Education in Nuclear Science

A Status Report and Recommendations for the Beginning of the 21st Century

A Report of the
DOE/NSF Nuclear Science Advisory Committee
Subcommittee on Education

U.S. Department of Energy • Office of Science • Office of Nuclear Physics
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Executive Summary

In April 2003, the DOE/NSF Nuclear Science Advisory Committee charged its Subcommittee on Education with broadly assessing “how the present NSF and DOE educational investments relevant to nuclear science are being made” and with identifying “key strategies for preparing future generations of nuclear physicists and chemists.” In particular, the agencies asked the Subcommittee to examine current educational activities, including K–12 education and public outreach, and to “articulate the projected need for trained nuclear scientists, identify strategies for meeting these needs, and recommend possible improvements or changes in NSF and DOE practices.” Consistent with this charge, we offer a series of recommendations both to the funding agencies—the DOE and the NSF—and to the broad community of nuclear scientists.

It is important to emphasize the success of current programs. The nuclear science research enterprise continues to make great strides in exploring the nature of nuclear and nucleonic structure, probing matter at extreme energy densities, understanding the processes of nucleosynthesis and stellar evolution, elucidating the nature of matter in the universe, and exploring the fundamental symmetries of nature. New facilities have come on line in recent years, and the community now looks forward to the Rare Isotope Accelerator. The field thus remains vital and exciting. At the same time, however, we observe a slow decline in the production of nuclear science Ph.D.’s, a scarcity of nuclear science courses available to undergraduates, a lack of ethnic and gender diversity in the field, and broad public misconceptions about all things “nuclear.”

Bearing these issues in mind, the Subcommittee held four two-day meetings and consulted frequently by phone and e-mail between May 2003 and the publication of this document, to discuss and formulate its responses to the NSAC charge. Further, we conducted extensive surveys among undergraduates, graduate students, postdoctoral fellows, and recent Ph.D.’s five to ten years following their doctorates. This report presents in some detail the results of these surveys, together with available demographic data, in support of our recommendations, given below.

In addition, we emphasize that the strength and future of the educational enterprise rest on forefront research opportunities and forefront facilities. Any effort to improve nuclear science education and to provide the nation with a skilled workforce and an educated populace will fail without the necessary investments in research opportunities as outlined in the 2002 NSAC Long-Range Plan for nuclear science.

Outreach

> *We recommend that the highest priority for new investment in education be the creation by the DOE and the NSF of a Center for Nuclear Science Outreach.*

Ph.D. Production

> *We recommend 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.*

Diversity and Professional Development

We recommend that there be a concerted commitment by the nuclear science community to enhance the participation in nuclear science of women and people from traditionally underrepresented backgrounds and that the agencies help provide the support to facilitate this enhanced participation.

We recommend that there be a concerted commitment by the nuclear science community to establish mentoring and professional development programs and that the agencies support such efforts through the funding of competitive proposals.

Undergraduate Education

We recommend that the NSF and the DOE continue supporting research mentorship opportunities in nuclear science for undergraduate students through programs and research grant support. Additionally, we recommend that they consider expanding support if proposals for undergraduate student involvement in nuclear science research increase.

We recommend the establishment of a third summer school for nuclear chemistry, modeled largely after the two existing schools.

We recommend that there be a concerted commitment by the nuclear science community to be more proactive in its recruitment of undergraduates into nuclear science, especially among underrepresented groups. We also recommend that the NSF and the DOE continue to be supportive of requests for recruitment and outreach support.

We recommend that the Division of Nuclear Physics of the American Physical Society consider the establishment of a community-developed recognition award for individuals providing research opportunities and/or mentoring to undergraduates in nuclear science.

We recommend the establishment of an online nuclear science instructional materials database, for use in encouraging and enhancing the development of undergraduate nuclear science courses.

Graduate and Postdoctoral Training

We recommend that the nuclear science community assume greater responsibility for shortening the median time to the Ph.D. degree.

We strongly endorse the Secretary of Energy Advisory Board's 2003 recommendation that new, prestigious graduate student fellowships be developed by the Office of Science in the areas of physical sciences, including nuclear science, that are critical to the missions of the DOE.

We also strongly endorse the accompanying recommendation that new training grant opportunities in nuclear science be established.

We recommend that prestigious postdoctoral fellowships in nuclear science be established, with funding from the NSF and the DOE.

We also endorse the broad principles reflected in the NSF's Criterion 2, which seeks to ensure that research activities have an impact beyond their narrowly defined intellectual objectives. Ancillary benefits of proposed research should be considered, including its success in promoting teaching, training, and learning; broadening the participation of underrepresented groups; enhancing the infrastructure for research and education; increasing scientific and technological understanding; and broadly benefiting society.

Introduction and Recommendations

The United States' leadership in science and technology demands enduring attention to adequate science education—not only the education of undergraduates, graduate students, and postdoctoral fellows, but also the education of precollege students and the broader public. The 2002 Nuclear Science Advisory Committee (NSAC) Long-Range Plan, "Opportunities in Nuclear Science," recognized this explicitly:

> The education of young scientists must be an integral part of any vision of the future of nuclear science, as well as being central to the missions of both the NSF and the DOE. Well-designed educational programs, ensuring a stable supply of nuclear scientists—as well as a scientifically literate society—are essential not only to the fertility of academic research, but also to the needs of medicine, defense, industry, and government.

This educational mandate is thus an essential part of the Department of Energy (DOE) and National Science Foundation (NSF) efforts in nuclear science, together with the maintenance of a vigorous research program and the construction and operation of state-of-the-art research facilities. Indeed, these three elements are closely linked. For example, without forefront research opportunities at our universities and national laboratories, we cannot attract and educate the next generation of talented scientists needed to meet the nation's demands in the area of applied nuclear science.

At the outset, it is important to underscore the success of current programs. Since the mid-1990s, the nuclear science research enterprise has made great strides in exploring the nature of nuclear and nucleonic structure, probing matter at extreme energy densities, understanding the processes of nucleosynthesis and stellar evolution, elucidating the nature of matter in the universe, and exploring the fundamental symmetries of nature. During this same decade, the Continuous Electron Beam Accelerator Facility (CEBAF) began operation at Jefferson Lab, and the Relativistic Heavy Ion Collider (RHIC) came on line at Brookhaven. The community now looks forward to the Rare Isotope Accelerator (RIA), which will allow us to map and define the limits of nuclear existence and help us to understand the origin of the elements and the generation of energy in the stars.

Nuclear science thus remains vigorous and stimulating, and our graduates are becoming the new leaders in the field, filling crucial roles in society. This success would have been impossible if our educational system were not producing top-flight researchers. And yet, some warning signals cannot be ignored: a decline in the production of nuclear science Ph.D.'s, a scarcity of nuclear science courses available to undergraduates, a lack of ethnic and gender diversity in the field, and broad public misconceptions about all things "nuclear."

In the following pages, the DOE/NSF NSAC Subcommittee on Education addresses each of these educational points in its response to a March 4, 2003, charge from the DOE and the NSF to NSAC. That charge, reproduced in Appendix A, requested NSAC to assess “how the present NSF and DOE educational investments relevant to nuclear science are being made and to identify key strategies for preparing future generations of nuclear physicists and chemists.”

In particular, the DOE and the NSF requested an assessment that would “document the status and effectiveness of the present educational activities, articulate the projected need for trained nuclear scientists, identify strategies for meeting these needs, and recommend possible improvements or changes in NSF and DOE practices. [The] report should also identify ways in which the nuclear science community can leverage its capabilities to address areas of national need regarding K–12 education and public outreach.”

Consistent with this charge, we address a series of recommendations both to the funding agencies—the DOE and the NSF—and to the broad community of nuclear scientists.

The Highest Priority: Broadening Our Reach

Nuclear science is a vital and exciting field; its several facets, including physics, chemistry, medicine, and engineering, offer intellectual stimulation and provide tangible benefits for the future of society. The 2002 Long-Range Plan presents a detailed picture of a lively and compelling field. Yet, in a time when the general public has become more and more critical of the need for basic scientific research, nuclear science faces especially acute public misperceptions. On the one hand, our field is sometimes characterized as a “mature”—a euphemism for “stale”—discipline offering little scope for exciting new discoveries; on the other, it is tarnished by the public fear surrounding anything “nuclear.”

These perceptions ignore the profound contributions of nuclear science in our daily lives, most visibly, perhaps, in modern medical diagnosis and treatment and in nuclear energy policy; they overlook the growing need for trained nuclear scientists in an age of reshaped global threats; and they pay no heed to the unpredictable benefits of cutting-edge basic research. Above all else, we were concerned by these misconceptions, by the often distorted public discourse that underlies them, and by the absence of focused educational resources that might correct them. Only a more broadly educated society—one with a practical, basic knowledge of nuclear science—can hope to deal effectively with a wide range of important scientific topics, including medicine, energy policy, and the potential for nuclear terrorism. A narrower concern, but one of particular consequence to our field, is the impact of distorted perceptions on the recruitment of future nuclear scientists. The omission or careless treatment of nuclear topics in precollege curricula can seriously limit the number of students who might ever consider a career in the field. And the absence of regularly taught undergraduate courses in nuclear science at many U.S. universities further obstructs the path to nuclear science careers. In addition, we strongly urge each nuclear scientist to become more active in educational outreach, particularly in K–12 science education.

In summary, we conclude that a new educational effort—a central organization, staffed with experts in nuclear science and in education—should be formed and supported by the federal granting agencies. Accordingly,

We recommend that the highest priority for new investment in education be the creation by the DOE and the NSF of a Center for Nuclear Science Outreach.

The Center would establish appropriate ties with the American Physical Society's Division of Nuclear Physics and its Committee on Education, as well as the Division of Nuclear Chemistry and Technology of the American Chemical Society. Its broad goal would be to approach the level of societal recognition currently enjoyed in space-based research programs. The Center would serve as a resource for all nuclear scientists and would help them promote their research and technical accomplishments to a broad audience. It would create materials to convey the excitement of nuclear science to the general public, help dispel widespread misconceptions by making people aware of the natural radiation in our environment, develop educational materials for K–12 teachers and students, and work to paint a more accurate picture of a vitally active field in the minds of legislators and academic leaders.

The Nuclear Science Pipeline: Production and Diversity

Underlying the recommendation for an outreach center is the recognized need for a continuing stream of nuclear science Ph.D.'s, men and women who will be leaders in nuclear science education and basic research, and who must also supply expertise critical to our nation's economic welfare and security—expertise in isotope science, radiation detection, nuclear medicine, and nuclear engineering, as well as the broad technical expertise to fill related "non-nuclear" positions in industry and government. To better understand the "Ph.D. pipeline" for nuclear science, we developed a detailed picture of the field's demographics, both its current profile and the dynamics of the past decades. Based on our analysis, we find that the current level of Ph.D. production in nuclear science may not be sufficient to meet future demand; to contribute adequately to the near-term needs of related fields such as nuclear engineering; or to realize the future opportunities outlined by the DOE Office of Science Twenty-Year Plan, the report of the Interagency Working Group on the Physics of the Universe, and the 2002 NSAC Long-Range Plan.

The reasons for this anticipated shortfall include the needs of homeland security, expected retirements at the national laboratories, and demands in nuclear engineering and nuclear medicine. For example, we note the projection that, within the next ten years, about three-quarters of the workforce in nuclear engineering will reach retirement age. Nuclear physics and nuclear chemistry Ph.D.'s must contribute at least modestly to filling the resulting demand. Therefore,

We recommend 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.

This would represent an increase from slightly more than 80 to about 100 new Ph.D.'s each year. We feel that this goal can be achieved without the allocation of additional resources by the NSF Division of Physics or the DOE Office of Science, principally by shortening the time students spend in the Ph.D. program and taking advantage of other funding opportunities for graduate students in areas of national need, at the same time that we enhance recruitment efforts aimed at students with undergraduate research experience. For this strategy to be successful, it is essential that the DOE and the NSF continue to place high priority on investment in graduate education and to maintain, at a minimum, their current level of educational expenditures.

Specific steps that address the issue of shortening the time to the Ph.D. degree are included in recommendations regarding graduate and postdoctoral education, discussed below.

Demographic data also highlight the striking underrepresentation of women and minorities within the nuclear science workforce. Women represent approximately 10% of tenure-track faculty and national laboratory employees. Recent progress in addressing this underrepresentation is encouraging, but inadequate: About 20% of new tenure-track faculty hires in nuclear science are female, compared with the few percent hired in the '70s and '80s. Minorities are even more poorly represented. Recruitment from both of these underrepresented groups will become increasingly necessary to meet the field's workforce needs—in terms of both diversity and numbers—in the coming years. To make progress, we must continue to transform our institutions to lower the barriers to inclusion and success, and we must give individuals today the tools to survive (in fact, to thrive) in a system still in transition.

We offer two recommendations to address the diversity gap in nuclear science. First, it is essential that we actively work to identify promising members of underrepresented groups and to increase the opportunities for their full participation in the community. It is also essential not only that we enable individuals to prosper within our current institutions, but also that we reexamine our basic assumptions and reevaluate our institutions to see how they might accommodate a broader group of individuals. Accordingly,

We recommend that there be a concerted commitment by the nuclear science community to enhance the participation in nuclear science of women and people from traditionally underrepresented backgrounds and that the agencies help provide the support to facilitate this enhanced participation.

The following steps might be taken as part of this concerted commitment:

- Enhance connections with the faculty and students of institutions and consortia that serve traditionally underrepresented groups.
- Establish programs that help facilitate the transition of early-career scientists into forefront research activities and educational opportunities. The agencies might, for example, establish and fund master's-to-Ph.D. bridge programs

for graduate students not yet fully prepared for doctoral-track graduate studies.

- Adopt policies that recognize the personal and family responsibilities of nuclear scientists, in particular, the prevalence of female nuclear scientists whose husbands or partners have a Ph.D. in the same field. Realistic family leave policies are a key example. Policies should also facilitate "partner hires."
- Develop effective models for enhancing the participation of individuals from traditionally underrepresented backgrounds and disseminate them via best-practice sessions.

