) Contributed to the significant increase in the number of undergraduates studying nuclear science and engineering.
  (2) Provided important training opportunities for students studying nuclear engineering, health physics, and other related disciplines.
  (3) Stimulated the hiring of new tenure-track faculty.
  (4) Provided seed money for a number of major infrastructure and instrumentation purchases and upgrades, thereby garnering substantial matching funds from universities.
  (5) Demonstrated to university administrators that university reactors are a national asset, valued by the Federal government, and thus a worthwhile long-term university investment.
  (6) Fostered important collaborations among members of each consortium, and with national laboratories and institutions outside the consortia.
  (7) Launched major new research thrusts that led to the leveraging of Federal funds among agencies, such as with the National Science Foundation.
  (8) Played an important role in freeing a number of university reactors from local threats of decommissioning. It is apparent that the INIE Program played a major role in stabilizing many of their futures.
  (9) Helped establish a new undergraduate nuclear engineering program at South Carolina State University, one of the Historically Black Colleges and Universities, which directly increased the number of minorities entering the field[24]. This program is the first to be created in over a quarter-century at any

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[24] This collaboration is the result of the DOE-NE *Program in Nuclear Engineering and Health Physics*, which pairs minority institutions with institutions offering a nuclear engineering degree to increase the number of minorities entering the field.

U.S. university and is the only undergraduate nuclear engineering program located at an HBCU[25].

- **Major funding programs at the level of INIE take on the order of five years to ramp up to a steady state. Thus, it was not a productive decision to stop funding INIE after FY2006, just as it had stabilized.**

- **The INIE program could be improved in the following ways. It should:**
  (1) Peer-review new consortium proposals and periodically perform rigorous peer-reviews of ongoing consortia[26]. This would achieve the best overall program.
  (2) Negotiate with universities to: (a) provide a one-time source of funds to refurbish existing reactors, and (b) ensure sustainable Federal funding for them.
  (3) Explore opportunities for distance training, as utilized by South Carolina State University, as a means of creating the necessary nuclear workforce without having to develop additional university reactors. Also, it is critical that programs at two-year colleges for training nuclear technicians have access to such distance learning opportunities.
  (4) Promote the enhancement of existing and the establishment of new two-year technician training programs at technical community colleges[27].
  (5) Collaborate with nuclear vendors and utilities to expand undergraduate student internships, graduate student traineeships, cooperative education opportunities, and training on reactor simulators at their facilities.

- **Finally, due to the elimination of the INIE program, the future of university research and training reactors is uncertain**.

5. Facilities for Measuring Actinide Cross Sections

A wealth of high precision nuclear data is needed to support the design of future nuclear reactors, including advanced light water reactors and Generation IV systems[28]. Without

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[25] It has been operational since 2000, beginning with 5 students, and recently produced its first two graduates. It is in partnership with the University of Wisconsin, and the students also participate in distance training with the reactor at North Carolina State University.

[26] The INIE program originated as a competitive peer-reviewed program. However, after selection of the consortium members, there was a rudimentary annual DOE review. This process did not result in any mandatory changes or loss of funding for underperformance. DOE also ran an annual review meeting at each ANS winter meeting. Nothing binding resulted from these meetings either.

[27] For example, the INIE Midwest Consortium helped to establish a Nuclear Technology Associate's Degree at Linn State Technical College's Advanced Technology Center. The program's primary focus is to graduate radiation protection technicians. Linn Tech is also developing three more degree programs: quality control technology, instrumentation and controls technology, and reactor operations technology.

[28] Advanced Light Water Reactors are the greatly improved reactors to be deployed over the next ten years. After that, the next generation to be brought online around 2020 and beyond is called

them, simulation studies will not be accurate enough to lead to reliable designs and conclusions[29]. To predict the performance of a total reactor system, researchers must know the various cross sections for isotopes such as plutonium-239 (Pu-239) to undergo neutron capture to plutonium-240 (Pu-240). Also, they must know the probability for Pu-240 to fission, that is, to split into two large fragments and release large amounts of energy that can be used for electricity generation[30].

From their systems analyses, DOE researchers have identified the cross sections listed in Appendix I as being of particular importance. The U.S. has neutron source facilities, *e.g*. the Los Alamos Neutron Science Center (LANSCE), that can be used for many of the cross section measurements, and capabilities not present in the U.S. usually can be found elsewhere[31].

