Assessment of Workforce Development Needs in the Office of Nuclear Physics Research Disciplines

Nuclear Science Advisory Committee
Subcommittee on Workforce Development

July 18, 2014

Overview

Nuclear physics is a key component of the scientific enterprise in the U.S. Nuclear physics research and development also provide the foundation to advance medicine, accelerator and detector technologies, and national and homeland security. To quote the 2013 National Academy of Science [NAS13] report *Nuclear Physics – Exploring the Heart of Matter*: "…nuclear science in the United States is a vital enterprise that provides a steady stream of discoveries about the fundamental nature of subatomic matter that is enabling a new understanding of our world. The scientific results and technical developments of nuclear physics are also being used to enhance U.S. competition in innovation and economic growth and are having a tremendous interdisciplinary impact on other fields …". The Department of Energy's Office of Nuclear Physics (NP) is the primary funding agency for nuclear physics, enabling not only the fundamental research but also the infrastructure to realize this research: the major accelerator facilities and associated large-scale instruments. A key component of the research activities is the training of students and postdoctoral scholars to realize the research and be prepared for future careers in fundamental and applied nuclear science. NP is also responsible for support of critical applications of nuclear science including advances in accelerator science, technology, and research and development of isotopes for a broad range of activities critical to the nation. The NP mission is well aligned with that of the Department of Energy (DOE) whose mission "is to ensure America's security and prosperity by addressing its energy, environmental and nuclear challenges through transformative science and technology solutions [DOE]."

The training of nuclear scientists has traditionally been very broad, requiring the early career scientists to be engaged in a wide range of fundamental experimental and theoretical research and technological activities that prepares them for the full spectrum of careers meeting the nation's needs. As documented in Table 1 and several surveys over the past 10 years, at least 45% of nuclear science Ph.D. recipients have careers outside of fundamental research, providing critical leadership and innovation in medicine, national and homeland security, energy, and other industrial applications. The U.S. also has a long tradition of attracting the best and the brightest from around the world for graduate studies and research in the physical sciences, including nuclear and accelerator sciences. At the same time there are many, highly effective activities that serve to develop and support U.S. students on their paths to becoming leaders in fundamental nuclear and accelerator science and contributing to applications in national and homeland security, medicine, energy, and industry. The nuclear science community and its funding sources have worked to sustain this delicate balance between preparing U.S. students for leadership positions and attracting the best and brightest from around the world.

However, the recruitment and training of U.S. nuclear scientists in fundamental and applied aspects of this discipline is nearing a crisis in critical areas. The 2004 Nuclear Science Advisory Committee (NSAC) subcommittee report on education recommended that "…the nuclear science community work to increase the number of new Ph.D.'s in nuclear science by approximately 20% over the next five to ten years" [NSAC04]. This recommendation was based on a detailed survey that showed a predicted large number of retirements and an anticipated increase in homeland security areas. However, the situation has not improved. The number of new Ph.D.'s per year has been at best flat. A large number of faculty who received their Ph.D.'s in the late sixties and early seventies have retired and are not being replaced at the same rate, as summarized in Figure 1. As NP and the nuclear science community upgrade its world-leading accelerator facilities CEBAF (Continuous Electron Beam Accelerator Facility) and RHIC (Relativistic Heavy Ion Collider), commissions FRIB (Facility for Rare Isotope Beams) which is currently under construction, and plans for a next generation electron-ion collider, it is critical that a highly talented, diverse workforce is available to realize the frontier scientific goals of these facilities and address the technological challenges required to enhance both the science and technology.

In addition, as documented in this letter, an increasingly larger fraction of the leaders in nuclear science received their Ph.D. training outside of the U.S., important subfields of nuclear chemistry and radiation science are almost non-existent at universities, there is insufficient training at universities to meet the demands in accelerator science and related technologies, and there is an increasing demand for scientists with a strong background in large-scale computing and modeling and the associated computer science needed for large-scale concurrent computing. These challenges are compounded because of the requirement that many of the employees at DOE and other government and some industrial laboratories need to be U.S. citizens and eligible for security clearances.

The present letter details the findings of the Subcommittee on Workforce Development of the Nuclear Science Advisory Committee (NSAC). These findings are supported by previous NSAC and National Academy of Science reports, a survey of DOE laboratory directors, data from the American Institute of Physics (AIP) and informal surveys of individuals in specific subfields, as summarized in Appendices III-V. We conclude with our recommendations for programs that could help address these challenges in workforce development. Appendix I provides the charge and Appendix II the list of members of this NSAC subcommittee. Acronyms used in this report are summarized in Appendix VI.

Table 1. Career paths of nuclear science Ph.D.s 5-10 years after the degree. Careers at national laboratories are about equally split between fundamental and applied science and development. Adopted from [NSAC04, NSAC13].

	[NSAC04]	[NSAC13]
University	39%	40%
National Labs	25%	27%
Business/Industry	32%	23%
Government agency	4%	10%

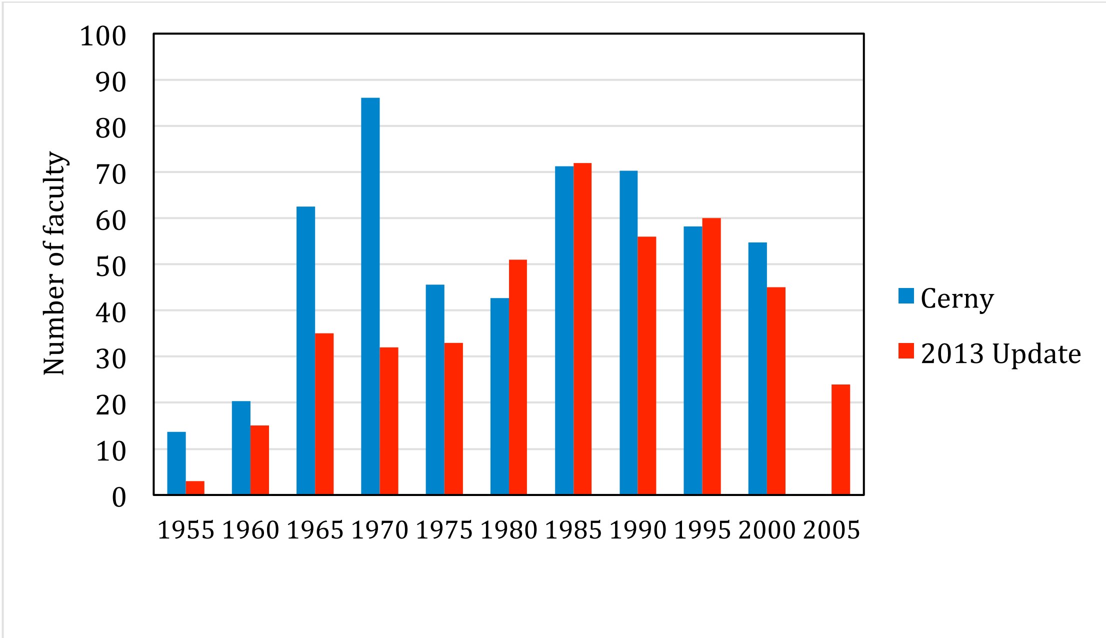

Figure 1. Year of Ph.D. of nuclear physics faculty in 2013 compared to Cerny report [NSAC04].

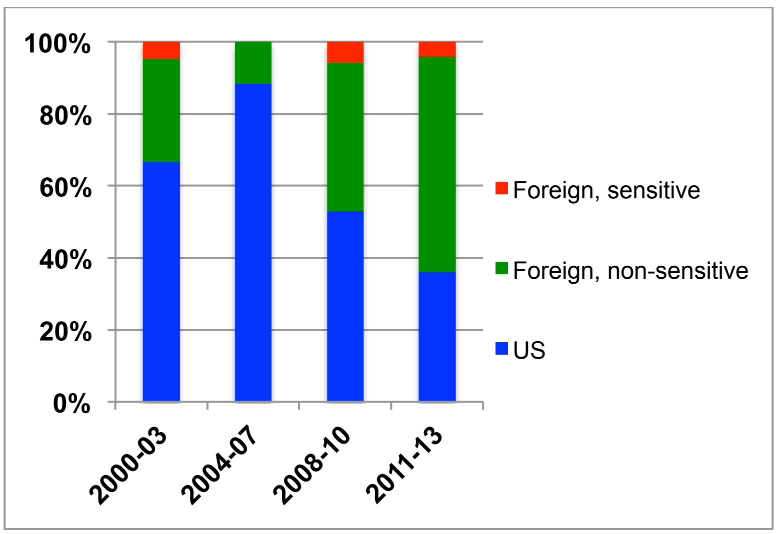

Figure 2. Country of Ph.D. degree of early career award recipients in NP 2000-13. Sensitive countries include Russia and China. Recipient data provided by NP supplemented by survey of individuals.