A commitment to the goals of the NSF's Criterion 2 would also have a salutary impact on diversity in nuclear science. We discuss this in a separate section, below.

A second recommendation recognizes effective mentoring as critical to preparing nuclear scientists for the future. This is particularly true for members of underrepresented groups, who face significant barriers to success in nuclear science research and education. But even among the broader community of nuclear science Ph.D.'s early in their careers, concerns about finding a job—and, for many, disappointed expectations of finding an academic or national laboratory position—point to a need for much better career advising. Therefore, it is essential that the nuclear science community work actively to provide mentoring and professional development opportunities for all aspiring scientists in the field, and especially for members of underrepresented groups. If this is done well, we can ensure that our students and postdocs have fulfilling careers. By being more supportive and welcoming, our field should also become more attractive to promising people early in their careers. Therefore,

We recommend that there be a concerted commitment by the nuclear science community to establish mentoring and professional development programs and that the agencies support such efforts through the funding of competitive proposals.

Two steps, in particular, might be taken in support of this commitment:

- Develop programs at professional meetings, such as the American Physical Society's annual Division of Nuclear Physics meeting, and at the national laboratories that provide realistic career advising and support professional development.
- At our universities, enhance mentoring and career advising of undergraduate and graduate students and postdoctoral scholars, especially members of underrepresented groups.

Increasing the representation of women and minorities in nuclear science would materially enrich the educational experience for all and improve our success in recruiting students to the field. Several of the recommendations in the following section thus also focus on encouraging diversity within nuclear science.

At the same time, it is important to underscore that diversity issues—and many of the other issues we have identified here—are not peculiar to nuclear science, or to physics more broadly. We thus see an opportunity for nuclear scientists to play a leading role in addressing matters of broad importance to education.

Enhancing the Undergraduate Experience

The undergraduate years offer the prime opportunity for introducing students to the tools and methodology of physical science. It is therefore especially important that the nuclear science community focus its attention on those crucial years for the recruiting and retaining of interested students. If science has not seized their interest, either before entering college or during their first year or so, they are much less likely to pursue a scientific career. Likewise, if they have an interest in science but no opportunity to participate in research, they are less likely to be attracted to graduate school. And as we have already emphasized, deep-seated misconceptions about nuclear science make our challenges even greater.

To gain a clearer picture of the undergraduate years, we conducted four surveys relevant to this critical period: one survey of nuclear physics course offerings in the U.S., two online surveys of undergraduate students (one of Research Experience for Undergraduates [REU] students and one of Conference Experience for Undergraduates [CEU] students), and one e-mail query of REU program directors. One important finding was the shortage of courses in nuclear science available to undergraduate students in the U.S. More hopeful was the success of those courses that are available, of opportunities for research, and of interactions with the larger nuclear science community in providing the kinds of experiences that materially aid the recruitment of future nuclear scientists. Accordingly, we strongly endorse the important role played by undergraduate programs aimed at training and motivating young scientists. These include

- The NSF REU and Research at Undergraduate Institutions (RUI) programs. The REU program has been particularly successful at engaging women and has had a demonstrably positive influence in motivating, equipping, and retaining bright and energetic students.
- DOE university research grant support, which allows 100 or more undergraduate students to pursue research in nuclear science with supported investigators at universities or national laboratories.
- The CEU program, which gives undergraduate students a venue for presenting research to and interacting with the professional community.
- Summer schools in nuclear chemistry and radiochemistry, sponsored by the Division of Nuclear Chemistry and Technology of the American Chemical Society and funded by the DOE's Office of Basic Energy Sciences and Office of Biological and Environmental Research. Given the declining number of students pursuing nuclear chemistry Ph.D.'s, these schools serve an important role in attracting new graduate students to the field.

Two recommendations follow from the success of these programs:

We recommend that the NSF and the DOE continue supporting research mentorship opportunities in nuclear science for undergraduate students through programs and research grant support. Additionally, we recommend that they consider expanding support if proposals for undergraduate student involvement in nuclear science research increase.

We recommend the establishment of a third summer school for nuclear chemistry, modeled largely after the two existing schools.

We also commend the nuclear science community, and specifically the American Physical Society's Division of Nuclear Physics, for its active and dedicated support of undergraduate research and for the quality of experiences it provides for the motivation and training of young scientists. Nonetheless, we wish to encourage an even deeper commitment among our colleagues to recruiting the most promising undergraduates into nuclear science. Therefore,

We recommend that there be a concerted commitment by the nuclear science community to be more proactive in its recruitment of undergraduates into nuclear science, especially among underrepresented groups. We also recommend that the NSF and the DOE continue to be supportive of requests for recruitment and outreach support.

As an example of such activity, several REU programs have funds designated for the purpose of program promotion and recruitment—funds that could be used for travel to institutions with high numbers of students from underrepresented groups. For recruitment to be effective, it is essential that good working relationships between institutions be established, and that individuals with interest in these areas be identified and encouraged to build and maintain these ties. More broadly, we believe that a mechanism should be available to publicly acknowledge and celebrate individuals committed to recruiting, developing, and mentoring undergraduate students. Therefore,

We recommend that the Division of Nuclear Physics of the American Physical Society consider the establishment of a community-developed recognition award for individuals providing research opportunities and/or mentoring to undergraduates in nuclear science.

Finally, we recognize the disparity in resources available to large Ph.D.-granting institutions and to the smaller four-year colleges that confer nearly half of all physics bachelor's degrees. In an effort to make additional resources available to these smaller institutions,

We recommend the establishment of an online nuclear science instructional materials database, for use in encouraging and enhancing the development of undergraduate nuclear science courses.

Graduate School and the Postdoctoral Years

To assess the effectiveness of the nation's investment in graduate and postdoctoral training and to help us understand the factors influencing a successful and satisfying career in nuclear science, we contacted 627 graduate students, 352 postdoctoral fellows, and 412 men and women who received their nuclear science Ph.D.'s five to ten years ago. We sought information about background, ethnicity, age, and citizenship status; probed attitudes about the adequacy of their preparation and about their current situation; and asked questions designed to allow assessments about "quality of life." The results (see "The Surveys: Some Revealing Results," page xxiii) indicated a high level of satisfaction among these individuals who have chosen careers in nuclear science. At the same time, we exposed some shortcomings that we believe can be addressed by a series of corrective measures.

Among these shortcomings was the lack of adequate career advising, mirrored in a significant degree of disappointment among Ph.D.'s five to ten years after their degrees—disappointment arising from a misunderstanding of the breadth of the "traditional job market" for nuclear scientists and thus an unrealistic focus on academic or national laboratory positions. We believe this "expectation-reality" mismatch can be addressed by active advising and mentoring efforts. This finding is one of the roots of our recommendation, above, for enhanced mentoring and professional development.

Also prominent among our findings was the length of time required for a student to progress from entry into graduate school to a first job. The median registered time from bachelor's degree to a Ph.D. in nuclear physics or nuclear chemistry has been 7.0 years over the last five reporting periods (1998–2002). Seventy percent of these Ph.D.'s then take one or more (almost mandatory) postdoctoral positions lasting an average of 3.3 years. Therefore, ten-plus years pass before the "typical" nuclear science Ph.D. has a first job. This is too long. Not only can it deter career-minded students who might instead choose to pursue a different advanced degree, but it also deprives the U.S. of the independent intellectual contributions of these talented scientists during a creative time of their lives. We believe that the time to the Ph.D. should be shortened to five and a half or six years.

We also recognize the value and importance of the postdoctoral experience for many newly minted Ph.D.'s. However, we urge principal investigators to evaluate the total time being spent by their postdocs during this stage of their careers and to make sure that these individuals are receiving the training they need to enhance their subsequent career prospects.

As a first step toward reducing the overall time to the first job,

We recommend that the nuclear science community assume greater responsibility for shortening the median time to the Ph.D. degree.

The following activities should be among those considered to realize this goal:

- Nuclear science faculty should conscientiously monitor the progress of their graduate students toward the Ph.D. degree.
- Recognizing that a high-quality Ph.D. program contains, in addition to research, various scholarly components such as coursework, qualifying examinations, and in some cases serving as a teaching assistant, nuclear science faculty should work with their departmental colleagues to optimize these components for their students' education. In doing this, individual graduate students' needs and goals should be taken into account.
- Nuclear science faculty should identify new ways to engage graduate students in research early in their graduate careers.
- The funding agencies should be apprised of graduate students' progress in their research and toward their degrees, and work to help faculty toward the goal of optimizing the educational experience and reducing the time to completion of the Ph.D. degree. Monitoring the placement of graduate students after their Ph.D. work, as well as the attrition of those who do not finish, will also provide important data to improve overall graduate student education.

At the same time, we recognize the overarching importance of quality—of ensuring that nuclear science continues to attract "the best and the brightest." Recent years have seen a tremendous increase in the number of graduate students in the life sciences, while in the physical sciences, the number of students has not increased, even though the scientific challenges are great and the need for scientists in the physical sciences continues to grow. The consequent need to increase the number of young Americans pursuing careers in the physical sciences and engineering was explicitly underscored in the Secretary of Energy Advisory Board's 2003 report, "Critical Choices: Science, Energy, and Security," which recommended new undergraduate, graduate, and postdoctoral fellowship programs.

We strongly endorse the Secretary of Energy Advisory Board's 2003 recommendation that new, prestigious graduate student fellowships be developed by the Office of Science in the areas of physical sciences, including nuclear science, that are critical to the missions of the DOE.

We also strongly endorse the accompanying recommendation that new training grant opportunities in nuclear science be established.

Prestigious fellowships would serve to attract the most promising graduate students, providing them with the flexibility to prepare for research in their subfield of choice. The training grants in nuclear science could, in particular, prepare undergraduate and graduate students and postdoctoral scholars for careers at the DOE and at the DOE-supported national laboratories that require expertise in nuclear science and its applications.

The need for this kind of support and encouragement extends beyond graduate school. There are relatively few ways in which nuclear scientists early in their careers are recognized for their accomplishments and potential, and even fewer ways in which this recognition extends beyond the nuclear science community. Prestigious postdoctoral awards in other physical sciences have served to meet both of these challenges. With similar postdoctoral fellowships in nuclear science, the visibility of nuclear science would be enhanced, encouraging undergraduate and graduate students to pursue such studies, and colleges and universities would be able to identify the top candidates for faculty positions.

The establishment of prestigious postdoctoral positions would also support a recommendation of the NSAC theory subcommittee in its 2003 report, "A Vision for Nuclear Theory."

We recommend that prestigious postdoctoral fellowships in nuclear science be established, with funding from the NSF and the DOE.

We recognize that the funding agencies will ultimately define the logistics to realize these prestigious opportunities. A reasonable approach to implementing this recommendation might be 12 two-year fellowships. In this approach, six of these fellowships would be awarded annually, with typically three each to theorists and experimentalists. Eligible applicants would have no more than two years of previous postdoctoral experience. At least initially, preference would be given to applicants with Ph.D.'s from U.S. universities. Compensation would be significantly above the standard stipend in nuclear science and would include an institutional payment to provide health benefits and a research account to provide some research independence for the recipient. The fellows could use their awards at any U.S. university or national laboratory; however, an effort should be made to limit the number of these prestigious scholars at a single host institution.

The mechanism for nomination of candidates for both graduate and postdoctoral fellowships should encourage the participation of both men and women of all ethnic backgrounds.

The NSF's Broader Impacts Criterion

Ensuring that research activities have an impact beyond their narrowly defined intellectual objectives is a challenging but critical component of the effort to achieve the goals of the national research program. To meet this challenge, the NSF has established a "broader impacts" criterion that takes account of the ancillary benefits of proposed research:

- How well does the activity advance discovery and understanding while promoting teaching, training, and learning?
- How well does the proposed activity broaden the participation of underrepresented groups (e.g., gender, ethnicity, disability, geographic, etc.)?
- To what extent will it enhance the infrastructure for research and education, such as facilities, instrumentation, networks, and partnerships?
- Will the results be disseminated broadly to enhance scientific and technological understanding?

- What may be the benefits of the proposed activity to society?

We support the broad principles reflected in this criterion. We therefore encourage the nuclear science community (and the individual scientists within it) to think broadly about the possible synergistic effects of their research and educational activities. In addition to more general activities, there are many ways in which nuclear scientists can use their education, training, and facilities—and the paradigm of the science—to contribute uniquely to the objectives embodied in this criterion. Possible activities include, but are certainly not limited to, the following:

- Nuclear science education and research aimed at the development of future scientists: postdocs, graduate students, undergraduates, and high school students and teachers. Efforts can include career advising and successful placement of apprentice scholars.
- Mentoring of future scientists not directly related to nuclear science education and research, in particular, the mentoring of men and women within traditionally underrepresented and disadvantaged groups.
- Activities that reflect favorably on the nuclear science community or that enhance public awareness and understanding of nuclear science and energy.
- Involvement in nuclear science and technology courses and workshops outside the university and basic science communities.
- Efforts to build and sustain relationships with institutions, and their students, that serve traditionally underrepresented groups.
- Involvement in public education and outreach to schools and to the public. Examples include lectures, tours of facilities, Web page development, and collaborations with teachers in the schools.
- Contributions of techniques, expertise, and workforce to areas of national need, including homeland security, medicine, and energy.
- Research that affects other areas of science.

Several of these activities would be facilitated by implementing the recommendations above, especially the recommendation for a Center for Nuclear Science Outreach, whose goals would include public education, the broad dissemination of research results, and the development of K–12 teaching materials.