Many of the fission and neutron capture cross section measurements are extremely challenging and entirely new techniques need to be developed. This is fertile ground for Ph.D. research work in nuclear physics and nuclear chemistry, and should be eligible for funding support from both DOE's Office of Science and the National Science Foundation.

Finally, much more fundamental work is needed to understand the basic physics of nuclear isotopes, fission, and neutron capture processes. A better theoretical understanding of the nuclear physics would provide better relative estimates of cross sections and their excitation functions, and reduce the uncertainties in many applications. Robust theoretical and experimental programs should be conducted in parallel and will benefit greatly from synergistic interactions.

6. Personnel for the Nuclear Workforce of Tomorrow

We first consider the potential supply of nuclear engineers needed for nuclear power generation between now and 2050. We consider three scenarios: (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.

Figures J-1 to J-4 and Tables J-1 to J-3 in Appendix J give recent data on nuclear employment and other post-degree activities of newly-trained nuclear engineers. Continued study seems to be substantially the most popular post-degree endeavor for Bachelor's and Master's degree graduates; for PhD's, employment within DOE, a university, or working abroad are the most popular.

Generation IV. Examples are the Very High Temperature Reactor that could produce hydrogen for the transportation industry and the sodium-cooled fast neutron spectrum reactor that could be used to recycle spent fuels containing the actinides.

[29] *Nuclear data sensitivity, uncertainty and target accuracy assessment for future nuclear systems*, G. Aliberti *et al., Ann. Nuc. Energy*, **33** (2006) 700, online at http://www.sciencedirect.com.

[30] For a simple description of nuclear fission and the generation of electricity in nuclear reactors, see http://www.howstuffworks.com/nuclear-power.htm.

[31] Important international laboratories are those at the Neutron Time of Flight facility at CERN in Geneva, Switzerland; the Institute for Reference Materials and Measurements in Geel, Belgium; and the Joint Institute for Nuclear Research in Dubna, Russia.

Perhaps the most striking aspect of the data in Fig. J-1 is that reactor vendors hire far more mechanical engineers than nuclear engineers. In fact it is common in the commercial nuclear industry to hire non-nuclear engineers and provide them with nuclear-related training. Retirees from the nuclear Navy have also played a role.

Scenario 1: Maintaining The Current Power Reactor Fleet With No Reprocessing.
With approximately 35% of nuclear workers reaching retirement age in the next five years[32] (detailed NRC data on retirement eligibility contained in Table J-4 is consistent with this projection), industry will very likely see some increase in engineering hiring across the board. This will heighten demands for nuclear engineering education, whether supplied by university programs or by the employers themselves. But the "status quo scenario" (the number of nuclear reactors remains fixed out to 2050 with no reprocessing) has a chance of being sustainable under these educational modalities.

Scenario 2: Doubling the Number of Power Reactors With No Reprocessing.
Doubling the number of nuclear reactors to about 200 by 2050 will require a very significant augmentation of the nuclear workforce, as estimated below:

Year	Approximate Number Required
2008	8,000*
2020	12,500
2030	15,000
2040	18,000
2050	21,500

Table 6.1. Estimated growth in the number of engineers with nuclear training needed to double the number of commercial nuclear reactors by 2050. Values include the needs of vendors, utilities, and the NRC[33]. (*): The approximate number employed today, taken from Fig. J-1.

These numbers are consistent with estimates from the Nuclear Energy Institute, which predicts that 175-225 additional engineers with some nuclear training will be needed per year over the next several years, rising to 225-275 per year by 2012[34]. Thus, moving out to the year 2050, vendors, utilities, and the NRC will need to increase their ranks by about 300 engineers with some nuclear training per year, plus replace retirees. This growth in manpower is a direct result of what would be an increasing demand for significantly improved reactor designs, increased reactor operations at the utilities, and a much greater oversight burden at the NRC.

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[32] *Nuclear Renaissance Presents Significant Employment Opportunities, NEI Tells Senate Panel*, Testimony at U.S. Senate Hearing by Carol Berrigan, Director of Industry Infrastructure, Nuclear Energy Institute, November 6, 2007; *NEI 2007 Workforce Survey*.

[33] Data from 2020 and beyond obtained from Dallas Frey, Director of Staffing & Organizational Development, Westinghouse International Headquarters, Monroeville, PA.