Findings

Challenges in attracting and training the leaders in fundamental nuclear science and technology. The Office of Nuclear Physics has a long tradition of recognizing individuals for high potential for leadership in nuclear science through the Early Career Award (ECA) and previous Outstanding Junior Investigator (OJI) and Presidential Early Career Awards in Science and Engineering (PECASE) programs. Eighty awards have been made since 2000 with 14% to women and 45% to support theoretical research. In addition to enhancing the scientific and technical contributions of the individuals, these awards also enhance the professional development of the recipients as leaders, project managers and communicators. The impact of these awards is much broader than to the individual recipient. They serve to highlight the importance of nuclear science in the broader physics and chemistry research enterprises, they inspire postdocs and graduate students to a higher level of excellence as they strive to become competitive for these awards, and more graduate and undergraduate students can be introduced to and trained in nuclear science and associated technologies because of the resources now available to their mentors.

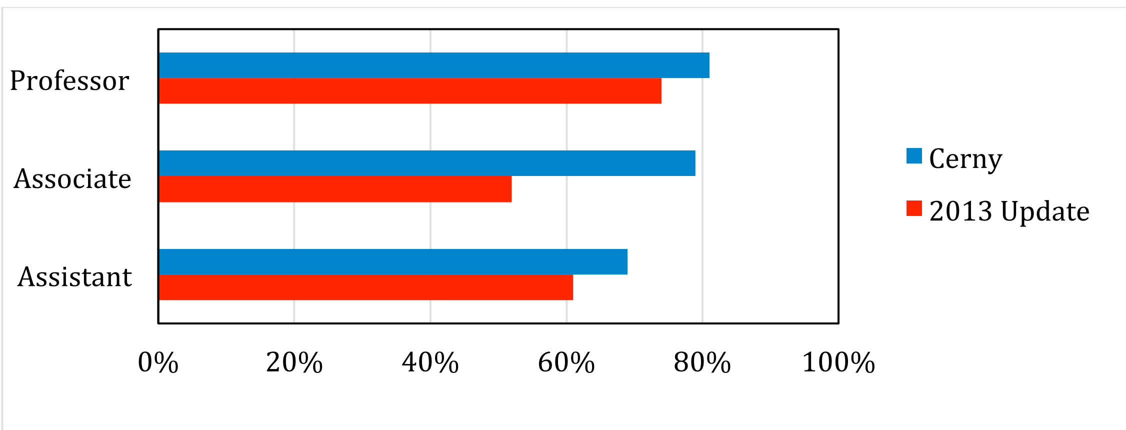

Figure 3. 2013 percentage of faculty with Ph.D. from U.S. institutions compared to Cerny report [NSAC04].

While over this period 58% of the awards went to individuals who received their Ph.D. in the U.S., in recent years there has been a substantial increase in the percentage of awards going to individuals who received their Ph.D. outside of the U.S., as summarized in Figure 2. Even if an individual received the Ph.D. from a U.S. institution, many are foreign nationals since about 45% of Ph.D. students in physics are international [AIP14].

An increasingly larger fraction of nuclear science faculty members have received their Ph.D. degrees from non-U.S. institutions. Figure 3 summarizes the fraction of current nuclear science faculty members who received their Ph.D. in the U.S. A smaller fraction of the faculty has received U.S. Ph.D. degrees in 2013 compared to 2004 and that fraction has become smaller for more recent Ph.D. recipients.

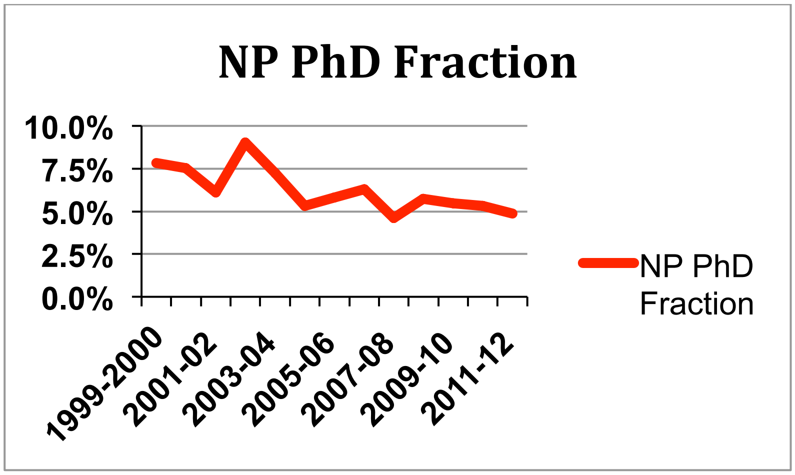

Figure 4. Ratio of number of Ph.D.'s reported in the NP Workforce Survey [NP13] to the total number of Ph.D.'s in physics reported by AIP [AIP10,AIP13]. The number of physics Ph.D.'s has been increasing in recent years more rapidly than those related to NP activities.

<u>Challenges in attracting best and brightest for Ph.D. study in nuclear science</u>. Although there has been a small increase in recent years in the number of Ph.D. degrees offered in NP-sponsored activities, they are a decreasing fraction (now about 5%) of the total number (about 1750 in 2012) of Ph.D.'s in physics in the U.S., as displayed in Figure 4. Of the approximately 100 Ph.D.'s awarded each year to NP-supported activities, about one half of the recipients are foreign nationals. Only a tiny fraction of the prestigious National Science Foundation Graduate Research Fellowships (NSF GRF) is awarded to students in nuclear physics, in many years none. From 2010 through 2014 (past five years) there have been six NSF GRF awards in nuclear chemistry/nuclear physics. This represents 0.06% of the total number of NSF GRFs (2000 awards in 2014). In contrast, for the DOE Graduate Research Fellowships in 2010, eight out of 150 (5.3%) were awarded to nuclear physics and in 2012 two out of 50 (4%). Therefore, the DOE GRFs have a much greater impact on the field of nuclear science. Ph.D. students in nuclear science are also eligible for the Computational Science (CSGRF) and Stewardship Science (SSGRF) Graduate Fellowships, both of which are relatively small programs, supporting only one or two nuclear science students each year (none of the current 65 CSGRF recipients is in nuclear science, while 8 of the 20 current SSGRF recipients are in nuclear science and engineering). This ability to target specific areas of workforce need is a significant benefit of the DOE graduate student fellowships relative to the NSF-administered ones and help to address the need to attract and train highly talented U.S. Ph.D. students in nuclear science. The Computational Science and Stewardship Science Graduate Fellowships require a practicum at a DOE laboratory, an important part of the training of the recipients, in contrast to NSF GRF where no restrictions on the activities of the recipients are placed. The CSGRF and SSGRF recipients are also required to participate in annual symposia where they interact with leaders from the DOE laboratories and are introduced not only to the science at the laboratories but also science policy. The role that CSGRF plays in addressing critical workforce needs is discussed in [Kre11] and Appendix III. Research mentors may not always be aware of fellowship opportunities for undergraduate and first and second year Ph.D. students and

the importance their input plays in successful applications, which may be another cause for the relatively low number of nuclear science students receiving NSF GRF and CSGRF.

The identification and training of Ph.D.'s in nuclear and radiochemistry are even more at risk. A decade ago the NSF Survey of Earned Doctorates stopped including nuclear chemistry because so few (<5) students reported receiving a Ph.D. in this subfield. Currently about 5 students per year receive a Ph.D. in nuclear chemistry [Man14], compared to the average of about 100 in all of NP-supported nuclear science. The current training in nuclear chemistry is highly distributed, with faculty mentors in many different departments (chemistry, biology, engineering, medical schools) and with very fragmented funding. Faculty members in medical schools often do not have direct access to graduate students. As examples, Departments of Radiology and Nuclear Medicine, where these faculty members are often tenured, only train MDs, although postdoctoral fellows can be trained in their laboratories if the programs are funded. Several divisions of the DOE support nuclear and radiochemistry research at universities and the national laboratories: Basic Energy Sciences (BES) for Heavy Element Chemistry; NP for the Isotope, the Isotope Production and the Low Energy Portfolio Programs; and Biological and Environmental Research (BER) for Radiochemistry Research and Training. Details are provided in Table 2.

For decades the Nuclear Chemistry Summer Schools (NCSS) have been successful in attracting undergraduate students to nuclear and radiochemistry and providing them with initial training. These schools, traditionally hosted in partnership with a DOE laboratory, are neither a research experience nor a course. Rather they are a training program that provides extensive hands-on activities in this discipline that is under-served at universities yet of critical importance to the DOE laboratories in realizing their research, technology and safety missions, and providing the talented workforce for innovations in nuclear medicine in diagnosing and treating disease and applications in industry, energy and homeland security. These "schools" must be held at institutions with the facilities to handle radioactive materials and sources as part of the training. They are also highly oversubscribed. Each school accepts 12 students from across the U.S. There are generally 100-200 applicants each year vying for the 24 total slots. All participants must be U.S. citizens. About 50% of the recent Ph.D.'s in nuclear and radiochemistry were initially trained at one of the NCSS, which is a very large fraction of the U.S. citizen Ph.D.'s in this field. Additionally, the Department of Homeland Security supports a Nuclear Forensics Summer School (NFSS), which has moved between the University of Nevada-Las Vegas, Washington State University and the University of Missouri , and is currently in its fifth and final year, with 8-10 students trained each summer.

Graduate education in nuclear and radiochemistry is offered at a very limited number of institutions. As summarized in Table 3, out of 670 programs in chemistry compiled by the American Chemical Society [ACS14] there are only 25 programs in Nuclear Chemistry and Technology (which would include engineering as well as chemistry departments).