Plan of the Report

Following a brief summary of our survey findings, the eight chapters of this report flesh out the outline above. Chapter 1 presents a detailed picture of the nuclear science community, with much of the data drawn from American Institute of Physics and NSF publications. Chapter 2 summarizes our surveys of undergraduate students and presents recommendations based on conclusions drawn largely from those surveys. Chapters 3–5 focus, respectively, on graduate students, postdoctoral fellows, and Ph.D.'s five to ten years after their degrees, each chapter summarizing in some detail the results of extensive surveys of those groups. Chapter 6 then draws on these survey results to present a series of recommendations to enhance the quality of graduate and postdoctoral training in the U.S. The issue of diversity, exposed as a serious concern in each of the foregoing chapters, is the focus of Chapter 7. Finally, Chapter 8 discusses current shortcomings in education and public outreach efforts and reiterates our recommendation for a dedicated outreach center.

The Surveys: Some Revealing Results

A Profile of the Community

Our recommendations rest in large measure on the results of surveys conducted among undergraduates, graduate students, postdocs, and recent Ph.D.'s five to ten years following their doctorates. The results of these surveys are summarized in Chapters 2–5; we offer a few highlights here. In addition, Chapter 1 offers a demographic picture of the nuclear science community. The key findings include the following:

- Women and minorities remain significantly underrepresented in nuclear science. The recent trend of 20% female new hires for tenure-track faculty is an encouraging improvement, but it remains inadequate.
- We observe a modest shift in the percentage of foreign Ph.D.'s taking positions in the U.S., including tenure-track faculty positions, where historical percentages of 20% foreign hires have now increased to over 30%. The implications are unclear.
- We also find indications that U.S. colleges and universities are losing positions in nuclear physics and nuclear chemistry—positions that are imperative to the Ph.D. stream.

Opportunities for Undergraduates

To assess exposure to nuclear science during the undergraduate years, we compiled data from 23 Ph.D.-granting physics departments, averaging 20 or more physics majors per year for the most recent available years (1999–2001). Among these largest departments, only six offered an undergraduate course in nuclear physics (which was thus available to fewer than 18% of the undergraduates represented by this sample). Another 12 departments offered a combined nuclear and particle physics course. The situation was similar among four-year colleges: Of the seven departments that averaged 15 or more physics majors per year, surveyed for the same time period, two offered a course in nuclear physics, one a combined nuclear/atomic physics course, and another a combined nuclear/particle physics course.

One hundred sixty-five undergraduates, from approximately 30 sites, responded to our survey of the REU program. Men and women were roughly equally represented among the respondents, but ethnic minorities were poorly represented. Asked why they chose to participate in an REU program, more than 60% of respondents said they did so in anticipation of attending graduate school, and overall, students expressed strong satisfaction with their research projects and with the value of the experience in terms of their future career plans. Students were also asked to assess the effect of the REU experience on their graduate school plans. About 65% expressed no change in plans, but nearly 25% experienced an increase in their interest, indicating that the experience bolstered interest and confidence in future graduate school plans.

We also surveyed the participants in CEU03, which took place in Tucson, Arizona, concurrently with DNP03. Of the 65 or so participants, 44 replied to the survey (about 68% overall). Among respondents, 27% were women and 73% men, representative of participation in the CEU program. Seventy-seven percent of CEU participants indicated plans to pursue graduate studies in physics or chemistry (52% "definitely," 25% "probably"). An additional 9% said they might pursue studies in those fields. Fully 90% reported that the CEU experience increased their interest in nuclear science, and among those planning for graduate school, 40% reported they would definitely or probably pursue nuclear science, while another 40% said they were not sure, but would consider it.

Graduate Students: Attitudes and Demographics

Graduate students were asked general questions about their background, ethnicity, age, and citizenship status, as well as their undergraduate experience, current experiences in graduate school, "quality of life," and career plans. Among respondents,

- About 80% were male and 20% female.
- Approximately 60% of the students were U.S. citizens. About 95% of these were Caucasian.
- The average age of the students was about 28 years.

- On average, non-U.S. citizens were older by about 1.5 years. The average age of U.S. females (about 26 years) was lower than either their U.S. male counterparts (27.5 years) or the average for the entire population.
- Most of the respondents were in their second through fifth year of graduate study, although 18% were in their sixth year or beyond. Nine percent had already completed five or more years of research.
- Over 80% had undergraduate research experience.
- Less than 30% of U.S. citizens (versus about 60% of foreign students) had taken an advanced undergraduate nuclear science course.

When students were asked to rank the “best things” about their graduate school experience, the overwhelming winner was the research experience. In second place came the students’ advisers, closely followed by graduate student colleagues, advanced classes, and teachers/professors. We found very little difference in these rankings among the different categories of respondents. The worst thing about graduate school life was said to be salary, followed closely by quality of life (i.e., no spare time, etc.) and advanced classes. Regarding salary, almost 80% of the students thought they were paid enough to ensure an adequate standard of living and that their standard of living was about what they expected when they started graduate school. Overall, more than 60% of the students thought that the working environment for women was positive. About 82% of U.S. women and more than 90% of foreign female graduate students rated their working environments as positive.

The U.S. and non-U.S. citizens responded very differently when asked to rank the adequacy of their undergraduate coursework as preparation for graduate school. Most U.S. citizens ranked their preparation as either average or above average; only about 20% said they had an excellent preparation for graduate school. In contrast, the majority of non-U.S. citizens said their preparation was excellent or above average. Similar attitudes emerged when U.S. citizens were asked to compare their preparation with that of foreign students—and vice versa. Also, U.S. citizens did not rate themselves highly when asked to compare themselves academically with other graduate students in their class. It is perhaps noteworthy that 21% of U.S. female students ranked themselves in the bottom 25% of their class—the only group to rank themselves this low.

Although 40% of nuclear science graduate students are non-U.S. citizens, 70% of those are planning careers in the U.S. Among all nuclear science graduate students, 25% said they were undecided about future jobs, but very few (less than 7%) were considering careers outside higher education or the national laboratories. Students considered learning communications skills, teamwork, and collaboration as important parts of their graduate education.

Postdoctoral Training: Evaluating the Experience

Only 29% of current postdoctoral fellows are U.S. citizens who received their degrees in the U.S., but 25% of the non-U.S. citizens also received their Ph.D.’s in the U.S. This indicates that the quality of advanced training in nuclear science in the U.S. brings many foreign students and postdocs into the U.S. program. Among the U.S. citizens, we found essentially no ethnic diversity, and the community of postdocs is overwhelmingly male (86% of the total). The average age was 32.4 years; the women, on average, were a year younger than the men. The average number of postdoctoral positions that had been held by the respondents was 1.5.

Overall, the postdoctoral community was very positive about the postdoctoral experience and the usefulness of getting a Ph.D. in nuclear science, despite stresses related to the temporary nature of the employment and the level of financial compensation. The average annual salary reported by the respondents was about $44,500. Twenty-eight percent of U.S. Ph.D.’s, but only 4% of non-U.S. Ph.D.’s, incurred significant debt (averaging $20,600 for the U.S. Ph.D.’s) getting their degrees. Female postdoctoral fellows appeared to experience different career-related stresses in their personal and family relationships than did men. Specifically, far more female than male respondents had spouses or partners with advanced degrees in nuclear science and full-time jobs. It is therefore reasonable to infer that women are significantly more likely to experience conflict between careers and personal relationships than men. Approximately 30% of the female respondents also indicated they felt they were at a large disadvantage in the field of nuclear science, principally because they were not treated as scientific peers and because no allowance was made for maternal responsibilities.

The overwhelming majority of postdoctoral fellows entered the field of nuclear science to become university professors and/or to perform basic research in an academic or national laboratory setting. Among those who had spent several years in the field, the percentage wishing to pursue this direction was even greater. As discussed below, however, fewer than two-thirds eventually find a job at a university or a national laboratory—and not all of these jobs are in academic research. This suggests a large mismatch between career expectations and the likely reality for 30–40% of the postdoctoral fellows in the field.

The single largest concern for the postdoctoral population, far outweighing any other, is the prospect of permanent employment. Indeed, a sizable percentage (10–15%) of those responding indicated they would not recommend a career in nuclear science to an incoming graduate student precisely because of the current long-term employment outlook.

Assessing Decisions: Ph.D.'s 5–10 Years Later

We also surveyed nuclear science Ph.D.'s who received their degrees between July 1, 1992, and June 30, 1998; a total of 251 replied. The mean age of the survey respondents was 38.5 years. Twelve percent of respondents were women, essentially the same percentage as in the full survey population. As expected, there were very few native-born ethnic minorities among the nuclear science Ph.D.'s. Among respondents, 78% described themselves as experimentalists, 22% as theorists.

Seventy percent of the respondents did at least one postdoc; roughly the same percentage of women and men took postdocs, and each accepted an average of 1.5 positions. However, the mean time spent as postdocs for the women was about seven months shorter than for the men, 2.7 years compared with 3.3 years.

Most nuclear science Ph.D.'s took both their first and their last postdoctoral positions as "necessary steps" (73% and 58%, respectively), but more than 20% also felt that the first and the last postdocs were the "only acceptable employment." About one-quarter of both the experimentalists and the theorists are tenured or tenure-track faculty; 25% of the experimentalists and 16% of the theorists are at national laboratories; and 37% of the experimentalists and 41% of the theorists are working in business or industry, for the government, or for non-profit organizations (BGN). As far as we could tell, all respondents are currently employed.

Ninety percent of respondents—and a remarkable 100% of the theorists—thought that obtaining a Ph.D. was "worth the effort," regardless of their current jobs. Fifty-eight percent of the respondents said they would get a Ph.D. in nuclear science if they had it to do over, while another 17% would choose a different subfield of physics or chemistry. Another 13% would pursue a Ph.D. in another field, and 12% would instead seek an M.D., J.D., or master's degree, or would not pursue an advanced degree at all. Those employed in BGN positions were more likely to choose another field or another degree than those in academic jobs or at national laboratories. In retrospectively viewing their doctoral education, respondents rated the quality of their research experience very highly. In summary, it appears that the current educational system is providing the needed expertise and allowing graduates to find employment that uses their skills, although more than half of the nuclear science Ph.D.'s are hired in areas outside higher education or basic nuclear science research.

A key element of this survey was seven concluding open-ended questions. When asked what advice they would give graduate students just beginning studies in nuclear science, a disturbing 24% of the 171 respondents said that entering students should strongly reconsider a Ph.D. in nuclear physics, largely because of poor job prospects. When asked to offer recommendations to doctoral programs in nuclear science today, the most common response (22%) paralleled the advice to graduate students: Much more assistance in career planning and guidance should be made available, particularly about careers in business, government, and nonprofit sectors. Finally, survey participants were also asked, “How did you decide to choose to study nuclear science?” The responses were similar to those noted in the postdoc survey: The respondents got involved because they had been inspired by a good undergraduate or summer research experience; they had developed a general interest in nuclear science, enjoyed the work, and wanted to continue; they had been guided into nuclear science as an undergraduate by a professor or other mentor; or as a graduate student, they had been inspired by or wanted to work with a specific professor.

1. Demographics: A Picture of the Community

Introduction and Overview

Nuclear science is a broad field that addresses complex questions about the nature of matter and the role of nuclear processes in the universe. The intellectual challenge of understanding strongly and weakly interacting systems of matter is at the forefront of science. A continued stream of nuclear science Ph.D.'s is essential if we are to ensure progress on this front. In addition, the expertise of nuclear scientists is critical to our nation's economic welfare and security. Expertise in isotope science, radiation detection, and nuclear medicine, and an understanding of nuclear reactions are essential intellectual underpinnings of the U.S. national laboratories and important for the many industries that apply nuclear technology. Nuclear scientists also contribute to the workforce and provide significant foundational expertise in related fields such as accelerator physics and nuclear engineering.

This chapter summarizes the current demographics of workers in nuclear science and projects the needs of the field over the next decade. Based on this analysis, we find that the current level of Ph.D. production in nuclear science may not be sufficient to meet current demand, to contribute adequately to the near-term needs of related fields such as nuclear engineering, or to realize the future opportunities outlined by DOE Office of Science Twenty-Year Plan, the report of the Interagency Working Group on the Physics of the Universe, and the 2002 NSAC Long-Range Plan.

Providing an adequate and diverse workforce for nuclear science will be a major challenge for our field. Hence, we recommend 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. (The data presented in the following sections may support an argument for an even larger increase in Ph.D. production, given the upcoming retirement of the many scientists trained in the late 1960s and early 1970s; however, we cannot make a compelling case that this need will not be met by foreign-trained scientists and scientists trained in other fields.)

We feel that this goal can be achieved without the allocation of additional resources by the NSF Division of Physics or the DOE Office of Science, principally by shortening the time students spend in the Ph.D. program and by taking advantage of other funding opportunities for graduate students in areas of national need, at the same time enhancing recruitment efforts to attract the most talented students. For this strategy to be successful, it is essential that the DOE and the NSF continue to place high priority on investment in graduate education and to maintain, at a minimum, their current level of educational expenditures.

Specific steps that address the issues of shortening the time to complete a degree and the time spent in postdoctoral positions are included in recommendations regarding graduate and postdoctoral education in Chapter 6.

Current data and trends also indicate that women and minorities are seriously underrepresented in the nuclear science workforce. Women represent approximately 10% of tenure-track faculty and national laboratory employees. Recent progress in addressing this underrepresentation is encouraging, but inadequate: About 20% of new tenure-track faculty hires in nuclear science are female, compared with the few percent hired in the '70s and '80s. Minorities are even more poorly represented. Recruitment from both of these underrepresented groups will become increasingly necessary to meet the workforce needs—in terms of both diversity and numbers—within nuclear science.

Even more important to the continued health of the nuclear science workforce is its quality. Two trends in the data discussed below indicate potential future problems. First, the demographic data hint that U.S.-trained scientists are having an increasingly difficult time competing for tenure-track faculty positions. A higher percentage of tenure-track faculty positions are filled by people who have received their education and training outside the U.S. Second, the number of faculty positions in nuclear science appears to be in slow decline. The absence of faculty positions at universities will make it increasingly difficult to attract and educate the best students. Forefront research facilities and research opportunities in nuclear science (including facilities at universities) are critical to maintaining a high-quality educational system and the availability of faculty positions. Along these lines, the 2002 NSAC Long-Range Plan identifies a dynamic program for nuclear science.

