NATIONAL ACADEMY OF SCIENCES
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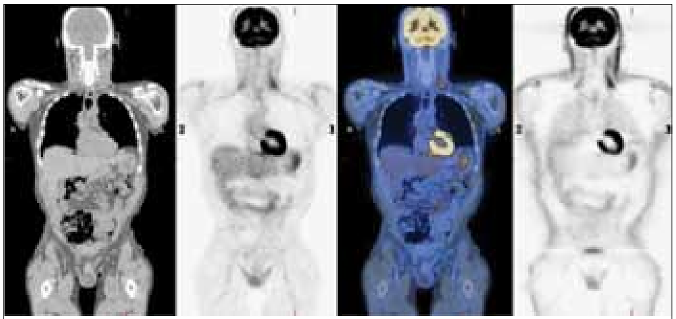
Assuring a Future U.S.-based Nuclear and Radiochemistry Expertise

Despite the growing use of nuclear medicine, the potential expansion of nuclear power generation, and the urgent need to protect the nation against nuclear threats and to manage nuclear wastes generated in past decades, the number of students opting to specialize in nuclear and radiochemistry has decreased significantly over the past few decades. Now, with many experts in these topics approaching retirement age, action is needed to avoid a workforce gap in these critical areas, for example by building student interest in these careers, by expanding the educational capacity of universities and colleges, and by providing more sector specific on-the-job training.

Since the 1970s, a steadily declining number of academic staff in nuclear and radiochemistry has led to decreases in the number of U.S. citizens with training in the fields of nuclear security, medicine, energy, environmental management, and basic research—and in the number of U.S. colleges and universities that offer research programs in these fields. By 2003, the number of nuclear chemistry Ph.D. degrees awarded in the United States (70-80 percent awarded to U.S. citizens) had dropped to just four. Similar trends occurred in nuclear science and engineering more broadly.

In 2008, several new efforts to increase the number of students in nuclear science and engineering were launched. For example, the Department of Energy created the Nuclear Energy University Program, which provides scholarships and fellowships at U.S. colleges and universities. In addition, the Department of Homeland Security's Domestic Nuclear Detection Office has been leading a joint effort with the Department of Energy, Department of Defense, and others to maintain a highly-qualified technical nuclear forensics workforce (that includes a large chemistry component).

These efforts appear to have helped stabilize the number of Ph.D.'s and faculty members in nuclear and radiochemistry in recent years. However, the situation is fragile: about 10 percent of the nation's experts in nuclear and radiochemistry are at or nearing retirement age (age 60+ years), and projections indicate that it is unlikely that there will be enough new graduates with training in nuclear and radiochemistry to fill this workforce gap. Should there be major funding cuts or policy changes, the U.S. supply of nuclear and radiochemistry expertise may be inadequate to meet changing needs.



Images of CT (computed tomography) and PET (positron emission tomography) scans, taken following the injection of the radiopharmaceutical fluorodeoxyglucose (^{18}F), also known as FDG. FDG is a glucose analog that is taken up by high-glucose-using cells. The CT scans show the patient's anatomy, and the PET scans show FDG uptake, allowing scientists to assess glucose metabolism in lungs, heart, brain, kidney, and cancer cells.
Source: Henry VanBrocklin

Box 1. Who are nuclear and radiochemists?

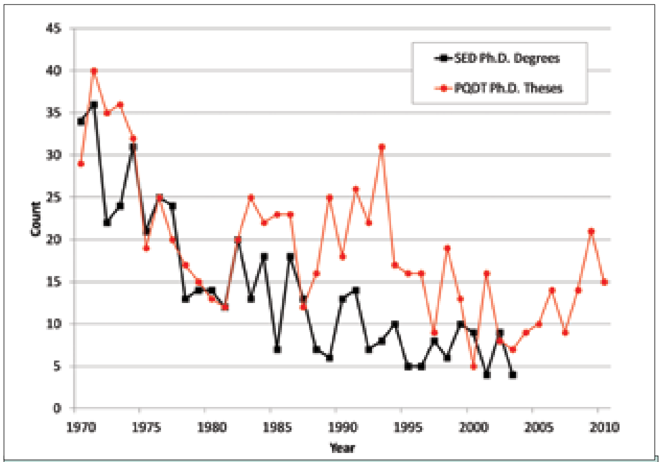
Most experts in nuclear and radiochemistry have one or more degrees in chemistry and have taken additional specialized courses and conducted laboratory work in nuclear and radiochemistry. Their research interests range from nuclear energy to medical imaging, environmental chemistry, and nuclear security.

Tracking Nuclear and Radiochemistry Expertise

Tracking expertise in nuclear and radiochemistry has proven challenging. There are no specific nuclear and radiochemistry undergraduate degree programs—instead, students majoring in chemistry can take advanced coursework in nuclear and radiochemistry to gain bachelors-level expertise in these topics. Projections of the future supply of bachelor's degree-level nuclear and radiochemists come from counts of the number of colleges and universities that offer coursework at this level and estimates of the number of chemistry graduates from each institution who may have taken such courses.