Table 2. Diversity of funding sources in nuclear and radiochemistry

DOE Program	# of Grants	Universities	National Labs
NP Low Energy Program	10; NCSS* until FY14	7, 12, 20, 26, 34, 41	LBNL, LLNL
NP Isotope Program	11 since 2009	13, 19, 29, 38, 41	BNL, LANL, ORNL, PNNL
NP Isotope Production Program	5 since 2009	19, 21, 30, 39, 41	
BES Heavy Element Program	47; 3 for NCSS*	1, 2, 3, 4, 5, 6, 9*, 11, 14, 15, 16*, 19, 23, 24, 25, 27, 28, 29*, 31, 32, 35, 36, 37, 40	ANL, BNL, LANL, LBNL, ORNL, PNNL
BER Radiochemistry Program**	11 since 2009; more in 2014	8, 10, 17, 18, 21, 25, 29, 33, 41	

*Nuclear Chemistry Summer School (NCSS) Support
** 7 to medical school programs

1.	Brown Univ.	15.	Rice Univ.	29.	Univ. of Missouri*
2.	Clemson Univ.	16.	San Jose State U*	30.	Univ. of Missouri Research Reactor
3.	Emory Univ.	17.	Sloan-Kettering Institute for Cancer Research	31.	Univ. of New Mexico
4.	Florida State Univ.	18.	Stanford Univ.	32.	Univ. of Notre Dame
5.	George Washington Univ.	19.	Texas A&M Univ.	33.	Univ. of Pittsburgh
6.	Hunter College (CUNY)	20.	Univ. of CA -Berkeley	34.	Univ. of Rochester
7.	Indiana Univ.	21.	Univ. of CA -Davis	35.	Univ. of Texas - Austin
8.	Massachusetts General Hospital	22.	Univ. of CA -Davis	36.	Univ. of Utah
9.	Michigan State Univ.*	23.	Univ. of CA -Irvine	37.	Univ. of Virginia
10.	Northeastern Univ.	24.	Univ. of CA -Santa Barbara	38.	Univ. of Washington
11.	Northwestern Univ.	25.	Univ. of CA – Los Angeles	39.	Univ. of Wisconsin-Madison
12.	Oregon State Univ.	26.	Univ. of Maryland	40.	Washington State Univ.
13.	Pennsylvania State Univ.	27.	Univ. of Michigan	41.	Washington Univ.
14.	Purdue Univ.	28.	Univ. of Minnesota		

The two current sites of the NCSS are San Jose State University (original site) and Brookhaven National Laboratory (BNL). Several reports [e.g., NSAC04, NAS12] have called for a third nuclear chemistry school to help serve the need for talented U.S. individuals in nuclear and radiochemistry but to date this has not transpired. In contrast, as of FY14 NP has ended its support of this training activity that is so critical to the missions of DOE and applications in homeland security, energy, and medicine. The profile of an individual who benefited from the NCSS is presented in Sidebar A.

The National Nuclear Security Administration (NNSA) has made significant investments in developing a highly talented U.S. citizen workforce to meet its mission to enhance "national security through the military application of nuclear science" [NNSA]. The first is the Stewardship Science Graduate Fellowship program [SSGF] that provides highly competitive fellowship support to Ph.D. students in the areas of low energy nuclear science, high-energy density physics, and materials under extreme conditions and hydrodynamics. About five 4-year awards are made annually, supporting in total about 20 students. The NNSA also hosts the Stewardship Sciences Academic Alliances Program [SSAA] that provides support to university-led research in low energy nuclear science, radiochemistry, high-energy density physics and materials under extreme conditions. In 2013 this program supported 14 individual investigator and 2 center grants in low energy nuclear science and radiochemistry. No funds are directly given to national laboratories; however, laboratory staff members can be unfunded co-PIs and collaborators. About 15 postdocs are supported and about 3 Ph.D. degrees are awarded each year through this program. A discussion of the SSAA program as a model for education in nuclear science is given in [Ciz14].

The non-proliferation program at NNSA has also made a major investment in workforce development. The University of California –Berkeley (UCB) hosts the Nuclear Science and Security Consortium Success Pipeline [NSSC], a consortium of 7 universities, 4 DOE laboratories, and 5 minority-serving institutions. In addition, NNSA recently announced the establishment of two more university-based consortia: one led by the University of Michigan and the other led by North Carolina State University. Each of these consortia has been awarded a five-year grant in the amount of $5M per year. The goal of the NSSC is to help train the next generation of nuclear scientists and engineers with the expectation that a reasonable fraction will eventually find employment at one of the national laboratories. The NSSC supports educational and research opportunities for undergraduate and graduate students including workshops and summer schools held at member universities and also at collaborating national laboratories. The disciplines within the NSSC include nuclear and particle physics, nuclear and radiochemistry, radiation detection, nuclear engineering, and policy. The NSSC has supported the development of new courses in nuclear science and engineering at several of its campuses and upgrades of university laboratories for both research and teaching. Funds are also available to provide support to faculty and laboratory staff for sabbaticals and adjunct positions, respectively, and to provide summer support for undergraduate students.

The nuclear science community, with support at least in part by NP, its staff and laboratories, hosts a number of discipline-specific "schools" that complement the training that is available at universities and helps to develop leaders in fundamental nuclear science and its applications. These range from the annual Exotic Beam Summer School (EBSS) and Hampton University Graduate Studies at JLab (HUGS) with extensive hands-on activities at a national laboratory to FIESTA 2014 (FIssion ExperimentS and Theoretical Advances) hosted by LANL. FIESTA would help train students in the experimental and theoretical research in fission that is important for applications of nuclear science in national and homeland security and energy but is seldom covered in the academic curriculum. A snapshot of such training activities in 2014 is summarized in Table 4.

Table 3. Graduate programs in nuclear chemistry and technology.
Includes programs in nuclear engineering departments. [Nucl-ACS]

Auburn University	University of Maryland, College Park
Colorado School of Mines	University of Missouri, Columbia
Clemson University	University of Nevada, Las Vegas
Florida State University	University of Notre Dame
Hunter College, CUNY	University of Pittsburgh
Indiana University	University of Rochester
Michigan State University	University of Tennessee, Knoxville
Oregon State University	University of Texas, Austin
Stony Brook University	University of Utah
Tennessee Technological University	University of Washington
Texas A&M University	Washington State University
University of Alabama	Washington University, St. Louis
University of California, Berkeley	

Sidebar A Jo Ressler is an exemplar of how the training from the Nuclear Chemistry Summer School set her on the path to making important contributions to the nuclear security of the U.S. Jo was in the 1995 class of NCSS at San Jose State University that led to her Ph.D. studies in nuclear chemistry at the University of Maryland. Her dissertation work was based on research at Oak Ridge National Laboratory while in residence at Argonne National Laboratory. Upon receiving her Ph.D., she did postdoctoral work at Yale University (supported by NP) followed by a faculty position at Simon Fraser University in Canada. In 2006 she joined the staff at Pacific Northwest National Laboratory and then Lawrence Livermore National Laboratory, where she has been a staff member since 2009. She currently plays leadership roles in nuclear nonproliferation, counterterrorism and nuclear forensics applications of nuclear radiation detection and analysis techniques.

<u>Challenges in attracting and developing a talented U.S. workforce in accelerator science and the associated technologies</u>. World-leading discovery science in the U.S. requires that DOE's accelerator-based, national user facilities have world-leading capabilities to answer the open questions in high-energy physics and materials and biological sciences, as well as nuclear science and its applications. The new generation of user facilities will be far more challenging to build and operate safely and cost-effectively than earlier accelerators and detector systems. Accelerators are also central to advances in medicine and industry, a multi-billion dollar enterprise with over 30,000 particle accelerators in the world [DOE09]. A sustainable supply of highly skilled scientists and engineers is required to meet the challenges in developing accelerators for fundamental science and applied research and development, the latter need highlighted in [NAS05]. As the most critical areas of technical expertise are not taught in American universities, the Office of Science, itself, must provide workforce development opportunities for rigorous, structured training for graduate students and post-doctoral scholars and the staff already at its national laboratories.

Table 4. Training programs in nuclear and accelerator science

Program	Where	How often
Exotic Beam Summer School http://fribusers.org/4_GATHERINGS/2_SCHOOLS/schools.html	Rotates between ANL, LBNL, NSCL, ORNL	Annually
FIESTA (FIssion ExperimentS and Theoretical Advances)	LANL	2014
Hampton University Graduate Studies at JLab http://www.jlab.org/hugs/	JLab and Hampton University	Annually
High-Energy-Density-Physics Summer School http://hedpschool.lle.rochester.edu	Organized by Fusion Science Center, U of Rochester	Annually
Jet and Electromagnetic Tomography (JET) Summer School http://jet.lbl.gov/Overview	Rotates sites in U.S.	Annually
Nuclear Chemistry Summer Schools (NCSS) http://chemistry.missouri.edu/nucsummer/	BNL and San Jose State U	Annually
Radiation Detection for Nuclear Security Summer School* http://science-ed.pnnl.gov/students_graduates/RDNS.stm	PNNL	Annually
Training in Advanced Low Energy Nuclear Theory (TALENT) http://www.nucleartalent.org	Rotates sites in U.S. and Europe; Hosted by FRIB theory users group	1-3 per year
U.S. Particle Accelerator School (USPAS) http://uspas.fnal.gov	Rotates sites in U.S.	Annually

*Does not provide travel or local expenses for student participants.