In this report, the nuclear science workforce refers primarily to nuclear physicists and nuclear chemists. However, accelerator physics is a very closely related field, and indeed, many accelerator physicists are trained at nuclear physics laboratories. For example, Michigan State University, one of the few universities with an accelerator physics program, is funded primarily by the NSF nuclear science program. While not quantified in this report, this contribution to the U.S. workforce is critical and should be recognized. The NSF and the DOE fund approximately five Ph.D.'s per year in accelerator physics as a component of their nuclear science programs. We judged that a detailed estimate of future workforce needs in accelerator physics was outside the scope of this report.

National Trends in the Scientific Workforce

The supply of nuclear physics and nuclear chemistry Ph.D.'s

The security and living standards of our complex and technical society require a highly educated workforce, and doctoral-level education in the physical sciences is an indispensable contributor to this workforce. Ph.D.-level scientists are essential to the independent thinking and forefront research that lead to intellectual and technical advances. And yet, there is considerable concern that current trends in physical science education will lead to an insufficient number of Ph.D. graduates in the near future. The National Science Board (NSB) concluded recently that "these trends threaten the economic welfare and security of our country" [NSB 2004].

In this chapter, we consider both the overall picture in physical science education and the narrower case of nuclear physics and nuclear chemistry. The two situations are closely related. The supply of nuclear science Ph.D.'s is a critical resource in answering the broad demand for physical scientists. Ph.D.'s in nuclear science are broadly capable of filling roles in government and industry: Nuclear science—by its nature the study of complex systems using advanced tools and cutting-edge theory—provides an ideal training ground for a highly skilled workforce.

To assess the status of the supply of Ph.D.'s, we used general demographic data on education in the physical sciences, as compiled by the American Institute of Physics (AIP) and the Commission of Professionals in Science and Technology (CPST). Details are available at the AIP Web site, *http://www.aip.org/statistics/*. Additional general data are available from CPST and can be found at *http://www.cpst.org/*. Periodic reports are available from a variety of sources, for example, the biennial NSB report on Science and Engineering Indicators [see, for example, NSB 2004].

We draw a number of key conclusions from this global information:

- One-third to one-half of physics Ph.D.'s ultimately work outside physics (mostly in engineering) [AIP 282.23]. This also holds for nuclear science, based on the limited data available from the AIP and our Ph.D.'s 5–10 Years Later survey, which is part of this report. This global trend represents a valuable transfer of knowledge to the broader U.S. financial and technology base, and is an essential contribution of the educational process in the physical sciences.
- Unemployment rates among Ph.D. physicists are consistently low, typically 1–2% [NSB 2004]. This indicates that the skills of this group are in high demand.
- The number of incoming Ph.D. students is expected to increase over the low of 1,000 in 2003 to about 1,400 over the next few years [AIP 151.39]. However, nuclear science must compete with the other physical sciences for the best of these students, and it is critical that our field project an appropriate, positive image.
- About half of incoming physics graduate students are from outside the U.S. This has been true since about 1997 [AIP 151.39]. While it is encouraging to observe that the U.S. continues to draw students from overseas, improvements in the economies and educational systems in other countries will increase the competition for these students when they graduate.
- The DOE and the NSF are the primary U.S. government agencies funding the education of Ph.D. students in the physical sciences (and, in particular, nuclear science).

Ph.D. production in the physical sciences reached a peak in the early 1970s at a level nearly twice that of today [UMI]. The trend in nuclear science is essentially identical. Within the next ten years, the vast majority of these Ph.D.'s will reach retirement age. Specifically, in nuclear science, it has been estimated that more than three-quarters of the workforce in nuclear engineering and at the national laboratories will reach retirement age during this same period [NRC News].

Figure 1-1 shows the trends in the supply of nuclear science Ph.D.'s, as well as Ph.D.'s in related fields that might help fill this potential need. The data are taken from the NSF Survey of Earned Doctorates. In order to confirm these statistics for the past five reported years, the numbers of nuclear physics and nuclear chemistry degrees were compared with the number of Ph.D. titles listed under "nuclear" in the UMI dissertation database [UMI]. The results suggest a 10–15% underreporting of nuclear science Ph.D.'s in the Survey of Earned Doctorates. The level of Ph.D. production has decreased by about 20% since the mid-1990s to approximately 75 nuclear physics Ph.D.'s and 10 nuclear chemistry Ph.D.'s per year. More dramatically, the total Ph.D. production of nuclear physicists and nuclear chemists is down to about half of the all-time highs reached in the mid-1970s. Over the past three decades, these same broad trends appear to be duplicated in the related fields of particle physics and nuclear engineering. In nuclear chemistry, Ph.D. production remains at an extremely low level.

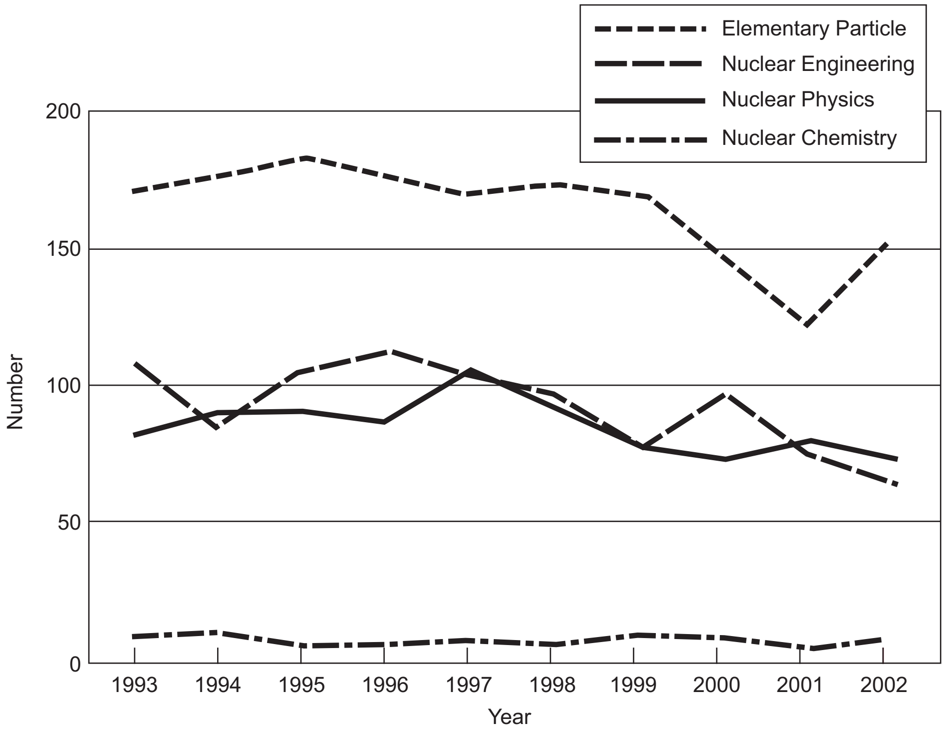


Figure 1-1. Number of Ph.D.'s per year in selected disciplines, as reported in the NSF Survey of Earned Doctorates.

Is there a looming shortage of scientists?

The needs in nuclear science education are tied to the global needs of the U.S. science and technology workforce. A considerable body of information suggests that the current educational system is not producing sufficient scientists to meet future demands. To answer the question posed in the title of this section, we drew material from several recent studies. The following selected statements from speeches, testimony, and reports reflect the tenor of these studies:

> As it happens, the U.S. scientific and engineering workforce is aging. The number reaching retirement age is likely to triple in the next

decade. This is compounded by another fact. For years, government and corporate requirements for specialized science and engineering skills have been filled, when needed, by foreign nationals. But, since September 11th, 2001, visa applications have declined dramatically, while at the same time, forces at work in the global economy are creating opportunities which encourage foreign scientists to find employment in their home countries.

—Speech to Congress (Feb. 14, 2004) by Shirley Ann Jackson, Ph.D.
President, Rensselear Polytechnic Institute

The scale and nature of the ongoing revolution in science and technology, and what this implies for the quality of human capital in the 21st century, pose critical national security challenges for the United States. Second only to a weapon of mass destruction detonating in an American city, we can think of nothing more dangerous than a failure to manage properly science, technology, and education for the common good over the next quarter century.

—U.S. Commission on National Security/21st Century (2001)

The future strength of the U.S. [science and engineering] workforce is imperiled by two long-term trends:

- Global competition for S&E talent is intensifying, such that the United States may not be able to rely on the international S&E labor market to fill unmet skill needs;
- The number of native-born S&E graduates entering the workforce is likely to decline unless the Nation intervenes to improve success in educating S&E students from all demographic groups, especially those that have been underrepresented in S&E careers.

It is in the national interest as well as the interest of individual students and scholars that the Federal Government—with other stakeholders in the S&E workforce—take action to guide the advanced education of scientists and engineers to better align with expected national skill needs. Areas of national skill needs include. . . Federal mission-related fields where enrollments are falling and projected needs rising, e.g., nuclear physics and engineering.

— National Science Board
The Science and Engineering Workforce:
Realizing America's Potential (2003)
[http://www.nsf.gov/nsb/documents/2003/nsb0369/nsb0369.pdf]

We further recommend that training grants be established in areas required to advance DOE's mission in the future, but for which the U.S. is not producing scientists and engineers. Some of these should be in traditional areas essentially unique to DOE such as nuclear

> engineering and nuclear science. Others will be especially useful in emerging areas like nanotechnology and biological engineering that must grow at the intersections of traditional disciplines.
>
> *—Secretary of Energy Advisory Board (2003)*

> In preparing Indicators 2004, we have observed a troubling decline in the number of U.S. citizens who are training to become scientists and engineers, whereas the number of jobs requiring science and engineering (S&E) training continues to grow. Our recently published report entitled The Science and Engineering Workforce/Realizing America's Potential (NSB 03-69, 2003) comes to a similar conclusion. These trends threaten the economic welfare and security of our country. If the trends identified in Indicators 2004 continue undeterred, three things will happen. The number of jobs in the U.S. economy that require science and engineering training will grow; the number of U.S. citizens prepared for those jobs will, at best, be level; and the availability of people from other countries who have science and engineering training will decline, either because of limits to entry imposed by U.S. national security restrictions or because of intense global competition for people with these skills. The United States has always depended on the inventiveness of its people in order to compete in the world marketplace. Now, preparation of the S&E workforce is a vital arena for national competitiveness.
>
> *—National Science Board Report [NSB 2004]*

Is there a looming shortage? The implications of these excerpts should be tempered with a recognition that workforce issues are complex. In 1989, the NSF released a report warning of a shortage of scientists due to an upcoming wave of retirements by 2003. The shortage did not materialize, in part because foreign-born and foreign-educated Ph.D.'s filled the positions, and in part because the end of the Cold War resulted in a decline in federal military research and development. The 1989 report is now seen as inaccurate, and current warnings are sometimes dismissed as yet another cry of "wolf." Many of the current predictions of a future shortage are based on the potential loss of an influx from the foreign workforce. Will this be an ongoing or a temporary problem?

The picture is similar in nuclear science; however, in addition to contributing to the scientific workforce, nuclear science Ph.D.'s have specific knowledge necessary for handling and detecting radiation, working with isotopes, and developing the next generation of nuclear technology. Impending retirements within the nation's nuclear workforce, together with the increasing threat of nuclear materials being used by terrorists, will increase the demand for scientists who understand the effects of these weapons and who are trained to develop techniques to mitigate the risk from them. The field of nuclear science is also working to address some of the major questions in physics and astronomy, and the field cannot be sustained without an adequate number of highly qualified young scientists.

The Employment Picture for Nuclear Science

Nuclear scientists find employment in three broad categories: (i) academia, which includes faculty at universities and four-year colleges, (ii) staff positions at national laboratories, and (iii) positions in business, government, or nonprofit organizations. In this section we outline the current demographics for nuclear scientists and, based on this information, make broad projections for future employment demand.

To begin, it is important to highlight several areas of particular concern—areas in which nuclear scientists and engineers make contributions not easily met by workers educated in other areas. First, we note that, according to the NSF Survey of Earned Doctorates, the number of nuclear chemistry Ph.D.'s has dropped from 40 per year in 1970 to 10 per year in 2000. This is coupled with the aging of the radiochemical workforce. This concern was highlighted in a 1999 study by the Members of the Senior Scientists and Engineers sponsored by the AAAS [AAAS]:

> Too few isotope experts are being prepared for functions of government, medicine, industry, technology and science. Without early rescue, these functions face nationally harmful turning points, including certainty of slowed progress in medicine and some technologies, near-certainty of shocks in national security, and probable losses in quality of health care.

A second area of concern is the significant drop in the number of nuclear engineers and the impending shortage in that field. According to the Nuclear Engineering Institute, the demand for nuclear engineers will triple in the next few years. Nuclear physicists and nuclear chemists will certainly contribute to meeting this need. The increase in nuclear science–based medical diagnostic procedures may also impose an additional demand in this area. Finally, scientists with expertise in radioactivity and nuclear properties will be increasingly important for homeland security.

Finally, it is important to note that this is a time of great potential for research in nuclear science. The 2002 NSAC Long-Range Plan outlined a number of current and new initiatives in the field. If new initiatives such as the Rare Isotope Accelerator (RIA) and the Underground Laboratory are realized, the field must maintain, or even slightly increase, its level of effort. At a time when there will be significant demand on the workforce, this could be difficult unless the number of new Ph.D.'s is adequate.