[34] *Nuclear Engineers and Staffing,* Workshop Presentation to the Working Group by Carol Berrigan, Director of Industry Infrastructure, Nuclear Energy Institute, Workshop held in Washington, D.C., Nov. 2007.

According to Table J-1 in Appendix J, approximately 20% of the Bachelors, 35% of the Masters, and 25% of the Ph.D. graduates in 2006 accepted employment with a vendor, utility, or the Federal government. Assuming that those in the "Not Reported" and "Still Seeking Employment" categories will have a similar distribution, the number of new graduates at all degree levels entering nuclear employment is about 160. This is a reasonable baseline figure.

Hence, assuming that the supply of nuclear engineers coming from university training programs follows recent trends, employers will need to train significantly more non-nuclear engineers to do nuclear engineering tasks than they do now. However, it is doubtful that the massive reactor building campaigns necessary to double the number of reactors by 2050 could thrive under such a burden. The clear message is that our capability for university-based training of nuclear scientists and engineers cannot be allowed to diminish further than it already has. Indeed, the signs seem obvious that our nation's college and university-based nuclear science and engineering programs will be asked to do a great deal more than they are at the present time. But due to the elimination of the INIE program, the future for university research and training reactors is highly uncertain. Enhancing the university-based programs to meet this emerging demand will require a significant long-term Federal effort.

Scenario 3: Doubling the Number of Reactors and Reprocessing Spent Fuel

This scenario has all the workforce challenges of the second scenario, plus the need for the highly trained nuclear chemists and radiochemists who are indispensable for reprocessing.

France has been operating spent fuel reprocessing facilities for some time, so it is interesting to examine how that country satisfies its nuclear workforce needs for these disciplines (See Appendix K). Apparently France is able to maintain its competency in nuclear chemistry, radiochemistry, as well as nuclear engineering by charging its governmental agency that does the reprocessing and related research, namely its Commissariat à l'Energie Atomique (CEA), with educating the workforce according to the country's needs. In the U.S. there is no governmental cadre of nuclear chemists and radiochemists who are charged with education. Those wanting to pursue these fields, especially for research careers, usually are educated under faculty mentors at universities. The growing scarcity of such mentors has thus led to a crisis in the U.S. In the long haul the U.S. will lose ground in its R&D on many fronts, including devising more efficient and safer methods of handling and processing both fresh and spent fuels for all future nuclear energy scenarios. Nuclear chemists and radiochemists with Ph.D.s would be needed to train the large cadre of radiochemical technicians who would carry out most of this work, and they would be needed at universities and national laboratories to spearhead the research that leads to breakthrough radiochemical technologies for spent nuclear fuel separations and reprocessing. Thus, any venture into spent fuel reprocessing, and fulfilling nuclear chemists' and radiochemists' many other cross-cutting roles in such areas as homeland security and public health, will not be possible unless expertise is imported from abroad. This modality is made much more difficult by the requirement that many of these workers must be U.S. citizens. In the U.S., market-driven forces will not be able to produce additional domestically trained nuclear chemists and radiochemists if the educational infrastructure continues to disappear.

Regardless of the future direction of nuclear power in the U.S., there are ancillary technologies that must be developed for a full exploitation of the potential of nuclear energy. One such technology is electricity storage, which could assist nuclear reactors in such ways as load following and stabilizing the voltage and frequency of the electrical grid. The APS previously reported on the challenges of this technology[35].

*Other Nucle*ar Workforce Issues

For the field of health physics, having adequate personnel for nuclear power, public health, and various other forms of radiation protection will become an increasingly difficult problem (see pp. 13-14) unless adequate funding is provided for degreed health physics programs. An area of concern for university faculty who train health physicists is the lack of nuclear power-related experience, which is important since nuclear reactors present unique radiation challenges on a scale not encountered by health physicists working in other radiological endeavors such as medical physics. In addition, retirements are taking a significant toll among this aging faculty workforce.

The homeland security and nuclear weapons aspects of the workforce issue are discussed both overtly (see pp. 6-7 above) and by implication throughout this report. As indicated in footnotes 9-11, these matters have been, and are, being studied carefully by the NNSA, the NSTC, and a number of professional organizations. Although detailed manpower estimates are for the most part not available, it is very clear that for the foreseeable future the nation will continue to need a significant number of talented, well-trained nuclear scientists and engineers, physicists, chemists, mathematicians, and computer scientists to maintain the strength of its homeland security and nuclear weapons programs[36]. These complexes must be safeguarded. This is a clear responsibility of the Federal government.