ANL	Argonne National Laboratory
BNL	Brookhaven National Laboratory
FRIB	Facility for Rare Isotope Beams
JLab	Jefferson National Laboratory
LANL	Los Alamos National Laboratory
LBNL	Lawrence Berkeley National Laboratory
NSCL	National Superconducting Cyclotron Laboratory
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory

The development of a workforce takes place over many years and must anticipate both the future demands for specific discipline skills, as well as the future supply of trained professionals with those skills. The demographics of the accelerator physics and technology workforce hired at JLab, FNAL, BNL, and LBNL over the past twenty years indicate that only 20 to 30% of those staff members received their primary training in the U.S. Of those receiving Ph.D.'s in accelerator physics in the U.S. over the past 30 years, roughly two-thirds were from university programs primarily funded by the DOE and one-third from the NSF. As of FY2014 the Physics Division at NSF announced a new funding opportunity in accelerator science that should serve to increase the number of students and postdocs in this discipline. New hires into accelerator science are supplemented (at levels of 30% to 40% of new hires) by high-energy or nuclear physicists already on staff; these employees need focused, intensive training courses in accelerator physics and technology to perform their new job. Therefore, to assure the workforce required to meet its mission, especially in areas where university programs are few, the Office of Science through the relevant program offices must maintain a direct influence in creating a sustainable national workforce pipeline, from the earliest entry point through the development of the scientific leadership.

Only a dozen programs in the U.S. provide Ph.D. training in accelerator physics. Among those universities the three largest programs, UCLA (SC-supported), MSU (in transition from NSF to SC support), and Cornell (NSF supported), offer an undergraduate course plus at most 1 or 2 regularly listed graduate courses, although most are not offered on an annual basis. In 2012 only about 100 graduate students were enrolled in these programs. Of the new initiatives in accelerator science training, those at Stony Brook University and Old Dominium University are coordinated with the SC Brookhaven and Jefferson laboratories, respectively. Based on the size and average turnover rates of accelerator research and operations staffs at accelerator-based national user facilities, American university programs cannot meet the demand either in number or in breadth of specialized training for a highly-skilled workforce in accelerator science and technology - demands that span the accelerators maintained by the Office of Science, other DOE and NSF laboratories, and accelerators in industry and medicine. In contrast to U.S. efforts, 75 institutes in Europe are engaged in accelerator science training at all levels, from undergraduate through career professionals, according to the EU TIARA (Test Infrastructure and Accelerator Research Area) [TIA13]. Even so, this report estimates that the supply of trained accelerator professionals is 20% less than the demand.

The scarcity of formal Ph.D. programs and lack of advanced graduate-level courses in accelerator science and technology in U.S. universities is directly addressed by the U.S. Particle Accelerator School (USPAS), an effective partnership of major research universities and DOE laboratories. Although USPAS courses are typically not held in a traditional campus setting, training modules are academically rigorous and carry direct university graduate credit. Students may choose from the full spectrum of accelerator science and technologies, most of which would never be covered at a university and very few if any touched on in a physics or engineering department. The range of course offerings is summarized in Table 5. Indeed, the several universities with accelerator science degree programs rely heavily on the USPAS to provide their students specialized courses beyond introductions to accelerator science. In addition, the USPAS offers formal certification of training via the USPAS-Indiana University M.S. in accelerator science. A similar M.S. program is under development with Old Dominion University. The USPAS fills a critical pipeline in workforce development for accelerator science and technology since undergraduate and early career graduate students participate and then pursue further studies and careers in this field. Of the nearly 4000 unique participants who have attended

USPAS courses, more than 2200 work at or have worked at DOE laboratories; more than 250 have become leaders in the accelerator field; 160 have taught courses for the USPAS, and 24 have become DOE program managers.

Table 5. Topics covered at the US Particle Accelerator Schools

Topic
Fundamentals
Beam physics
Diagnostics and controls
Microwave measurements
rf-technology
Radiation & safety systems
Synchrotron radiation, FELs and Lasers
Magnet systems
Management and accelerator applications
Mathematical and computer methods
Accelerator design
Accelerator technology
Plasmas and collective effects

Challenges in attracting, training and retaining a talented U.S. workforce in high-performance computing and simulations for nuclear science and its applications. Many of the frontier activities in science, engineering, and technology that address the needs of the nation and industry require state of the art computations and simulations of complex systems on large scale computers. Very few universities have access to the largest computer systems. To be successful in these activities requires a deep knowledge of both the science and the technology that drives the computations and the ability to develop and implement new paradigms in computer science to use effectively the largest computer systems. The Computational Science Graduate Research Fellowships have worked to identify the most talented U.S. students working in high-performance computing and the exciting science they want to address. These fellowships require the recipient to spend a practicum at a national laboratory, making these awards truly traineeships. However, this effort falls far short of the needs for these highly talented individuals at the DOE laboratories for fundamental and applied science, that is exacerbated by the highly competitive opportunities in the private sector. Retention is a very serious issue, as scientists well trained in high-performance computing typically have the ability to move into diverse and rewarding areas. Focused research opportunities for undergraduates supported by both NSF and DOE have been successful at recruiting students into computational nuclear physics and nuclear astrophysics, but much more could be done. Extensive training of beginning graduate students could also be very effective in attracting the best and brightest into computational nuclear science. More in-depth training is available through the SciDAC (Scientific Discovery through Advanced Computing) program, which has been extremely successful in training graduate students and postdocs. This program brings together graduate students and postdocs in applied math and computer science and nuclear science to tackle many of the most difficult and important problems. The extended duration of the SciDAC projects allows for in-depth training and collaborations across many universities and national laboratories, to the great advantage of both. The NNSA Advanced Scientific and Computing program similarly trains people across six university centers. Many of the students and postdocs trained through this program have gone on to successful laboratory, university and industrial positions across the U.S. Strong support of these programs is crucial to the future nuclear science workforce. Training in Advanced Low Energy Nuclear Theory (TALENT), endorsed by the FRIB Theory Users Group, hosts modules on high-performance computing and computational tools for nuclear physics. An individual who started his career in fundamental computational nuclear physics and now has impact on national nuclear security is profiled in Sidebar B.

<u>Challenges in recruiting and retaining a highly talented workforce for DOE laboratories, especially U.S. citizens</u>. We requested input from all of the DOE laboratories about disciplines that are important to their laboratory, yet not-well presented in the academic curriculum, as well as challenges in recruiting and retaining a highly talented workforce. Samples of the letters sent to SC and non-SC DOE laboratory directors are provided in Appendices IV and V, respectively. To date we have received replies from 12 laboratories, all but one of which reported challenges in recruiting and retaining workforce in critical areas. Table 6 summarizes the competencies where laboratories are having difficulties meeting their needs for a talented (and often U.S. citizen) workforce and the academic disciplines that could be responsible for such training. Many of these competencies are inherently multi-disciplinary. A critical example is computational science where candidates may have experience doing computations and simulations, but not on high-performance computers, or candidates may have a background in computational mathematics but limited exposure to realistic applications or analysis methods for very large-scale data sets. Another is in nuclear science and radiochemistry where the laboratories need U.S. citizens with strong background in these areas to not only support applications of these sciences but also have the foundation to build on this training for activities beyond what would be included in an academic curriculum, such as nuclear weapons design. A profile of such an individual is highlighted in Sidebar A. To quote from the Sandia reply: "18% of the 183 post-doctoral employees hired were foreign nationals… For Sandia, we believe the number of foreign national hires overall is large and that it is a reasonable indicator that the available pool of U.S. citizen candidates for Ph.D.-level research at Sandia is inadequate to meet the needs of the laboratories." At INL while the split between U.S. and foreign national postdoc applicants is about 50/50, all positions in national and homeland security require U.S. citizenship. Even at a multi-disciplinary laboratory such as BNL, only about one-third of R&D openings are filled with U.S. citizens.

In June 2014 a new opportunity was announced by the DOE WDTS: the Office of Science Graduate Student Research Program (SCGSR) [SCGSR]. This competitive program would provide Ph.D. students in priority research areas the opportunity to spend 3-12 months in residence at an Office of Science laboratory. The SCGSR would provide the supplemental funds to cover the local expenses of the student while in residence at a laboratory. The priority areas for 2014 include the fundamental science areas in NP in experiment and theory, as well as applied research in nuclear data, accelerator research and development, isotope development and production, advanced detector technology research and development, and more general applications of nuclear science and technology. Heavy element radiochemistry and accelerator and detector R&D for Basic Energy Sciences are also current priority areas. Students must be candidates for the Ph.D. degree and submit a research proposal and letters of support from the dissertation advisor and the collaborating DOE laboratory scientist. Only U.S. citizens are eligible. If the student's faculty advisor has grant funds to support the student being in residence at a DOE lab for an extended period of time, that student would not be eligible for this award, unless the student's proposed project was beyond the scope of the advisor's research grant. The project has the potential to help address the challenges in training a workforce that can meet the needs of the DOE laboratories. The recipients would have the opportunity to be in residence at a DOE laboratory for an extended period of time when the DOE lab collaborator is responsible for introducing the recipient to the broader science and technology missions of that laboratory through a variety of professional development activities.