It is similarly difficult to estimate the level of expertise at the Ph.D. level. As the Survey of Earned Doctorates questionnaire is no longer recording Ph.D. graduates in nuclear chemistry, the committee searched the ProQuest Dissertations and Theses database for theses tagged with nuclear chemistry as a topic or subject term. The database shows the number of theses with nuclear chemistry as a subject keyword increased from 5 in 2005 to 15 in 2010, likely due to increases in funding for nuclear and radiochemistry research.

The committee also found that the database may present an underestimate of the number of nuclear and radiochemistry Ph.D. graduates each year: the majority of students seemed to choose to use topic terms such as chemistry, analytical chemistry, and environmental chemistry to describe their theses, even if their projects focused on nuclear and radiochemistry.



U.S.-granted Ph.D. degrees and dissertations in nuclear chemistry by year, from 1970 to 2010, based on the National Science Foundation Survey of Earned Doctorates (black squares) and the ProQuest Dissertation and Theses (red circles) databases. Survey of Earned Doctorates data are based on selection of the term "nuclear chemistry" as the subfield of study on the questionnaire that was given to Ph.D. recipients that year. ProQuest Dissertation and Theses data are based on the selection of the term "nuclear chemistry" as the subject area on the dissertation submission form.

Source: NSF 2010, ProQuest 2011

Educational Opportunities in Nuclear and Radiochemistry

In the university setting, academic research programs in nuclear and radiochemistry are typically found within chemistry departments. However, out of over 100 chemistry graduate departments across the United States, the committee identified only 13 departments that have two or more faculty members who specialize in nuclear and radiochemistry and who offer one or more courses devoted entirely or in part to nuclear and radiochemistry. Thus, there is little or no nuclear and radiochemistry coursework offered to undergraduate or graduate students at U.S. universities. Furthermore, only five of the top 25 ranked U.S. chemistry departments offer nuclear and radiochemistry research or coursework.

Supply and Demand for Nuclear and Radiochemistry Expertise

The committee's projected supply and demand for radiochemistry expertise over the next five years is shown in Table 1. Estimates of demand were based on anticipated retirements by nuclear and radiochemists, and on expected growth in the field of nuclear medicine. Projections of supply were based on estimates of the number of bachelor's –level graduates in chemistry likely to have taken advanced courses in nuclear and radiochemistry, and on projections of the number of PhD-level graduates who choose nuclear chemistry as a subject keyword for their theses.

As indicated earlier, the academic pipeline in nuclear and radiochemistry has stabilized in recent years, and projections may underestimate the number of Ph.D. level graduates with the expertise in nuclear and radiochemistry. However, given the anticipated increased demand in many sectors such as nuclear medicine and nuclear energy, this steady but low number of graduates in nuclear and radiochemistry is not conducive for sustained growth of the field.

The Transfer of Skills

Each year, there are over 100 Ph.D. graduates in fields such as nuclear engineering or nuclear physics. These graduates could potentially fill gaps in the nuclear and radiochemistry workforce, however, students who specialize in nuclear engineering or physics usually don't have the knowledge of synthetic, analytical, and other aspects of chemistry needed for tasks such as preparing reagents for nuclear medicine, developing new techniques in nuclear power generation, or

Table 1. Projections of Supply and Demand for Nuclear and Radiochemistry Expertise Over the Next Five Years

	Bachelor's degree-level expertise	Master's degree-level expertise	Ph.D.-level expertise
Currently employed	412	252	747
Projected **demand** for additional nuclear and radiochemists	198	93	301
Projected **supply** of nuclear and radiochemists	250	55	65

removing radioactive materials from the environment. Similarly, although there continue to be large numbers of graduates in topics such as general, inorganic, or physical chemistry each year, these graduates typically lack the specialized knowledge of nuclear reactions, decay modes, and chemical properties of radioactive elements and isotopes necessary for a career in nuclear or radiochemistry.

On-the-job training is one option to equip students to carry out certain specialized roles in the nuclear and radiochemistry workforce. The large nuclear reactor-services vendor AREVA has 12 training centers in France, Germany, and the United States and offers over 500 training programs. Similarly, the Los Alamos and Livermore National Laboratories have developed specialized in-house curricula to train and mentor nuclear and radiochemistry research staff.

Such training fills gaps in expertise in the short term, but does not provide the same quality of preparation and expertise as that of a Ph.D. specifically in nuclear and radiochemistry. Furthermore, the long-term health of the nuclear and radiochemistry field demands the depth of commitment of those who devote their entire careers to the discipline. For example, professionals trained in other disciplines are unlikely to become faculty in university settings that produce future Ph.D. students in nuclear and radiochemistry. While it is necessary to meet the impending shortages of trained personnel, it will not be possible to sustain a discipline in this manner.