The national role of nuclear scientists

The nuclear science Ph.D. stream provides the workforce needed to continue basic nuclear science research at universities and national laboratories and to develop new technologies and methods related to nuclear science. In addition, Ph.D.'s in nuclear science have historically filled a variety of other roles in government and industry. Our survey of Ph.D.'s five to ten years after their degrees showed a broad range of careers, ranging from finance to medical physics. Training in nuclear science offers specific expertise in the areas of radiation detection and the application of nuclear properties. Further, although nuclear physicists and nuclear chemists are not specifically trained as nuclear engineers or medical physicists, they contribute significantly to the development of new technologies and methods in those areas, and their background qualifies them as candidates to fill part of the growing need in those same fields.

Various surveys of business leaders indicate that the qualities desired in physical science graduates are their problem-solving skills, ability to work as part of a team, and analytical talents—all essential skills sharpened in the course of a Ph.D. education. The extremely low unemployment rate among nuclear science graduates is a further indication that these graduates possess critical skills.

The DOE and NSF nuclear science directorates also fund research related to accelerator physics, and some of the graduates develop expertise in this underrepresented area. Particle accelerators play a key role in medical diagnostics and treatment, industrial processing, and other areas of science.

Table 1-1 illustrates the roles of nuclear scientists by providing a breakdown of the current jobs held by the 195 respondents to our Ph.D.'s 5–10 Years Later survey. The data indicate that between one-third and one-half of nuclear science Ph.D. recipients take jobs in nuclear science at colleges, universities, and national laboratories (70 out of 195). Hence, up to two-thirds of such graduates take positions outside academia and the national laboratories. This represents a necessary and desirable transfer of expertise to other fields and also indicates the demand for the skills learned while earning a nuclear science Ph.D.

The Ph.D.'s who leave the nuclear physics and nuclear chemistry fields (about 60% of the total) provide a key resource for the nation. In the previous section, we discussed the potential growth in the demand for nuclear scientists. They will be

Table 1-1. Current job status of 195 respondents to the Ph.D.'s 5–10 Years Later survey. Only 70 of these respondents reported their current jobs as being in nuclear science in universities, colleges, or national laboratories.

Current Employer Type	In nuclear science		In a related field		In a different field		Total	
	N	%	N	%	N	%	N	%
Ph.D. University	27	36.5%	15	33.3%	10	13.2%	52	26.7%
Other College/ University	9	12.2%	10	22.2%	6	7.9%	25	12.8%
National Lab	34	45.9%	8	17.8%	6	7.9%	48	24.6%
Business/ Industry	3	4.1%	8	17.8%	52	68.4%	63	32.3%
Government Agency	1	1.4%	4	8.9%	2	2.6%	7	3.6%
Total	74	100.0%	45	100.0%	76	100.0%	195	100.0%

expected to contribute to the needs of homeland security, to help meet the need to replace the aging professional nuclear workforce, and to transfer technology and advanced analytical methods to business and government. Many of these needs are best met with the kinds of expertise developed in the course of nuclear science Ph.D. study, particularly, by the study of basic nuclear properties and nuclear techniques. Hence, we anticipate the percentage of people leaving the field to remain constant, at least, and perhaps to rise as demand in other areas lures Ph.D.'s out of basic nuclear science research.

Data sources

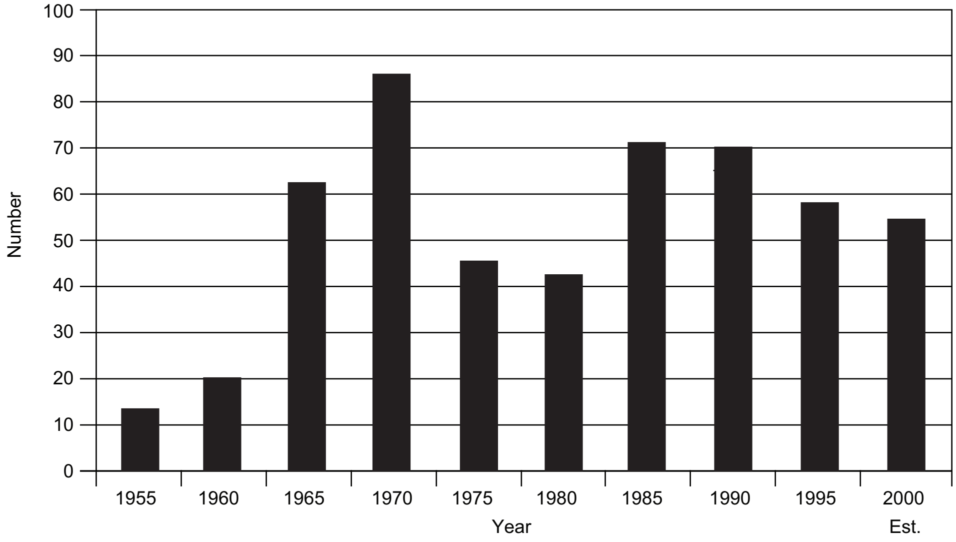
The data summarized below were obtained by querying the physics division directors at DOE national laboratories and by compiling a database of all faculty at four-year colleges and universities. We did not attempt to determine the workforce status of nuclear scientists in areas outside academia and the national laboratories. (Historically, more than half of nuclear science Ph.D.'s end up working outside of these areas [AIP 282.23].) As shown in Table 1-1, our survey of Ph.D.'s five to ten years after their degrees provided some information on the employment picture for this group, and the numbers are consistent with the general trends observed by the AIP.

The database for university and four-year college faculty was compiled from Web sites, the NSF/DOE principal investigator list, and the AIP lists of physics departments in the U.S. [AIP GP]. Information was recorded for faculty who list nuclear physics or nuclear chemistry as their primary research interest; for each individual, this information included job title, year of Ph.D., Ph.D.-granting institution, gender, specific area of study, and experimental or theoretical specialty. The database includes approximately 1,000 entries. The data were compiled in 2003 and probably reflected information that was one year old at that time. To assess the situation at the U.S. national laboratories, we obtained data from Argonne (ANL), Brookhaven (BNL), Los Alamos (LANL), Lawrence Berkeley (LBNL), Lawrence Livermore (LLNL) and Oak Ridge (ORNL) national laboratories, and the Thomas Jefferson National Accelerator Facility (JLab). For staff below the age of 50, we requested details regarding gender, ethnicity, year of Ph.D., and origin of Ph.D. The division directors were also asked to outline their expected hiring over the next ten years.

Age distribution of nuclear scientists and future demand

To judge the demand for nuclear physicists and nuclear chemists in the next decade, it is necessary to estimate the age demographics of the current workforce. For the national laboratories, this information was provided by the division directors, but it was not directly available for faculty. In order to assess this aspect, we compiled the year of Ph.D. in our faculty database. The distribution is shown in Figure 1-2 for all tenure-track faculty, excluding emeritus faculty. Data were not available for approximately 30% of the faculty in the database, and the numbers have been scaled accordingly. The observed trends are very similar to the age distribution of faculty for all physical sciences [AIP Statistics].

Figure 1-2. Year of Ph.D., consolidated in five-year increments, for those identifying themselves as nuclear scientists who hold any rank of professor (emeritus excluded) and who are on the tenure track at four-year colleges and universities in the U.S. Data on the year of hire were not available but can be estimated as the year of Ph.D. plus four years.

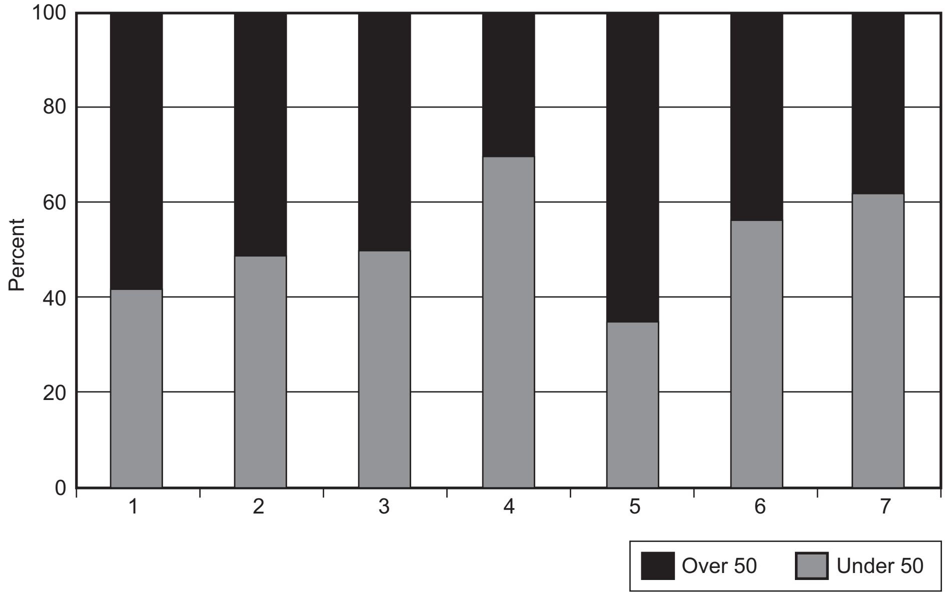


The data in Figure 1-2 indicate a fairly constant demand of 12 to 15 new tenure-track faculty per year. In addition, approximately five nontenured research faculty positions are filled per year. The data also suggest a recent drop in the number of positions being filled. The drop is not dramatic, but it is worrisome in light of the fact that in ten years, the demand for nuclear physicists and nuclear chemists is likely to increase. The loss is compounded by the fact that the large bulge of positions held in the late ’60s and early ’70s in nuclear science are apparently not being replaced, as a new, corresponding bulge has not appeared. It is critical for the health of the field and the future supply of nuclear scientists that the number of available faculty positions not continue to decline.

The age distribution for nuclear scientists at the national laboratories is shown in Figure 1-3. Overall, 50% of the laboratory nuclear scientists are above the age of 50. While not a dramatic statistic, this does point to a large number of retirements within the next 10 to 15 years. Accordingly, physics division directors estimate hiring 175 Ph.D.-level career staff over the next ten years, or approximately 18 per year. This number does not include the additional demand that may be required by initiatives such as RIA and the Underground Laboratory.

In summary, it appears that the demand for nuclear physicists and nuclear chemists in academia and at the national laboratories will be approximately 35 to 40 Ph.D.’s per year—12–15 tenure-track faculty, 5 nontenured research faculty, and 18 national laboratory researchers—over the next ten years. These numbers are probably slightly higher than, but similar to, the hiring rates in these areas over the past ten years. In the concluding section of this chapter, in assessing the total number of nuclear physics and nuclear chemistry Ph.D.’s required to fill this need, we assume that up to two-thirds of the graduates will work in business, in government, or for nonprofit organizations (see also Chapter 5, which summarizes the current employment picture found in our Ph.D.’s 5–10 Years Later survey). Indeed, the low unem-

Figure 1-3. Age distribution of nuclear scientists at the national laboratories. The laboratories represented (ANL, BNL, JLab, LANL, LBNL, LLNL, and ORNL) are identified only by numbers.



ployment rate for nuclear science graduates, coupled with the expected additional demand for skills in this area, argues that we adopt a number at or even above the upper end of this historical range. (We discuss elsewhere in this report the corresponding imperative that the nuclear science community prepare students for appropriate careers.)

Trends in the national origin of nuclear science Ph.D.'s

Are nuclear scientists trained in the U.S. competitive with those trained elsewhere? The low unemployment rate for physical science Ph.D.'s suggests that the answer to this question is yes. However, it is instructive to look at the origin of recent hires in academia. Figure 1-4 indicates that nuclear physics and nuclear chemistry positions at colleges and universities are increasingly being filled by foreign-educated scientists. The historical average of 80% of faculty hires having received their Ph.D.'s in the U.S. has dropped to slightly below 70%. Though not a dramatic decline, this change is suggestive of future trends. (A close look at the database confirms that the influx of scientists into the U.S. after the end of the Cold War did not have a large influence on the trends seen in Figure 1-4, since many of those people were senior scientists and were hired into ranks higher than assistant professor.) A similar, though somewhat less dramatic, trend is seen in the data from the U.S. national laboratories, as shown in Figure 1-5.

One of the national laboratory physics division directors noted that it was not possible to find high-quality U.S. Ph.D.'s with experience in basic nuclear science. This is echoed in recent searches for faculty and postdocs, in which many positions were filled by non-U.S. Ph.D.'s. It may be a particular concern for national security if U.S. scientists with expertise in basic nuclear science are less competitive than those from Europe and Japan.

Figure 1-4. Percent of tenure-track faculty who received their Ph.D.'s from U.S. institutions.