Sidebar B Joe Wasem was trained in lattice Quantum Chromo Dynamics (QCD) addressing fundamental aspects of nuclear theory and has made a career transition to nuclear security and stockpile stewardship.

Joe graduated with a B.S. degree from Caltech in 2005 and went on to do graduate work at the University of Washington under NP-supported Martin Savage, completing his degree in 2010. Joe was initially introduced to research being performed at Lawrence Livermore National Laboratory (LLNL) through the High Energy Density Physics Summer Program in 2005, where he worked on aspects of inertial confinement fusion. In graduate school, the close connection between the nuclear theory groups at LLNL and Washington provided an opportunity for Joe to continue his work on lattice QCD at LLNL. His research focused on using the computational technique of lattice QCD to calculate non-perturbative nuclear physics observables directly from QCD. Lattice QCD involves a combination of high-performance computing resources, including graphics processing units and other parallel computing structures, to perform massively parallel calculations on a leadership-class computational scale. This research involved quantities relevant to nuclear physics, such as nucleon form factors, parity violating interactions, and scattering parameters, as well as nuclear binding energies.

During the second year of Joe's post-doc, collaborations were formed between Joe and projects in the LLNL Weapons and Complex Integration (WCI) directorate to pursue research interests in those areas. At the end of Joe's second year as a post-doc he was offered a staff position in the WCI directorate where he currently has a position in the Secondary Nuclear Design Program.

Table 6. Core competencies at national laboratories that are not well represented in the academic curricula and/or have challenges in recruiting and retaining staff**.**

Academic area	**Competencies**	**National Laboratory[1]**
Nuclear science	Actinide science	LLNL
	Nuclear science	BNL, LANL, LLNL, PNNL
	Nuclear radiochemistry	LANL, NSCL, ORNL
	Radiation chemistry[2]	BNL, ORNL, SNL
	Nuclear quality assurance & fabrication	ORNL
	Computational nuclear science and simulations	INL, JLab, LANL
	Nuclear non-proliferation	BNL
Accelerator science & technology	Accelerator physics	BNL
	High-power rf	FNAL, JLab, NSCL, ORNL
	Superconducting magnet engineering	FNAL, JLab
	Cryogenic engineering	FNAL, JLab
	Beamline physics & engineering	BNL
Plasma and high energy density science	High energy density science	LLNL
Materials science	Energetic materials	LLNL
	Material defects	SNL
	Computational materials science	SNL
	Neutron and x-ray scattering, modeling and simulation	ORNL
	Materials science	BNL
Other physical sciences	Geoscience experimentalists and theorists (simulations)	INL
	Chemistry	BNL
	Sustainable energy	BNL
Life science	Computational biology, informatics, comparative genomics, biophysics	BNL, ORNL, PNNL

[1] "Ames Laboratory has been fortunate that we have been successful in recruiting scientific staff to meet the Office of Science mission". ANL informally provided partial information.
[2] The field of radiation chemistry was well described by BNL. At SNL this was radiation-matter interactions; at ORNL this was radiation protection.

Engineering	Advanced manufacturing	LLNL
	Applied electromagnetics	LLNL
	Nondestructive evaluation	LLNL
	Precision engineering	LLNL
	Structural materials	LLNL
	Ultrafast diagnostics	LLNL
	Power systems, electronics & engineering	ORNL
	Nuclear reactor engineering and energy	BNL, INL, ORNL
	Nuclear engineering of thermal hydraulics	ORNL
Computational science & engineering	Computational sciences/simulation	ANL, BNL, INL, LLNL, ORNL, SNL
	Cyber security	INL, LLNL, ORNL
	Dynamic mesh algorithms	LLNL
	High-performance/ Extreme/exascale computing	ANL, INL, LANL, LLNL, ORNL, PNNL, SNL
	Data informatics and big data	ANL, LLNL, ORNL, PNNL
	Applied mathematics (Numerical PDEs/high-order discretization modeling-LLNL)	ANL, LLNL, ORNL
	Software quality assurance	LLNL
	Solvers	LLNL
	Uncertainty quantification	LLNL
	Visualization and scientific data analysis	LLNL, ORNL
	Data acquisition software	FNAL, ORNL

ANL Argonne National Laboratory, SC
BNL Brookhaven National Laboratory, SC
FNAL Fermi National Accelerator Laboratory, SC
INL Idaho National Laboratory, NE
JLab Thomas Jefferson Laboratory, SC
LANL Los Alamos National Laboratory, NNSA
LLNL Lawrence Livermore National Laboratory, NNSA
NSCL National Superconducting Cyclotron Laboratory, NSF
ORNL Oak Ridge National Laboratory, SC
PNNL Pacific Northwest National Laboratory, SC
SNL Sandia National Laboratories, NNSA

Challenges in attracting U.S. students for fundamental and applied studies in nuclear science and related fields. Nuclear physics is not offered at a large fraction of colleges and universities offering the bachelor's degree. The 2007 white paper [NSAC-WP07] *A vision for nuclear science education and outreach for the next long range plan* found that only 18% of Ph.D. granting institutions with 20 or more physics majors offered a nuclear physics course. Another 43% offer a combined nuclear and particle physics course that is often taught by a particle physicist, since many of these departments have no faculty member in nuclear physics. A similar pattern was observed for the 7 bachelor-only departments that averaged 15 or more physics majors a year. Only 2 offered a course in nuclear physics with another 2 offering a course where nuclear physics was combined with particle or atomic physics. Therefore, a large fraction of the physics majors in the U.S. have no opportunity to be introduced to nuclear physics at their schools. Nuclear and radiochemistry is taught at less than 4% of colleges and universities with a chemistry program. At the same time, Ph.D. studies in nuclear science are offered at only 87 U.S. universities, and accelerator physics is offered at less than a dozen universities, compared to 195 that offer a Ph.D. degree in physics [NSAC13,AIP13]. Therefore, for U.S. students to become engaged in Ph.D. studies in nuclear and accelerator science, they need to develop a keen interest in these fields while undergraduate students. To address this, a multi-faceted approach to education, outreach, and training activities is needed to encourage U.S. students to pursue Ph.D. study in the core mission areas of NP: research and technologies in nuclear and accelerator science and engineering.

Nuclear engineering can complement nuclear physics and chemistry in serving to develop a nuclear science workforce. Today the field of nuclear engineering encompasses more than just the design and operation of nuclear power plants. Nuclear engineers play crucial roles in nuclear medicine, radiotherapy, oil and gas exploration, materials testing, homeland security, and nuclear non-proliferation, areas in which nuclear scientists also make significant contributions. The demand for people trained in these fields appears to be increasing. There was concern soon after the Fukushima reactor accident that students would no longer be interested in nuclear engineering as a field of study. In fact, the opposite has happened. Applications and enrollments at both the undergraduate and graduate levels have been increasing. The U.S. government has identified the training of the next generation of nuclear scientists and engineers as an important mission. Both the U.S. Department of Homeland Security and the DOE National Nuclear Security Administration have funded several large university-based projects whose major goal is student training.

The Nuclear Chemistry Summer Schools are an exemplar for identifying talented U.S. students in physics and chemistry, introducing them to nuclear and radiochemistry, and training them for opportunities for advanced studies in this highly under-served field.

The Science Undergraduate Laboratory Internship (SULI) program is another highly effective way to introduce undergraduate students to the opportunities for fundamental and applied research in nuclear and accelerator science at DOE laboratories and provide the initial training needed to further their studies and research in these areas. The SULI program complements the NSF-supported Research Experiences for Undergraduates (REU) that support students in all STEM (science, technology, engineering and math) disciplines with many strong programs in nuclear science and at university-based accelerator laboratories. The full list of 2014 REU sites in physics is [REU]; at two (Old Dominium University and William & Mary University) the students have the option to conduct research at JLab. While the REU program is based at universities, the SULI program is based at the DOE laboratories. Thus an advantage of the SULI program is that it introduces the recipients to the fundamental and applied scientific opportunities at the DOE laboratories, complementing the more familiar setting of colleges and universities. The nuclear physics community also hosts the highly successful Conference Experience for Undergraduates (CEU) at the annual meeting of the American Physical Society (APS) Division of Nuclear Physics (DNP). All undergraduates in nuclear science and accelerator science and associated technologies are eligible to apply, including SULI, REU and individual-PI supported students. Not only do participants make poster presentations and learn about the current research efforts in nuclear science, they are introduced to opportunities for graduate study and research and how to prepare for those opportunities. The CEU program has been remarkably successful in making the participants feel included in the research enterprise and encouraging their interest in further graduate work in nuclear and accelerator science.

Every year a few students in nuclear science spend summers at NP laboratories as part of the Community College Internship program. The SULI and REU activities reach out to students from a broad spectrum of backgrounds, including women, under-represented minorities and students from economically disadvantaged backgrounds. Because only the laboratory where the student is placed is tracked and 2011 is the last year for which data are available, it is difficult to analyze the areas of research and technology in which the SULI students are engaged and if indeed their participation could help address the disciplines that are under-served at colleges and universities.