But overall, it is the responsibility of society as a whole to ensure that the U.S. has a well-trained nuclear workforce for the future. Creating new reactor designs, revolutionary medical applications of radiation, and many other nuclear endeavors present exciting challenges for the future. As such, the nuclear science and technology community should develop programs to encourage faculty colleagues, graduate students, undergraduate students, K-12 students, teachers, and the general public to view fields in nuclear science and technology as exciting areas of research that present intellectually and financially rewarding career paths.

7. Summary and Recommendations

This study considered the readiness of the U.S. nuclear workforce and related educational facilities to meet future challenges in a number of areas, including a possible significant expansion of nuclear power in the U.S., safeguarding the U.S. nuclear weapons complex, defending the country against nuclear and radiological terrorism, development of nuclear forensics capabilities, providing adequate radiological healthcare for its citizens, and promoting occupational health and safety for the nation's workforce.

7.1. Summary

1. After more than three decades since the last nuclear reactor, TVA's Watts Bar Unit 1, began construction, an increasing demand in the U.S. for clean, affordable energy and a sustainable lifestyle has placed renewed positive emphasis on nuclear power as a

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[35] *Challenges of Electricity Storage Technologies,* APS Panel on Public Affairs, May 2007, http://www.aps.org/policy/reports/popa-reports/index.cfm .

[36] This includes the role of physicists and others in ensuring nuclear weapons nonproliferation.

growing share of our energy supply. Plausible scenarios for the future include concepts such as doubling the number of nuclear fission reactors (from about 100 to about 200), and possibly beginning a program of closing the fuel cycle by reprocessing and recycling spent fuel. In order for these ideas to have any chance of success, the country will require an approximate doubling (or more) of its workforce associated with nuclear power. It is far from obvious that this can occur if we continue to rely on the existing unstructured, unpredictable educational modes that are described in this report. Among the ideas discussed are ways to reinvigorate the nation's university-based nuclear training programs via infusion of resources from the universities themselves and from the government, and the need to involve the nuclear power industry even more directly in training its own workforce than it does now.

2. The long stasis in the U.S. demand for new civilian nuclear power reactors led to a greatly reduced interest among undergraduates for nuclear science and engineering programs. This put great pressure on U.S. universities to scale back in these areas. Many did, so that today there are many fewer degree programs available. Retirements are also having a substantial negative impact. However, the DOE has for a period provided dramatically increased funding for these curricula. This played a major role in increasing undergraduate student enrollments in nuclear engineering programs from a low of about 500 in 1999 to over 1900 in 2007. Declaring the problem to be solved, DOE recently attempted to terminate its university programs, prompting Congress to transfer the programs, except for the university reactor fuel services, to the Nuclear Regulatory Commission (NRC). These "feast or famine" gyrations have led to significant instabilities: the number of university nuclear engineering departments has decreased from 66 in the early 1980s to 30 today, and the number of university reactors has dwindled from 63 to 25 during essentially the same period.

3. It should be kept in mind that nuclear scientists, engineers, and technicians specializing in nuclear reactor design, construction and maintenance need to be trained on nuclear reactors and simulators. The diminishing pool of university-based "teaching reactors" may put these training programs in peril. However, students can also be trained at vendor and utility facilities or non-defense-related reactors owned by the government, so there appears to be a need for coordination of these efforts among academia, industry, and government.

4. The continuing, largely static, nuclear engineering workforce needs of U.S. firms have been met through a combination of hiring those trained in university nuclear engineering programs and retraining others whose original expertise was in some other field (usually mechanical engineering). Also, retirees from the nuclear Navy have played an important role. This somewhat *ad hoc* approach may be sufficient as long as the number of nuclear reactors remains relatively static or grows at a slow but steady pace. However, large increases in the number of reactors and/or instituting the reprocessing and recycling of spent reactor fuel are likely to make this *modus operandi* untenable. Dealing with that eventuality will clearly call for approaches in which government, industry, and academia each play a major role.