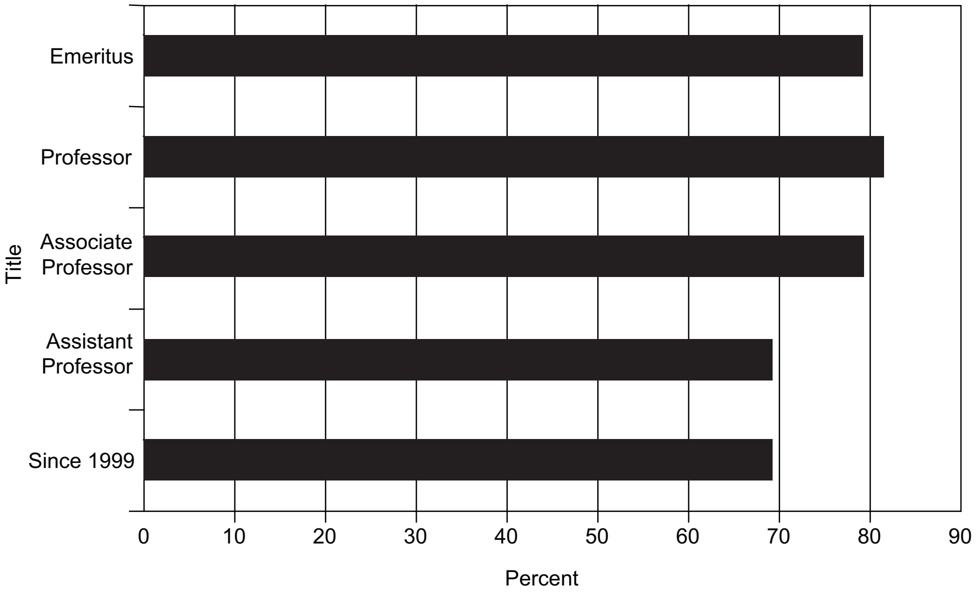
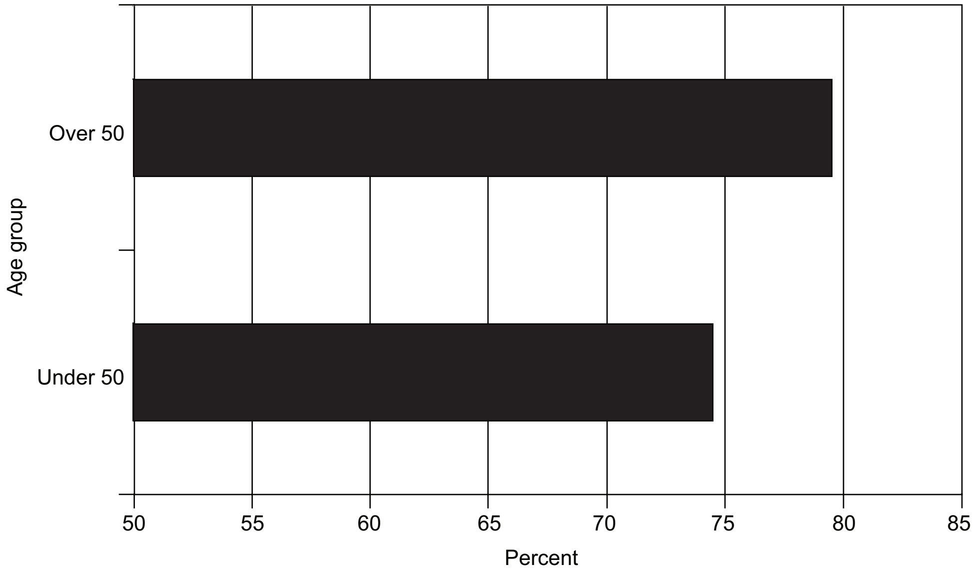


Figure 1-5. Percent of career national laboratory staff who received their Ph.D.'s from U.S. institutions.



Status of underrepresented groups

Historically, all gender and ethnic groups have not been proportionally represented in nuclear science, and this certainly remains the case. Very few ethnic minorities are to be found in the nuclear physics and nuclear chemistry academic workforce. This is a problem common to all the physical sciences. The situation for women is better, but their representation is well below that seen in some other scientific disciplines. The fraction of women among nuclear scientists at the national laboratories is 10%; at universities and colleges, 9%.

We do see some evidence of recent progress in hiring women at colleges and universities. Figure 1-6 shows the percentage of hired tenure-track faculty who are women versus the year they received their Ph.D. The trends are encouraging: Over the past ten years, 20% of new hires have been female, a substantial increase from the 1970s and 1980s. Nonetheless, even current levels are more than a factor of two below that required for long-term equity.

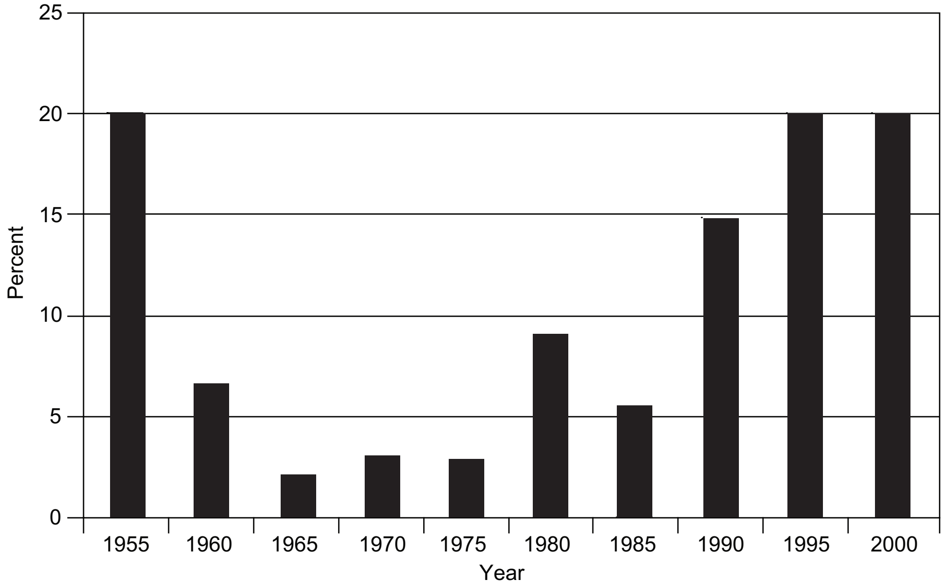


Figure 1-6. Percent of tenure-track faculty who are female, as a function of the year they received their Ph.D.'s. Each bar represents a five-year average.

Estimation of future workforce needs

Based on our findings, a conservative estimate of the number of Ph.D. recipients required to fill tenure-track academic positions and career national laboratory staff positions in nuclear science is approximately 35 to 40 per year. This total is the sum of the estimated 12 to 15 faculty positions, 5 research faculty, and 18 national laboratory positions to be filled per year. To estimate the total number of Ph.D.'s required per year, we should expect more than one-half (and perhaps up to two-thirds) of all nuclear science Ph.D.'s to take other jobs—a historical (and salutary) trend. We therefore estimate that about 90–100 Ph.D. graduates per year are required. This demand can be roughly met by the current graduation rate, assuming all Ph.D. graduates remain in the U.S.

Currently (2000–2002), 38% of the Ph.D.'s in nuclear science go to temporary visa holders. Historically, about half of these individuals return to their home countries or to other foreign countries upon graduation. If we assume the current annual Ph.D. production in nuclear science to be about 85 per year, this implies an annual loss of about 16 scientists from that pool. This loss, however, is partially offset by the foreign-trained Ph.D.'s who currently take about one-third of the new faculty positions (four or five per year) and the 25% who take career staff positions at the national laboratories (four or five per year). The net annual loss is thus about 10%. The net outward flow suggested by this crude calculation again indicates that the annual U.S. Ph.D. production in nuclear science may, in fact, be inadequate to supply the ongoing needs of universities, national laboratories, and industry—even apart from sources of additional demand.

These additional demands on the Ph.D. pipeline are in part demographic and in part a reflection of real increasing needs. The number of students trained in nuclear science has dropped by half since the 1970s. Scientists who graduated then are now nearing retirement and will need to be replaced in the coming ten years. Further, in the next decade, the demand for nuclear engineers will triple, increasing numbers of nuclear scientists will be needed for national security, and growth in nuclear medicine will exacerbate the shortage of personnel in that field. At the same time, nuclear scientists will be looking to realize the new opportunities envisioned in the DOE Office of Science Twenty-Year Plan and the report of the Interagency Working Group on the Physics of the Universe (for example, RIA and research at the Underground Laboratory).

Summary and Recommendation

The central conclusion to be drawn from the demographic picture depicted in this chapter is that demand in the near future for nuclear physics and nuclear chemistry Ph.D.'s will be somewhat higher than the current 80–90 Ph.D.'s per year indicated by data from the Survey of Earned Doctorates. The reasons include the needs of homeland security, retirements at the national laboratories, and demands in nuclear engineering and nuclear medicine. For example, within the next ten years, it is estimated that more than three-quarters of the workforce in nuclear engineering and at the national laboratories will reach retirement age. Nuclear physics and nuclear chemistry Ph.D.'s will contribute a modest amount to filling the resulting demand. Therefore,

We recommend 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.

Several steps might be taken by the community to realize this recommendation:

- Shorten the time students spend in the Ph.D. program. Specific steps that address this issue and the time spent in postdoctoral positions are included in recommendations regarding graduate and postdoctoral education in Chapter 6.
- Become aware of and take advantage of funding opportunities for graduate students in areas of national need—opportunities outside the NSF Division of Physics and the DOE Office of Science.
- Encourage the best and brightest undergraduate physics and chemistry majors to take advantage of undergraduate research opportunities in nuclear science, then actively recruit these experienced undergraduates to continue their nuclear science studies and research as graduate students.

We feel that by implementing these steps, the goal of increasing Ph.D. production can be achieved without the allocation of additional resources by the NSF Division of Physics or the DOE Office of Science. For this strategy to be successful, it is essential that the DOE and the NSF continue to place high priority on investment in graduate education and to maintain, at a minimum, their current level of educational expenditures.

Several additional conclusions emerge from the demographic findings presented above—conclusions that are addressed in part by recommendations in Chapters 6 and 7:

- Women and minorities remain significantly underrepresented in nuclear science. The recent trend of 20% female new hires for tenure-track faculty is an encouraging improvement, but it remains inadequate.
- We have observed a modest shift in the percentage of foreign Ph.D.'s taking positions in the U.S., including tenure-track faculty positions, where historical percentages of 20% foreign hires have now increased to over 30%. The reason for this could be increased demand coupled with the reduced pool of U.S.-trained applicants. However, it may also be related to the quality of the available applicants and the appropriateness of their expertise.
- We have also found indications that U.S. colleges and universities are losing positions in nuclear physics and nuclear chemistry—positions that are imperative to the Ph.D. stream. It is therefore essential that forefront opportunities exist in nuclear science and that the DOE and the NSF implement the recommendations of the 2002 NSAC Long-Range Plan.

References

AAAS: "The Education and Training of Isotope Experts," AAAS report presented to Congress, 1999.

AIP 151.39: American Institute of Physics, "Enrollments and Degree Report," AIP Pub. R-151.39, August 2003.

AIP 282.23: American Institute of Physics, "Initial Employment Report: Physics and Astronomy Degree Recipients of 2000 and 2001," AIP Pub. R-282.23, January 2004.

AIP GP: American Institute of Physics, "2003 Graduate Programs in Physics," AIP Pub. R-205.27, 2002.

AIP Statistics: See *http://www.aip.org/statistics/*; additional statistics from R. Czujko, private communication.

NRC News: *NRC News*, No. S-01-022.

NSB 2004: National Science Board, "Science and Engineering Indicators—2004," NSB report 04-07, January 2004, pp. 3–24 (*http://www.nsf.gov/sbe/srs/seind04/*).

UMI: UMI dissertation database, available at *http://www.umi.com/umi/*.

2. The Undergraduate Experience: Survey Results and Initiatives

Introduction

The field of nuclear science is poised on the threshold of several new and exciting opportunities, as presented in great detail in the 2002 NSAC Long-Range Plan. Ensuring a strong workforce in nuclear science will become increasingly important with the construction of new facilities. If new initiatives such as the Rare Isotope Accelerator (RIA) and the Underground Laboratory are realized, the field must maintain, or even slightly increase, its level of effort. This, together with society's broader needs, will require a steady supply of talented, trained, and motivated undergraduate students.

The undergraduate years offer the prime opportunity for introducing students to the tools and methodology of physical science. The window of time during which science can grab their interest and propel them toward a career in science is rather narrow, and it is therefore especially important that the nuclear science community focus appropriate attention on these crucial years for the recruiting and retaining of interested students in the field. If science hasn't seized their interest, either before entering college or during their first year or so, they are much less likely to pursue science as a career. Likewise, if they have an interest in science but no opportunity to participate in research, they are less likely to be attracted to graduate school.

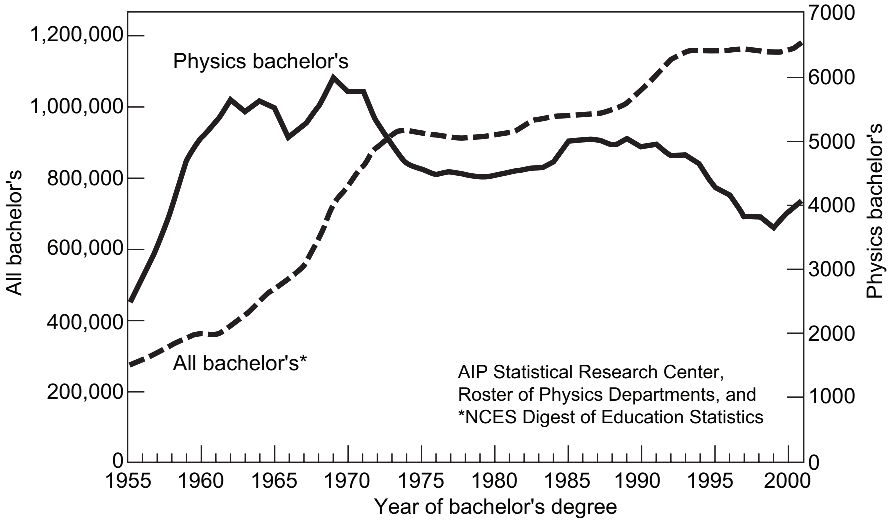
The challenge for nuclear science is even deeper, in that misperceptions of the field are often deep-seated and badly in need of correcting. The availability of undergraduate nuclear physics courses, opportunities for nuclear science research, and interactions with the larger nuclear science community are the kinds of corrective measures that can provide the important experiences that help recruit future generations of nuclear scientists. The field as a whole benefits from appropriate attention to these critical undergraduate years.

The Nuclear Science Pipeline

The "pipeline" serves as a useful metaphor for characterizing the undergraduate-graduate school connection and subsequent career pursuits. For the purpose of this report, the pipeline refers to the pursuit of careers in nuclear science. We recognize the crucial role that this pipeline serves in sustaining and maintaining a strong, healthy national nuclear science program, and we consider its improvement and maintenance one of the community's highest priorities.

According to recent American Institute of Physics (AIP) statistics, after almost a decade of declines in undergraduate degree production, the number of students receiving bachelor's degrees in physics in recent years is on the rise. Present undergraduate enrollment data suggest that similar increases can be expected for the next few years [AIP 151.39]. At least in the short term, this would appear to reverse the downward trend in degree production, seen in Figure 2-1, that has long been a matter of deep concern for the physics community, and not least for the nuclear science community.