Recommendations

The committee commends current and past efforts to support nuclear and radiochemistry workforce education and development, for example by setting up summer schools to help supplement inadequacies in undergraduate education. However, the various initiatives have been largely created independently by different federal funding agencies, each with a slightly different emphasis on outcome. Therefore, there is great potential for gaps in funding between the various parts of the academic pipeline, and no comprehensive plan to address these issues. Furthermore, it is not clear that currently favorable funding levels will continue, despite the critical role of nuclear and radiochemistry in national security and environmental protection. Based on its findings, the committee makes the following recommendations for action that both the public and private sectors can take to ensure an adequate supply of nuclear and radiochemistry expertise in the future. These recommendations call for action in three main areas of need: building structural support and collaboration between institutions, providing educational opportunities through on-the-job training, knowledge transfer, and retention; and in better data collection and tracking of the workforce.

Institutional Needs

Given the relatively small population of nuclear and radiochemists in the United States, it is essential to strengthen connections between current experts, and those who will supply and will need expertise in the future. Partnerships between the larger nuclear and radiochemistry programs at universities and national laboratories, and programs of colleges, research

Box 2. Research Directions in Nuclear and Radiochemistry

Innovative research and scientific expertise are required to tackle the many urgent research needs in nuclear and radiochemistry. Here, the committee has identified several of the most exciting research opportunities:

Nuclear Medicine
- Developing new radioisotopes and radiopharmaceuticals to allow targeted delivery of drugs to individual cancer cells

Nuclear Power
- Developing next generation fuels based on actinides require new chemical separation methods to meet society's energy demands

Homeland security
- Novel methods could help detect the illicit transportation of radioactive materials on a global scale

Weapons
- Developing and interpreting radiochemical signatures would allow scientists to accurately analyze performance and maintain weapon reliability without direct testing

Non-proliferation and Arms Control
- Additional nuclear forensics could help develop non-proliferation efforts world-wide

Environmental remediation and management
- Developing novel separation technologies could help develop long-term remediation strategies, especially for long-lived radionuclide fission products and actinides

institutes, medical facilities, and industry would help ensure an adequate supply of faculty, staff, students and postdoctoral fellows to satisfy both current and future professional and academic needs.

- Formalized collaborative partnerships for research and education in nuclear and radiochemistry should be established between universities, national laboratories, and relevant industrial sectors.

Educational

Educational programs are needed to develop experts for critical and time-sensitive jobs. In many sectors, the need for specialists or "on-the-job" training—whether for new Bachelor's degree holders or for mid-career scientists changing fields—cannot be met by the traditional academic system, because of the immediacy or classified nature of the work. Other types of educational program are needed to supply these types of training.

- To meet short-term workforce needs, resources and expertise should be made available to support on-the-job training in national laboratories, industry, and elsewhere.

With a large number of specialized nuclear and radiochemistry experts who are eligible to retire in the next five to ten years, a process is necessary to minimize the impact of losing many years of experience. Developing procedures to formalize knowledge retention and transfer would help overcome this challenge, especially at the national laboratories.

> ***Box 3. Summer Schools***
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> For nearly three decades, the U.S. Department of Energy has funded the American Chemical Society Division of Nuclear Chemistry and Technologies Summer Schools in Nuclear and Radiochemistry at San José State University and Brookhaven National Laboratory. The schools offer an intensive 6-week program of lectures and laboratory work that covers fundamental aspects of nuclear and radiochemistry and applications in medicine, forensics, and environmental management. Enrollment is limited to 12 U.S. citizen undergraduate students, and from 1984 to 2010, 577 students graduated from the program. Recently, similar summer schools have been duplicated by the Department of Homeland Security with a focus on forensics science and by the Actinide Science Network (ACTINET) in Europe.

- To ensure that long-term critical workforce needs can be met, federal agencies should identify and prioritize urgent requirements for, and fund efforts to ensure, knowledge transfer and retention.

Workforce Data Needs

A program or system to gather and track the metrics necessary to assess supply and demand, would make it easier to measure changes resulting from government and academic efforts to boost the nuclear and radiochemistry workforce.

- A federal source of supply and demand data for nuclear and radiochemistry expertise should be available.

Read or purchase this report and locate information on related reports at
http://dels.nas.edu/bcst

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The National Academies appointed the above committee of experts to address the specific task requested by U.S. Department of Energy National Nuclear Security Administration, the National Science Foundation, and the U.S. Department of Energy Office of Basic Energy Sciences. The members volunteered their time for this activity; their report is peer-reviewed and the final product signed off by both the committee members and the National Academies. This report brief was prepared by the National Research Council based on the committee's report.

EXPERT CONSENSUS REPORT

For more information, contact the Board on Chemical Sciences and Technology at (202) 334-2156 or visit http://dels.nas.edu/bcst. Copies of *Assuring a Future U.S.-based Nuclear and Radiochemistry Expertise* are available from the National Academies Press, 500 Fifth Street, NW, Washington, D.C. 20001; (800) 624-6242; www.nap.edu.