The Visiting Faculty Program (VPF) has been successful in integrating faculty and their students from minority-serving institutions in frontier research in experimental and theoretical nuclear science at SC laboratories. Examples include Professor Jorge Lopez from the University of Texas-El Paso who studies the theory of the nuclear equation of state. Professor Lopez, joined by his students, has spent several summers at Lawrence Berkeley National Laboratory (LBNL) in the Nuclear Science Division and at Argonne National Laboratory in the Physics Division. Another example is Professor Brooke Haag while at Hartnell College. She is a member of the STAR detector collaboration at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) and has spent a summer at LBNL working on data analysis and interpretation.

Before students can participate in SULI and other opportunities for undergraduate students and be on the path for a career that addresses workforce needs in the DOE scientific and technological enterprises, they need to have a solid background in science and mathematics and a strong desire for a career in STEM. The DOE laboratories and individual investigators have a strong tradition in reaching out to school students, their teachers and their families. The Department of Energy's National Science Bowl is an effective way to recognize the talents of school children and in particular middle school students who need to take advanced science and math courses in high school to prepare for undergraduate studies in physics and chemistry. As another example for excellence in outreach, Jefferson Lab has long hosted Becoming Enthusiastic About Math and Science (BEAMS), a laboratory-intensive experience at JLab for middle school students. Given the economic diversity of the east Virginia region, this program reaches students who may have had relatively little previous exposure to the excitement of science and the high technologies at a major accelerator laboratory.

Recommendations

Developing future research leaders in fundamental and applied nuclear and accelerator science and technology must begin with undergraduate students and be sustained through early careers. World-leading nuclear science in the U.S. requires national user facilities with world-leading capabilities. These facilities are a mission-critical responsibility of the Department of Energy, which need a continuing stream of highly trained staff to advance the technologies, as well as realize the frontier scientific opportunities.

There is a delicate balance between attracting the best and the brightest from around the world for graduate studies and developing and supporting U.S. students on their paths to leadership in nuclear science and associated technologies and applications. Two of our findings show trends that this balance may no longer be the case. First, an increasing fraction of the Early Career Awards (and their earlier counterparts) and faculty hires go to scientists who received their Ph.D. outside of the U.S. While this indicates that the strength of the U.S. program attracts first-rate post-Ph.D. scientists, which is welcome, the decreasing fraction of U.S. trained awardees and faculty hires is worrisome. Second, the national laboratories are having increasing difficulties in identifying U.S. citizens for sensitive areas of applied research in areas of national and homeland security. Therefore, many of our recommendations come from the desire to enhance the development of a talented U.S. workforce by increasing the participation of U.S. students in the opportunities in fundamental and applied nuclear science.

Our overarching recommendation encompasses the specific recommendations to follow:
We recommend that all stakeholders expand and enhance the training opportunities for undergraduate and graduate students and postdocs

- **to attract and develop the leaders in fundamental nuclear science and the technologies that enable it,**
- **to supply a sustainable workforce of nuclear scientists in critical applications in national and homeland security, medicine, energy, and industry.**

The specific recommendations will be targeted at the DOE/SC Office of Workforce Development (WDTS) with its responsibilities across the Office of Science (SC); the Office of Nuclear Physics (NP), with its responsibilities in nuclear and isotope science and technologies; and/or the individual investigators at universities and laboratories who mentor students and postdocs.

- **We recommend that the WDTS increase the number of awards with full support and a practicum opportunity given directly to graduate students to enhance their training, targeted to areas with demonstrated need.** The awards could be modeled on the Computational Science (CSGRF) and Stewardship Science (SSGRF) Graduate Research Fellowships. The recipients would be expected to participate in an 8-12 week practicum at a DOE laboratory or facility, similar to what is required for CSGRF and SSGRF recipients to ensure these are training programs linked to SC missions. These awards would be for a minimum of 2 and a maximum of 4 years of Ph.D. study and at a minimum would provide the recipient with a competitive stipend and funds for remission of tuition and fees. The practicum is most effective when it complements the focus of the dissertation studies; in principle it could be at any time during the student's graduate studies. Depending upon the number of competitive applications, we project that 5-10 of these awards would be made annually to students in NP-supported activities. Incremental funds to support these awardees during their practicum could come from successful applications to the new SC Graduate Student Research Program [SCGSR], which also lists priority research areas.

- **We recommend that the WDTS, NP and other SC offices work together to increase support for "schools" in areas with critical workforce development needs and sustain their support at viable levels.** These "schools" provide multi-disciplinary training which complements the single-disciplinary education offered at colleges and universities.
  - **Nuclear Chemistry Summer Schools**. Sustain strong full funding for two Schools and expand to a third one with sufficient funding.
  - **US Particle Accelerator School.** Sustain this school that provides training that not only complements, but goes well beyond, what can be offered at universities. Expand the range of USPAS offerings to include detector technology and to provide more extensive professional training to career staff.
  - Expand the support of **Laboratory or discipline-specific "schools"** such as the Exotic Beam Summer School, Hampton University Graduate Studies at JLab (HUGS), Training in Advanced Low Energy Nuclear Theory (TALENT) or ones in fission theory and experiment that complements the training available more locally.

- **We recommend that the Department of Energy and the WDTS create new opportunities for high-performance computational science multi-disciplinary training across SC and in collaboration with NNSA through SciDAC and other initiatives.** Such training is broad since students and postdocs interact with computer scientists and it helps to foster a commitment to computational sciences and collaborations between universities and national laboratories. This training could be realized via "schools" that bring together nuclear and computer scientists or short training courses hosted by SciDAC or other high-performance computing multi-investigator initiatives.

- **We recommend that NP and other SC and DOE offices work to reverse the decline in the number of both nuclear and radiochemistry faculty and students at universities.** Universities are where graduate students are trained, yet the number of nuclear chemistry Ph.D.'s has decreased to the level at which they are no longer tracked. Faculty support is critical when universities consider hiring and tenure. Both nuclear chemists and radiochemists are needed. We recognize that this is challenging given the flat NP research budgets since 2010, where the research budget supports graduate students and postdocs across NP. It is essential to continuously examine the balance between research, operations and construction to ensure a thriving future with both new scientific opportunities and the workforce to pursue them.

- **We recommend that WDTS in collaboration with discipline-specific offices such as NP establish prestigious postdoctoral training opportunities in areas of demonstrated need and with an opportunity to couple to DOE laboratories or facilities.** Subfields should include nuclear physics and chemistry; high-performance computational science; accelerator science, engineering and technology. Recipients would be expected to propose a research plan that couples their activities to opportunities at DOE laboratories or facilities. This expectation would serve as an introduction to the broader, multi-disciplinary research at the laboratories and complement their training at their home institution.

- **We recommend that SC and NP sustain Early Career Awards (ECA).** These awards highlight the exciting research and technological contributions of early career scientists and educators, serving to inspire students and postdocs across the field, as well as enhance the training of students and postdocs mentored by the ECA recipients.

- **We recommend that the DOE enable students and postdoctoral scholars at DOE laboratories to attend conferences by exempting them from DOE conference travel limitations.** DOE conference travel is essential to workforce development but the travel limitations hinder these activities and disproportionately affect students, postdocs and early career staff.

Broadening the participation of U.S. students in nuclear science and technologies. To encourage the full spectrum of U.S. students to pursue careers in nuclear science and technology requires them to become excited about science, technology, engineering and math (STEM) early in their careers. This includes reaching out to women and students from backgrounds traditionally under-represented in the STEM enterprise. These recommendations would help to broaden the participation of U.S. students.

- **We recommend that WDTS and the sponsoring laboratories sustain SULI opportunities at all DOE laboratories and that SULI opportunities be increased in**

disciplines where there is a need to enhance U.S. workforce development to meet the needs of the DOE and other government agencies. The SULI program is a critical entry-level component of workforce development. It has been very valuable in inspiring students to pursue advanced degrees in DOE SC-related fields and introducing them to the opportunities at the DOE laboratories.

- **We recommend that WDTS sustain and support outreach activities at DOE labs** to introduce school students and teachers to the labs and provide training that complements what is offered in schools.

- **We recommend that WDTS enhance visibility of DOE/SC labs to students and teachers from minority serving institutions and women**, building on efforts in SULI, Community College Internships, Visiting Faculty Program, and outreach activities for students and teachers.

A challenge in addressing the charge from the Office of Workforce Development is the lack of information about the workforce needs and the opportunities that exist to enhance the training of students and postdocs. The following recommendations would address this need.

- **We recommend that WDTS work with the hosting laboratories to track the research groups and the careers of SULI participants to obtain a quantitative assessment of the impact of these opportunities and training. These assessments should be used to inform the number of SULI opportunities and target these opportunities to disciplines of demonstrated need.** SULI has been very valuable in inspiring students to pursue advanced degrees in DOE SC-related fields and introducing them to the opportunities at the DOE laboratories. There are almost no publicly available tracking data on the SULI program; only the laboratory where the student is placed is available. This recommendation would realize an assessment of the program and inform enhancements of its effectiveness. With sufficient resources, this tracking effort could be extended to other SC-supported activities, such as the Nuclear Chemistry Summer School.