5. There is also likely to be a severe shortage of nuclear scientists, engineers and technicians in several sectors of government responsible for regulatory, safety, or emergency response matters – both for the nuclear power industry and for other areas of national security concern (e.g. transportation and shipping). Agencies with these responsibilities include (among others) the Nuclear Regulatory Commission (NRC), the

Department of Homeland Security, the Department of Transportation, the state Port Authorities, the Department of Defense, and the Department of Energy[37]. It seems clear that it is mostly the responsibility of Federal and state governments to train and maintain this workforce, though there is a smaller role for private industry as well.

6. One might expect that the reduced university-based training opportunities in nuclear science and engineering would have had a dramatic effect on the manpower levels in the nuclear weapons complex. This does not appear to have been the case. This is understandable, if only from the point of view that the design and construction of nuclear weapons will never be a part of publicly-available nuclear science and engineering curricula. Rather, these workforce members for the most part will be trained *in situ*. Perhaps that is why the steady and precipitous 40-year decline in the number of Ph.D.'s granted in nuclear chemistry – to the point where the numbers each year are now in the low single digits – seems to have had little effect on our nuclear weapons programs. However, with the recent reconfiguring and downsizing of the weapons labs, coupled with an aging (and now retiring) workforce, this situation is confused and uncertain at best (the same is true for many other aspects of the critical technologies workforce). These matters have been, and are, being studied carefully by the DOE-NNSA, the NSTC, and a number of professional organizations because it is clear that for the foreseeable future the Nation will continue to need a significant number of talented, well-trained nuclear scientists and engineers, physicists, chemists, mathematicians, and computer scientists to maintain the strength of its homeland security and nuclear weapons programs.

7. The continually growing use of radiation in medicine, biological research, and in industry has led to a shortage of health physicists and other workers who are trained to use many kinds of radiation sources – tracer radioisotopes, X-ray facilities, positron emission tomography (PET) scanners, medical cyclotrons, etc. A solution to these manpower issues lies primarily in collaborations between academia and private industry.

8. Recent experience has shown the need not only for better measurements of nuclear fission and neutron capture cross sections but also for the development of improved theories of nuclear fission and neutron capture based upon fundamental physics and chemistry rather than the phenomenological models currently in use. This suggests the need for renewed educational programs addressing these issues at U.S. universities and national laboratories.

7.2. Recommendations

1. The federal government should assume significant responsibility for educating the next generation of nuclear scientists and engineers by doing the following:

1.a. Naming a single Federal agency to act as steward for an ongoing, robust university-based nuclear science and engineering education program, and funding it as appropriate.

1.b. Stabilizing the long-term funding and management of nuclear science and engineering education programs, in particular for the university research and training

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[37] For example, the NRC provides the nation's response in dealing with an accident involving a nuclear power plant. The Nuclear Emergency Support Team (NEST) is charged with dealing with suspected terrorist incidents involving nuclear or radiological weapons.

reactor facilities that are so important to the education of nuclear scientists and engineers. It is essential that this be done – the number of such programs cannot be allowed to diminish further.

1.c. Establishing a two-part funding program for university reactors that: (i) negotiates with universities to provide one-time funding to bring each reactor up to an acceptable level of modernization, and (ii) then provides annual Federal funding to maintain that level.

1.d. Helping to establish two-year nuclear technician training programs at community colleges to meet future nuclear workforce needs.

1.e. Helping to establish the use of distance learning methods to exploit training reactor facilities more effectively, thereby making them accessible to students at other campuses, including minority-serving institutions.

1.f. Instituting educational programs that train displaced workers in other engineering and science disciplines to perform nuclear engineering and technology jobs. This task could be carried out in partnership with private sector firms.

1.g. Establishing a cross-cutting workforce initiative that addresses the national security, energy, and public health needs for trained nuclear chemistry and radiochemistry personnel. The initiative should include fellowships and scholarships for students, support for postdoctoral researchers, incentives that stimulate industrial support of faculty positions, effective means of outreach to the general public, as well as increased support for summer schools in nuclear chemistry and radiochemistry.

1.h. Helping to provide adequate funding for degreed health physics programs and ensuring that there is a sufficient number of faculty with nuclear reactor-related experience to train the necessary numbers of health physicists for nuclear power and other industries.

1.i. Continuing and increasing the support from the Department of Energy's Office of Science (DOE-SC) and the National Science Foundation (NSF) for research on the fundamental physics and chemistry of actinide fission and neutron capture, along with measurements of relevant data.

2. Nuclear vendors and utilities should expand undergraduate student internships, graduate student traineeships, cooperative education opportunities, and training on reactor simulators at their facilities.