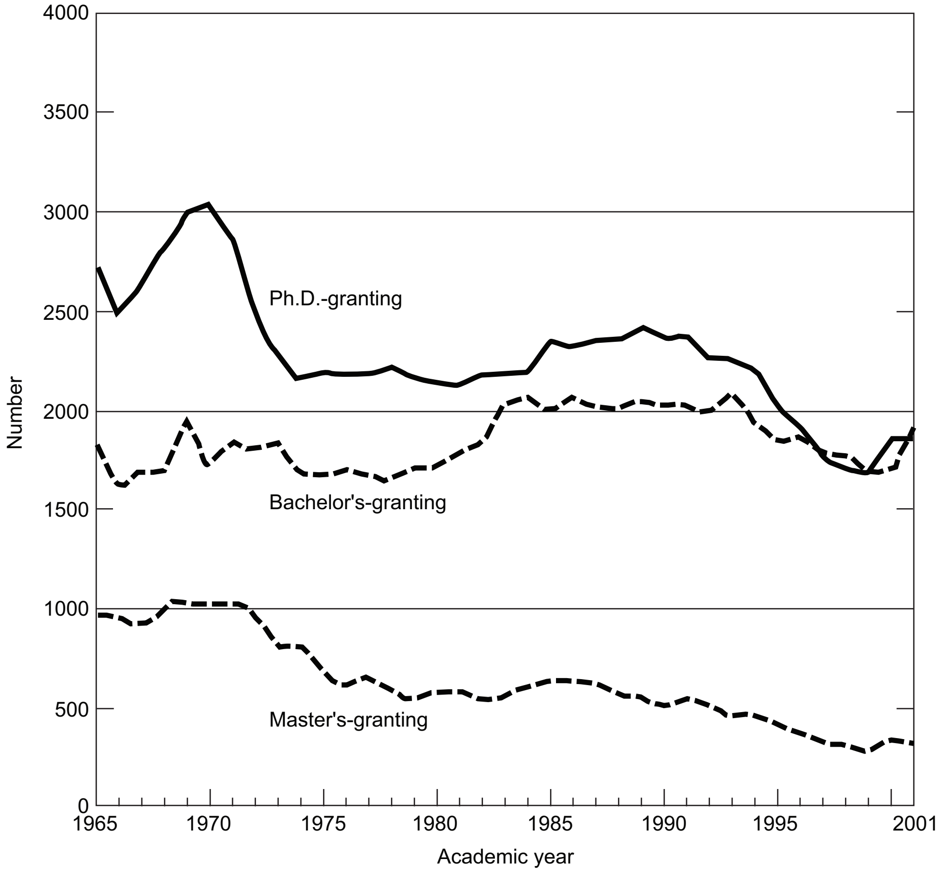
Figure 2-1. Physics bachelor's degree production over time, compared with the total U.S. bachelor's degree production in all fields.



AIP Statistical Research Center, Roster of Physics Departments, and *NCES Digest of Education Statistics

In this context, it is useful to look at the institutional origins of these physics bachelor's. Although institutions granting only bachelor's degrees tend to be much smaller than their Ph.D.-granting counterparts, these more numerous institutions were still responsible for producing 47% of all physics bachelor's degrees in 2001, as shown in Figure 2-2 [AIP 151.39].

Figure 2-2. Physics bachelor's degrees conferred in 1965–2001 for bachelor's-, master's-, and Ph.D.-granting institutions.



AIP Statistical Research Center, Enrollments and Degrees Report.

During the years leading to the bachelor's, the nuclear science community appears to be doing a very good job engaging undergraduate students in the laboratory, providing research experiences and access to the best national facilities; the "leakage" rate of students into other attractive fields is nonetheless apparent. We therefore recommend that there be a concerted effort by the nuclear science community to be more proactive in its recruitment and retention of undergraduates in nuclear science, especially among underrepresented groups, given their very low participation rates. We also recommend that the NSF and the DOE continue to support requests for recruitment and outreach support.

Feeding the pipeline

While several experiences throughout a student's career contribute to the feeding of this pipeline, a few are worth noting for their key roles

K–12 Outreach—K–12 outreach in the physical sciences (and nuclear science in particular) represents one of the first key opportunities to help feed the pipeline. In attempting to broaden outreach efforts in this area, however, we face a tougher challenge than in other areas in physical science, owing largely to the societal stigma attached to the word "nuclear." Public fear of radiation and nuclear power is clearly evident in society today, yet several very effective modern medical diagnostic and treatment methods using nuclear techniques are broadly accepted and valued for their effectiveness. Better outreach offers the dual benefits of exposing students at the earliest stages of their education to nuclear science as an attractive career path and creating a better-educated and more broadly informed society.

High School Physics Courses—Students typically experience their first substantial, and therefore crucial, encounter with physical science in high school. According to AIP statistics, the likelihood that a student will receive a bachelor's degree in physics is much greater if he or she has taken a physics course in high school. A much larger percentage of physics bachelor's degree recipients (92%) reported that they had taken at least one high school physics course, compared with less than 30% of all high school seniors [AIP 211.31]. Owing to the notable uniformity of the undergraduate physics curriculum across the U.S., and its highly sequential nature, it is important that students desiring to major in physics enroll in physics courses starting at the beginning of their freshman year. The quality of high school physics courses thus plays a crucial role in feeding the pipeline.

Undergraduate Courses and Research Experience—During the undergraduate years, contributors to the nuclear science pipeline include nuclear physics courses (or at least in-depth study of the subject as part of a modern survey), opportunities to conduct research with faculty, summer school experiences in specialized subjects, and opportunities to present undergraduate research in a formal setting and to interact with the larger nuclear science community.

Undergraduate research

Arguably the single most important factor in influencing an undergraduate's future plans in science is the opportunity to conduct research with faculty. The most fundamental understanding and appreciation of science is achieved not through classroom instruction or the reading of textbooks, but through the apprenticeship-type experiences of conducting research one-on-one with trained scientists. Working with scientists and instrumentation provides an authentic scientific experience, something the classroom cannot fully provide.

Undergraduate research opportunities in nuclear science form the heart of educational training and provide the kind of hands-on experience that strengthens students' knowledge and skills in modern techniques, sharpens and deepens their interest in the subject, and plants the seed of a long-term commitment to the field. Nuclear science research groups and university and national laboratory programs have a strong tradition of involving undergraduate students in research. These students are treated as full group participants and make substantial contributions to group efforts.

Students at larger research universities typically have greater access to modern facilities, and therefore better potential for getting involved in research. However, close to 50% of physics graduate students emerge from smaller bachelor's-granting institutions, many of which have few if any research programs. It is, therefore, important that similar research opportunities be made available to these students.

The following summarizes briefly the programs that provide the majority of research opportunities and resources for undergraduate students in nuclear science. The community has benefited greatly through the years from these NSF- and DOE-sponsored research programs. Their value and success are demonstrated in part by the survey results summarized later.

- NSF Research Experience for Undergraduates (REU)—The NSF funds a large number of research opportunities for undergraduate students through its REU Sites program (*http://www.nsf.gov/home/crssprgm/reu/start.htm*). The nuclear science community has been a strong participant in this program, especially at university-based laboratories. The program has been particularly successful at engaging women and has had a demonstrably positive influence in motivating, equipping, and retaining bright and energetic students in the field of nuclear science.
- NSF Research at Undergraduate Institutions (RUI)—The RUI program has had direct impact on faculty at undergraduate institutions, enabling them to maintain active research programs, often in collaboration with larger university- and laboratory-based groups. The RUI program enables faculty to involve undergraduate students in meaningful research experiences both at home and at world-class research facilities not typically available at their home institutions.
- DOE university research grants—The DOE supports principal investigators (PIs) through university research grants. While the main purpose of these grants is to conduct research in nuclear science (often associated with experiments conducted at the national laboratories), important educational benefits accrue from these grants. Approximately 100 or more undergraduate

students are supported each year through these grants. Students work directly with the PIs or their research groups, and work is conducted at the university or at one of the national laboratories.

- DOE Science Undergraduate Laboratory Internships (SULI)—This DOE-funded program (*http://www.scied.science.doe.gov/scied/erulf/about.html*) places students in paid internships at any of several DOE facilities, where they work with scientists or engineers on projects related to the laboratories' research programs.

Conference experience and interaction with the community

The Conference Experience for Undergraduates (CEU), held annually since fall 1998, provides undergraduate students who have conducted nuclear science research the opportunity to present the results of their research, to interact with the larger community, to learn of exciting opportunities in nuclear science and research, and to explore graduate school options. Each year, approximately 200 undergraduate students are supported to pursue nuclear science research, through various NSF and DOE programs. Of those, 60 to 70 each year participate in the CEU program. While these numbers are encouraging, the fraction of these students who subsequently continue on to graduate school in nuclear science is low. We therefore recommend that the nuclear science community engage in more aggressive recruitment and retention efforts in order to encourage more of these students to consider staying in the field.

Summer schools in nuclear chemistry

The Division of Nuclear Chemistry and Technology of the American Chemical Society sponsors summer schools in nuclear and radiochemistry, funded by the DOE's Office of Basic Energy Sciences and Office of Biological and Environmental Research. The summer schools include lecture and laboratory components covering the fundamentals of nuclear theory, radiochemistry, nuclear instrumentation, radiological safety, and applications to related fields. The two summer school sites are located at San Jose State University in California and Brookhaven National Laboratory in New York, and each is limited to 12 students, a total of 24 each summer. The program has seen growth in the number of applicants in recent years, increasing from about 40 in 1999 to approximately 100 per year today.

The program has enjoyed success over the years and has placed students into well-recognized nuclear and radiochemistry graduate programs. According to current program statistics [Clark], essentially all students go on to some sort of post-baccalaureate training. Approximately 70% of program participants go on to pursue Ph.D.'s in physics and chemistry, most of which focus on nuclear and radiochemistry. As reported in Chapter 1, the current production rate of nuclear chemistry Ph.D.'s is extremely low (about 10 per year), especially compared with rates in 1970 (about 40 per year). Therefore, recruitment and training of young scientists into the field of nuclear and radiochemistry remains a very high priority for the nuclear science community. Should the number of applicants for this summer school program continue to increase, we recommend the establishment of a third nuclear chemistry summer school, modeled largely after the existing two. This recommendation is directed to the broad nuclear science community (since the summer schools are not funded by the DOE and NSF nuclear physics programs) and underscores the crucial contribution nuclear chemistry continues to make to the U.S. nuclear science program.

Surveys

We conducted four surveys relevant to issues in undergraduate education: one survey of nuclear physics course offerings in the U.S., two online surveys of undergraduate students (one of REU students and one of CEU students), and one e-mail query of REU program directors. A summary of our findings follows.

Nuclear physics courses in the undergraduate curriculum

The number of undergraduate courses offered in nuclear physics across the nation is low, leaving students who do not have access to such courses largely ignorant of the field until well into their graduate studies. An undergraduate course in nuclear physics, in addition to providing an introduction to some of the profound ideas and concepts basic to the development of twentieth-century physics, can offer a lively encounter with some of the most important and engaging questions of modern nuclear science. It has the potential to stimulate interest in research with faculty, to encourage the pursuit of nuclear science in graduate school, and to correct some of the misleading notions of nuclear science common in society. In summary, and perhaps most importantly, increasing the presence of nuclear physics courses in the U.S. undergraduate curriculum would provide a positive means of feeding and sustaining the pipeline.

The following data are drawn largely from the AIP [AIP 151.39] and from the online course catalogs of the most prolific producers of undergraduate physics degree recipients. The entries in the course catalogs were often supplemented by phone calls to verify that listed courses were actually being taught.

The average graduating class size for physics bachelor's recipients at Ph.D.-granting institutions was 10.6 in 2001. These departments (24% of the total number of physics departments) graduated about half of the physics bachelor's nationwide. Departments granting only bachelor's degrees (67% of the total) accounted for 47% of the physics bachelor's, the average class size being 3.7 (see also Figure 2-2). The few (9% of the total) master's-granting departments had an average class size of 4.4 in 2001. Our survey included none of the master's-granting departments, nor did it consider nuclear engineering courses offered by the schools of engineering.

We compiled data from 23 Ph.D.-granting physics departments, averaging 20 or more physics majors per year for the most recent available years (1999–2001). Together, these departments (13% of the 182 Ph.D.-granting institutions nationwide) graduated a yearly average of 793 students, representing 19% of all physics bachelor's recipients. Among these, six departments offered an undergraduate course in nuclear physics, which was thus available to fewer than 18% of the undergraduates represented by this 23-institution sample. Of the remaining institutions, 12 departments (representing 43% of the total student sample) offered a combined nuclear and particle physics course (two of these departments had no nuclear scientists on the faculty).

The "modern physics" course, a staple among physics bachelor's programs, sometimes includes nuclear physics on its list of covered topics, though exposure is understandably weak, owing to the breadth of the course's subject matter.

Of the seven bachelor's-only departments that averaged 15 or more physics majors per year over the same time period, two offered a course in nuclear physics, one offered a combined nuclear/atomic physics course, and yet another offered a combined nuclear/particle physics course. Together, these four departments offered nuclear physics to 30% of the majors at these seven bachelor's-only institutions, and nuclear/atomic or nuclear/particle physics to 24%.

In conclusion, approximately 18% of the physics bachelor's degree recipients attending the largest Ph.D.-granting departments surveyed had the opportunity to take a class or seminar in nuclear physics (plus 43% for a combined course in nuclear/particle or nuclear/atomic physics), and 30% of those attending the largest bachelor's-granting departments had the opportunity to take a class in nuclear physics (plus 24% for combined nuclear/particle or nuclear/atomic physics).

For comparison, seven of those same Ph.D.-granting departments offer an undergraduate course in plasma physics, offering exposure in that field to 24% of the undergraduate sample; ten (representing 37% of the undergraduate sample) offer an undergraduate course in high-energy particle physics.