- **We recommend that WDTS establish dedicated resources to continually assess the current, near term and longer term needs for a highly-talented, diverse workforce** to realize the missions of the DOE and other government agencies and the private sector that require a workforce with the skills of individuals trained in DOE-sponsored programs.

- **We recommend that the research mentors of undergraduate and graduate students should expand their knowledge of the SULI program and prestigious fellowship and training opportunities for their students and help these students develop competitive applications for these awards.** The Division of Nuclear Physics of the American Physical Society and the Division of Nuclear Chemistry and Technology of the American Chemical Society can help disseminate the announcements of these opportunities and best practices in developing competitive proposals. For most graduate fellowship programs, students can apply starting in their senior year as undergraduate students, with the final opportunity at the beginning of their second year of graduate study. With improved mentorship by informed research supervisors, 10-20 students could receive such awards annually, integrated over all of the funding agencies that award fellowships. With NP budgets that continue to support the current number of graduate students, an increase in the number of nuclear science and technology students receiving fellowships would increase the number of U.S.-trained Ph.D. students in these disciplines.

Acknowledgements. We would like to thank the DOE laboratory directors for their informative replies to our requests for information on a very short time scale and Jim Corones from the Krell Institute for reports on the CSGRF.

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Appendix I: Charge to NSAC: Assessment of workforce development needs

Department of Energy
Office of Science
Washington, DC 20585

February 19, 2014

To: Chairs of the Office of Science Federal Advisory Committees:
Professor Roscoe C. Giles, ASCAC
Professor John C. Hemminger, BESAC
Professor Gary Stacey, BERAC
Professor Mark Koepke, FESAC
Professor Andrew J. Lankford, HEPAP
Dr. Donald Geesaman, NSAC

From: Patricia M. Dehmer
Acting Director, Office of Science

Charge: Assessment of workforce development needs in Office of Science research disciplines

The Office of Science research programs have a long history of training graduate students and postdocs in disciplines important to our mission needs as part of sponsored research activities at universities and DOE national laboratories. In addition, the Office of Workforce Development for Teachers and Scientists supports undergraduate internships, graduate thesis research, and visiting faculty programs at the DOE national laboratories.

We are asking the assistance of each of the Office of Science Federal Advisory Committees to help us identify disciplines in which significantly greater emphasis in workforce training at the graduate student or postdoc levels is necessary to address gaps in current and future Office of Science mission needs. As part of your expert assessment, please consider:

- Disciplines not well represented in academic curricula;
- Disciplines in high demand, nationally and/or internationally, resulting in difficulties in recruitment and retention at U.S. universities and at the DOE national laboratories;
- Disciplines identified in the previous two bullets for which the DOE national laboratories may play a role in providing needed workforce development; and
- Specific recommendations for programs at the graduate student or postdoc levels that can address discipline-specific workforce development needs.

Please submit to me, no later than June 30, 2014, a letter report describing your findings and recommendations. These results will be used to help guide future activities and investments.

If you would like to discuss the charge, please do not hesitate to contact me (patricia.dehmer@science.doe.gov). Thank you very much for your help with this important task.

Printed with soy ink on recycled paper

Appendix II: NSAC Workforce Subcommittee Members

Hari Areti	T. Jefferson National Laboratory
William Barletta	Massachusetts Institute of Technology
Joe Carlson	Los Alamos National Laboratory
Jolie Cizewski, chair	Rutgers University
Donald Geesaman, ex-officio	Argonne National Laboratory
Ed Hartouni	Lawrence Livermore National Laboratory
Andrew Hutton	T. Jefferson National Laboratory
Silvia Jurrison	University of Missouri
Eric Norman	University of California-Berkeley
Michael Thoennessen	Michigan State University
Sherry Yennello	Texas A&M University

The findings and recommendations in this report were discussed and finalized during six conference calls in the April-June 2014 time period.

Appendix III. Computational Science Graduate Fellowship background information

White paper on Computational Science Graduate Fellowships [Kre11] (2pages)

TARGETING GRADUATE AND POSTDOCTORAL FELLOWSHIPS TO MEET CRITICAL CHALLENGES

Our nation faces great challenges in the coming years, and many of these will be addressed through the development of scientific understanding and engineering advances that support the Department of Energy's mission areas in energy, the environment and national security. In particular, as we focus more on solving the problems related to global climate warming, energy independence, non-proliferation and environmental remediation, DOE will need to support an increasingly strong workforce with expertise in relevant scientific fields. The continual infusion of new talent from young scientists and engineers trained to perform multidisciplinary research involving key disciplines such as nuclear and fusion physics, climate science and systems biology will be an essential element of this workforce development. Support for many of these research fields has been seriously neglected over the past twenty years, and as a result, there are very few qualified young researchers ready to step in and participate in these essential research endeavors for the DOE. In addition, while there are exceptions to the rule, very few graduate and postdoctoral students in the university system are trained to work in the multidisciplinary research environments found at the DOE National Laboratories.

In order to assure that the nation trains new scientists and engineers in these critical technology fields, the DOE should consider investing in targeted graduate and postdoctoral fellowship programs designed to train the kind of talent needed to meet these challenges. These programs should target key scientific and engineering disciplines needed to advance the DOE's mission areas, and must stress training for multidisciplinary research.

The DOE's Computational Science Graduate Fellowship (CGSF) provides an excellent example of the type of program that can address the concerns raised above. This fellowship has become widely known for its unique approach, which is to focus on targeted needs of the DOE, and to interact with each student in a very proactive fashion to meet these needs. The CSGF program requires that the student design a program of academic study that provides a broad interdisciplinary education experience. Fellows are also required to complete a three-month internship at a DOE National Laboratory with a Lab scientist as mentor, thus exposing the student first-hand to a DOE interdisciplinary research environment and providing the Lab with an extended opportunity to evaluate new talent. In addition, attendance at an annual conference of the fellows is required, providing exposure to presentations by leading DOE researchers as well as an opportunity for the graduating fellows to present their research.

The CSGF has successfully identified and supported some of the very best graduate students in the nation and has trained over 200 students at more than 50 U.S. universities over the past sixteen years to meet the nation's workforce needs. Graduates of the CSGF now work in DOE laboratories, private industry and educational institutions.

There are a number of "lessons learned" from both the structure and execution of the CSGF program that will be valuable to consider when developing these proposed targeted fellowship programs.

1. It is important to attract the best and the brightest to these programs. Recruitment to the program should be extensive and targeted. The goal is to seek and find the very best and connect them with the DOE.

2. The application process must be carefully tailored to specific program needs. The application itself must be designed to elicit particular information about the student's knowledge of and interest in program-relevant issues. The application and selection process must be crafted to evaluate *individuals* as future scientists and engineers. The application is not simply a research proposal plus grades.

3. A detailed and extensive selection process based on exposing the applicant's intellect and creativity is critical; in particular, selection should not be just "by the numbers" such as grades or GRE scores. It is vital that the selection committee be technically expert, and that they understand and agree with the program goals as laid out in the application itself.

4. The program must connect the fellows with future employers in a substantive way. Internships within the fellowship must engage both the fellows *and the employing institutions*.

5. The program can and should guide the academic development of the fellows by establishing predefined curricular guidelines and monitoring the fellows' progress in meeting those requirements. The program must have a renewal process that evaluates both the student's academic progress and that measures the fellow's activities against program requirements.

6. The program should continuously engage the relevant research communities in executing and refining the program. Science and engineering are very dynamics areas, and needs and targeted skills evolve over time. It is important that any fellowship keep abreast of these advances.

7. While the strategic goals of the program should be set and made clear up front, the program execution should embody the substance of continuous improvement. Program tactics can be regularly adjusted in the face of experience and opportunity while continuing to meet the program goals.

Recognizing the success of CSGF via its structure and execution and the need for an infusion of new talent into areas of importance to stockpile stewardship, NNSA began support of the Stewardship Science Graduate Fellowship (SSGF) a few years ago. The success of the SSGF in attracting the best young people to problems of interest to NNSA is a concrete example of how the fundamental principals of CSGF outlined above can be followed to create programs in other disciplines. Specific requirements were changed; for example, there is more flexibility in the program of study and the student is required to complete the internship at an NNSA Lab rather than any DOE Lab.

It is clear that the same approach of retaining the strengths of CSGF while tailoring specific requirements to the needs of a particular technical area can be followed to create effective fellowships in other disciplines of importance to the missions of DOE.

DOE has an opportunity to address critical workforce needs through the development of new fellowship programs in targeted mission-critical areas. The very successful DOE Computational Science Graduate Fellowship program provides a model that can inform the development of these new fellowship programs.

Congressional testimony on Computational Science Graduate Fellowships

UNIVERSITY OF CALIFORNIA, BERKELEY

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COLLEGE OF ENGINEERING
DEPARTMENT OF MECHANICAL ENGINEERING
BERKELEY, CALIFORNIA 94720-1740

April 9, 2014

From: Prof. Tarek I. Zohdi, President of US Association for Computational Mechanics (USACM)
Re: DOE Computational Science Fellowship Program

This testimony addresses the Department of Energy and the Computational Science Graduate Fellowship program. My name is Tarek Zohdi, and I am the President of the US Association for Computational Mechanics (USACM). I am also the Chair of the UC Berkeley Computational Science and Engineering Program.

I would like to express the support of the USACM for maintaining the CSGF program at FY 2014 funding levels. My understanding is that this program is in danger of being eliminated. This would represent a significant blow to the computational science community.

Computational science is an interdisciplinary field which cross-cuts science and engineering, computer science, mathematics, and statistics. It is a field that is vital to the US interests in Big Data and Exascale Computing, among other strategic initiatives.

The CSGF program is widely viewed as one of the best and most competitive graduate fellowship programs. The program supports doctoral students in STEM fields at many institutions across the US. These students are also required to spend a summer practicum at one of the national laboratories. Further, they are required to develop an interdisciplinary program of study that incorporates courses in the aforementioned fields. To my knowledge, this program has also provided training in high-performance computing, such that these budding scientists can learn the tools they need to utilize large, institutional computing clusters.

There is not another graduate fellowship program like this in the United States or elsewhere. It was designed in no small part to help develop the next generation of computational scientists working at our national laboratories, and it has been very successful in doing that.

The USACM believes this program to be absolutely essential, and once again, I urge the committee to consider maintaining its funding at the FY 2014 level. Please do not hesitate to contact me if you have any questions concerning the importance of this novel program.

Tarek Zohdi

T. I. Zohdi
Professor, Department of Mechanical Engineering, UC Berkeley
Chancellor's Professor, UC Berkeley
President, The United States Association for Computational Mechanics
Chair, UC Berkeley Computational Science and Engineering Program
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Appendix IV. Example of letter sent to SC DOE laboratory directors

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Thom Mason, Director
Oak Ridge National Laboratory
Oak Ridge, Tennessee
masont@ornl.gov

April 23, 2014

Dear Dr. Mason,

We would appreciate your input regarding the recent DOE Office of Science Workforce Development charge, and specifically we would appreciate your help in identifying disciplines where the current Workforce is inadequate to meet Office of Science mission needs. In response to the charge, we seek to identify disciplines where an insufficient number of students are trained in the U.S. at the graduate student and postdoctoral level, as indicated by (1) lack of representation in academic curricula, or (2) difficulties in recruiting and retention due to high national and international demand. Some of the disciplines that have been suggested include accelerator science, detectors & instrumentation, computational science, and nuclear radiochemistry. Your laboratory may have experienced a shortage in some or all of these disciplines, or in others not included in this list.

Where available, data demonstrating a deficit in the Workforce would be helpful, as it will allow us to illustrate the shortage of a qualified workforce in our reports. Such data could consist of indicators of a small available pool in recent searches, a high fraction of international hires, or numbers indicating retention difficulties.

Your laboratory's input relevant to this charge will be valuable. You may receive a request for similar information directly from the Office of Science. We do not want to double the effort required to collect this information. If you believe your response to SC adequately describes your needs on a time scale that is useful to us, a copy of that reply would be sufficient. We will also be collecting information from other members of some of our respective communities. If you would prefer that we contact another individual at your laboratory, please let us know. Because of the short time frame for the response to this charge, we hope to hear from you as soon as possible but not later than May 5, 2014.

Thank you for considering this invitation and your assistance in this matter.

Sincerely,

Jolie A. Cizewski, Ph.D., Chair Workforce Subcommittee, Nuclear Science Advisory Committee

Ritchie Patterson, Ph.D., Chair Workforce Subcommittee, High Energy Physics Advisory Panel

Barbara M. Chapman, Ph.D., Chair Workforce Subcommittee, Advanced Scientific Computing Advisory Panel

Attachment: Assessment of workforce development needs in Office of Science research disciplines from Patricia M. Dehmer, Acting Director, Office of Science

Appendix V. Example of letter sent to non-SC DOE laboratory directors

RUTGERS
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Bill Goldstein, Director
Lawrence Livermore National Laboratory
Livermore, CA
goldstein3@llnl.gov

April 23, 2014

Dear Dr. Goldstein,

Dr. Patricia M. Dehmer, Acting Director of the DOE Office of Science (SC), has recently charged the SC Advisory Committees to assess the workforce needs in Office of Science research disciplines; the charge is attached. Because of the multi-disciplinary nature of your Department of Energy laboratory that employs scientists trained with SC funding, the Nuclear Science Advisory Committee workforce sub-committee would appreciate your help in identifying disciplines where the current workforce is inadequate to meet the needs of your laboratory. In response to the charge, we seek to identify disciplines where an insufficient number of students are trained in the U.S. at the graduate student and postdoctoral level, as indicated by (1) lack of representation in academic curricula, or (2) difficulties in recruiting and retention due to high national and international demand. Some of the disciplines that have been suggested include accelerator science, detectors & instrumentation, computational science, and nuclear radiochemistry. Your laboratory may have experienced a shortage in some or all of these disciplines, or in others not included in this list.

Where available, data demonstrating a deficit in the workforce would be helpful, as it will allow us to illustrate the shortage of a qualified workforce in our reports. Such data could consist of indicators of a small available pool in recent searches, a high fraction of international hires, or numbers indicating retention difficulties.

Your laboratory's input relevant to this charge will be valuable. You may receive a request for similar information directly from the Office of Science. I do not want to double the effort required to collect this information. If you believe your response to SC adequately describes your needs on a time scale that is useful to us, a copy of that reply would be sufficient. I am also requesting information from the Office of Science laboratories. If you would prefer that I contact another individual at your laboratory, please let me know. Because of the short time frame for the response to this charge, I hope to hear from you as soon as possible but not later than May 9, 2014.

Thank you for considering this invitation and your assistance in this matter.

Sincerely,

Jolie A. Cizewski

Jolie A. Cizewski, Ph.D., Chair Workforce Subcommittee, Nuclear Science Advisory Committee

Attachment: Assessment of workforce development needs in Office of Science research disciplines from Patricia M. Dehmer, Acting Director, Office of Science

Appendix VI. Acronyms used in this report

ACS	American Chemical Society
AIP	American Institute of Physics
ANL	Argonne National Laboratory
APS	American Physical Society
BEAMS	Becoming Enthusiastic About Math and Science, JLab outreach effort
BER	Office of Biological and Environmental Research, Department of Energy
BES	Basic Energy Sciences, Department of Energy
BNL	Brookhaven National Laboratory
CEBAF	Continuous Electron Beam Accelerator Facility
CEU	Conference Experience for Undergraduates
CSGRF	Computational Science Graduate Research Fellowships
CUNY	City University of New York
DNP	Division of Nuclear Physics
DOE	Department of Energy
EBSS	Exotic Beam Summer School
ECA	Early Career Award
EU	European Union
FEL	Free electron laser
FIESTA	FIssion ExperimentS and Theoretical Advances, hosted by LANL
FNAL	Fermi National Accelerator Laboratory
FRIB	Facility for Rare Isotope Beams
GRF	National Science Foundation Graduate Research Fellowships
HUGS	Hampton University Graduate Studies at JLab
INL	Idaho National Laboratory
JLab	Jefferson National Laboratory
LANL	Los Alamos National Laboratory
LBNL	Lawrence Berkeley National Laboratory
LLNL	Lawrence Livermore National Laboratory
M.S.	Master of Science degree
MD	Doctor of Medicine or medical doctors
MSU	Michigan State University
NCSS	Nuclear Chemistry Summer Schools
NE	Office of Nuclear Energy, Department of Energy
NFSS	Nuclear Forensics Summer School, Department of Homeland Security
NNSA	National Nuclear Security Administration, Department of Energy
NP	Office of Nuclear Physics, Department of Energy
NSAC	Nuclear Science Advisory Committee
NSCL	National Superconducting Cyclotron Laboratory
NSF	National Science Foundation
NSFGRF	National Science Foundation Graduate Research Fellowships
NSSC	Nuclear Science and Security Consortium Success Pipeline
OJI	Outstanding Junior Investigator
ORNL	Oak Ridge National Laboratory

PDE	Partial differential equations
PECASE	Presidential Early Career Awards in Science and Engineering
Ph.D.	Doctor of Philosophy degree
PI	Principal investigator
PNNL	Pacific Northwest National Laboratory
QCD	Quantum Chromo Dynamics
R&D	Research and Development
REU	Research Experiences for Undergraduates
rf	radio-frequency
RHIC	Relativistic Heavy Ion Collider
SC	Office of Science, Department of Energy
SCGSR	Science Graduate Student Research Program
SciDAC	Scientific Discovery through Advanced Computing
SNL	Sandia National Laboratories
SSAA	Stewardship Sciences Academic Alliances Program
SSGRF	Stewardship Science Graduate Research Fellowships
STEM	Science, Technology, Engineering and Math
SULI	Science Undergraduate Laboratory Internship
TALENT	Training in Advanced Low Energy Nuclear Theory
TIARA	Test Infrastructure and Accelerator Research Area
UCB	University of California –Berkeley
UCLA	University of California – Los Angeles
USPAS	U.S. Particle Accelerator School
VPF	Visiting Faculty Program, WDTS, DOE
WCI	Weapons and Complex Integration Directorate, LLNL
WDTS	Office of Workforce Development for Teachers and Students, SC/DOE