These data represent upper limits for the entire population of physics bachelor's degree recipients, as not all majors choose to take an elective course in nuclear physics, even when available, and the survey included only the largest degree-granting departments. In particular, many bachelor's-granting institutions have a small number of physics faculty and are thus able to offer primarily (if not solely) "core" courses for the physics major. Given that bachelor's-only institutions produce nearly half of bachelor's degrees in the U.S. (see Figure 2-2), we conclude that a large portion of students entering graduate school have no formal instruction in nuclear physics until they encounter it (if they do at all) in graduate school.

We recognize that it can be especially difficult to offer elective courses in nuclear physics in small departments at bachelor's-granting institutions, where staffing limitations can limit the curriculum to basic core courses. We therefore recommend the establishment of an online nuclear physics instructional materials database, for use in encouraging and enhancing the development of undergraduate nuclear physics courses. The intent is not to provide a "remote learning" course in nuclear physics, but rather to make available an extensive database of useful tools and resources for departments developing their own course offerings, or integrating current and cutting-edge nuclear physics content more fully into their current offerings.

Survey of Summer 2003 REU students

In late summer of 2003, we administered a survey to REU students from sites that offered the option to do research in nuclear physics. One hundred sixty-five undergraduates responded, from approximately 30 REU physics programs. The following is a brief review of the conclusions we drew from this survey.

The numbers of male (85) and female (80) respondents were well balanced, but the numbers of responses from students from primarily Black- or Hispanic-serving institutions were very low (approximately 1% of the total for each), likely reflecting the low REU participation rate of these groups. The institutions of origin of the respondents are characterized in Figure 2-3. A larger percentage of women (52%), compared with men (37%), came from private institutions.

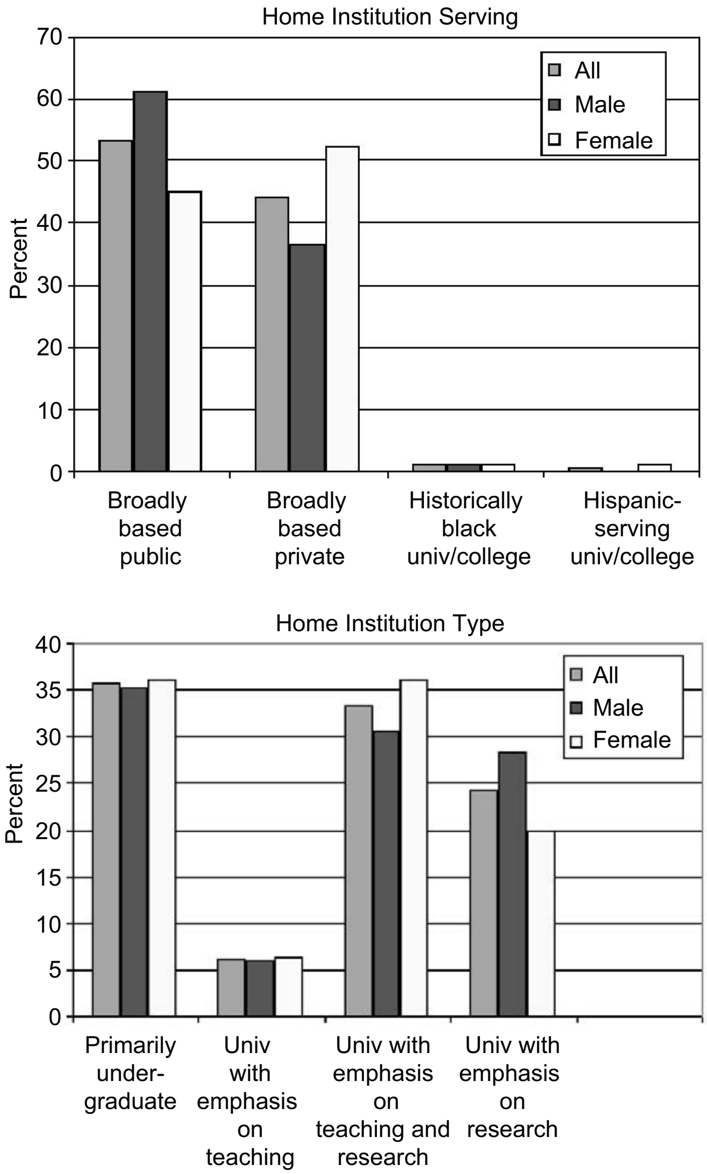


Figure 2-3. Types of home institutions represented by REU survey participants. Respondents were asked to characterize their home institutions with one of the descriptions from each group of four.

Asked to rank several reasons why they chose to participate in an REU program, more than 60% of respondents said they did so in anticipation of attending graduate school, while nearly 30% were curious about physics research. Overall, students expressed strong satisfaction with their research projects, and with the value of the experience in terms of their future career plans. Interestingly, women felt more positively than men about the career value of the experience, while expressing less overall satisfaction with their research projects.

Students generally felt academically well prepared for the REU experience, though women felt slightly less prepared than men. In Figure 2-4, a fairly clear correlation can be seen between responses to this question and the type of home institution, with the percentage of students who felt best prepared being especially well correlated with the degree of research emphasis at the home institutions. (However, it is difficult to assess the degree to which this perception accurately reflects preparation.)

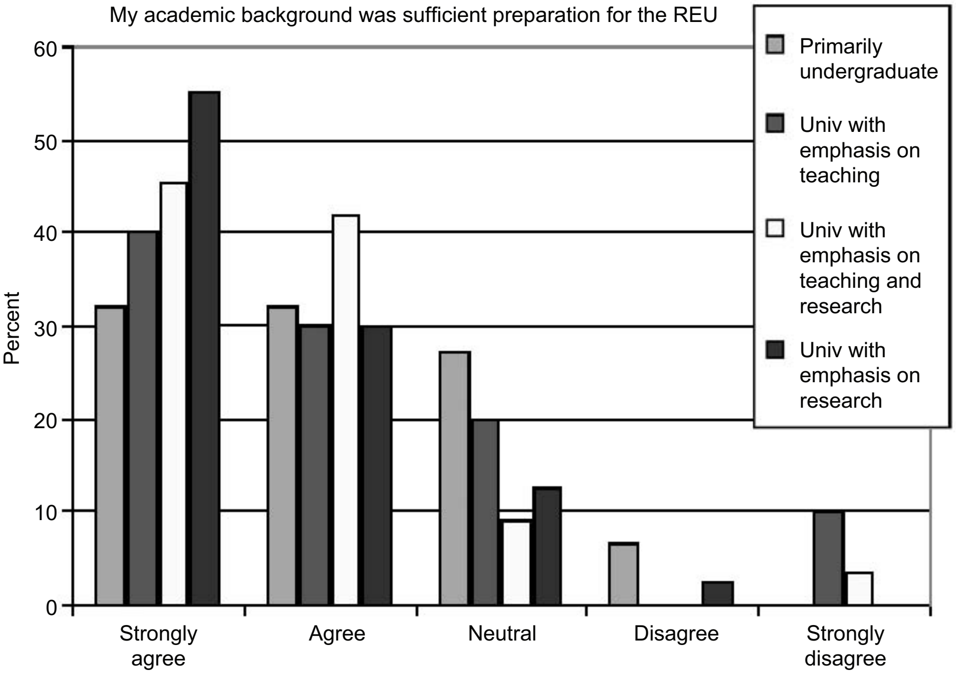
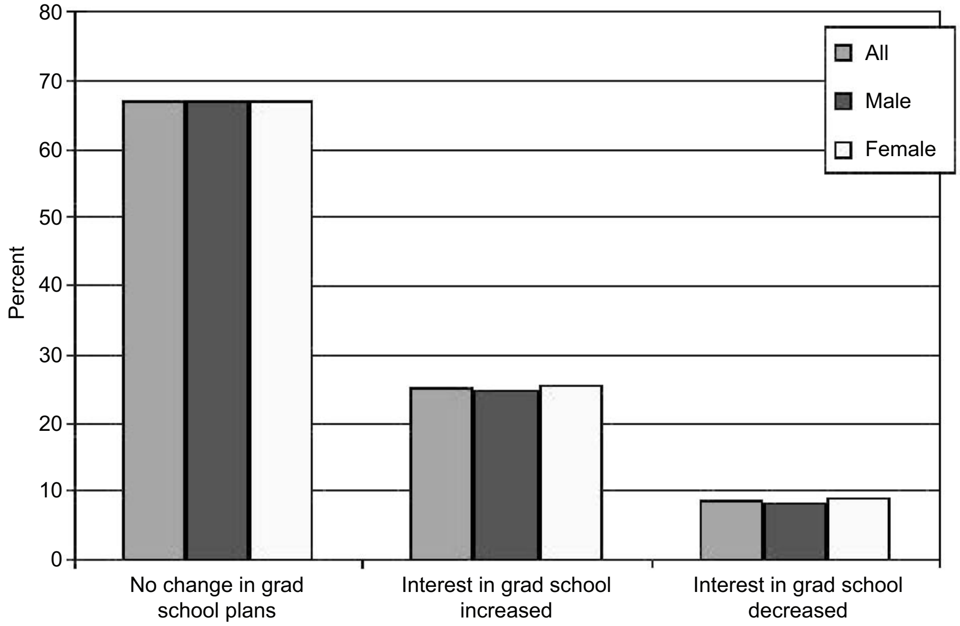


Figure 2-4. Sense of academic preparedness among REU participants from different types of institutions. As in Figure 2-3, respondents selected the description appropriate to their home institutions.

Women felt more strongly that they had become contributing members of a research group, whereas men and women felt equally strongly that the experience helped equip them to continue research at their home institutions.

Finally, students were asked to assess the effect of the REU experience on their graduate school plans. Admittedly, students who are most likely to apply to the REU program are those with an interest in physics research, and with plans to attend graduate school. This is apparent in Figure 2-5, where approximately 65% of respondents expressed no change in plans. However, nearly 25% experienced an increase in their interest, indicating that the overall experience bolstered interest and confidence in future graduate school plans. The REU experience therefore positively influences students' career plans, underscoring its vital role in motivating, engaging, and equipping the future workforce in physics.

Figure 2-5. Influence of the REU program on graduate school plans.

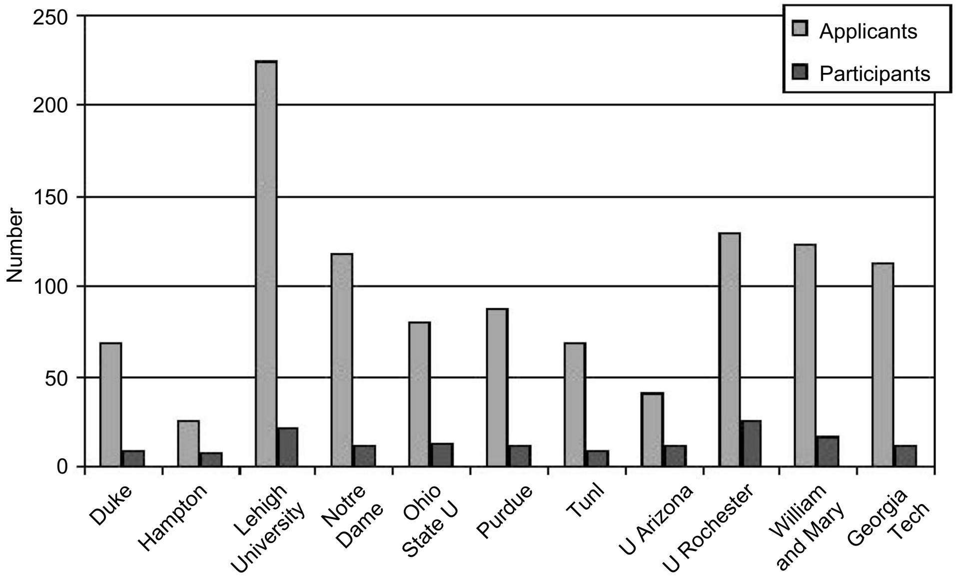


In response to a question about their favorite parts of the REU experience, students highlighted getting involved with real equipment in real research, working with their advisers (for whom they had much praise), working in a group toward a common goal, getting a taste of graduate school, meeting and building friendships with other students from around the country, working independently, being trusted as a colleague, being exposed to the university and laboratory research environment, and attending the lecture series that accompanied many of the programs.

Survey of REU program directors

Program directors at several REU sites were queried regarding the number of applicants and number of students admitted; the results are shown in Figure 2-6.

Figure 2-6. Number of applicants and participating students at several REU sites.



At the majority of the sites queried, the number of applicants was quite a bit larger than the number of slots filled, indicating that the program is competitive. Not known, however, is the number of programs to which students typically apply—a number that would help us gauge the number of students who are not accepted at any REU site. It is worth noting, however, that in the written responses section of the REU survey, several students indicated that they chose their site because it was the only one at which they were accepted, further evidence that the program is competitive.

We are very concerned about the low participation rate among underrepresented groups in the REU program. Figure 2-3 strongly suggests that few African American or Hispanic students participate. Indeed, responses from the REU program directors regarding the fraction of their applicants from underrepresented groups showed little difference from the numbers in Figure 2-3, with two exceptions: Hampton University (a well-known historically Black institution) received 48% of its applications from African American students and admitted seven Black students (out of a total of eight). Lehigh University received 9% of its applications from African American, Hispanic, or Native American applicants and ended up with 14% of its participants being from one these groups. Otherwise, the record indicates that much more aggressive recruiting efforts are needed if the percentage of underrepresented students in the REU participant pool is to reflect broader societal profiles.

Survey of Fall 2003 CEU participants

Finally, we surveyed the participants in CEU03, which took place in Tucson, Arizona, concurrently with DNP03. Of the 65 or so participants, 44 replied to the survey, about 68% overall. Among respondents, 27% were women and 73% men, representative of participation in the CEU program. Essentially all participants were pursuing undergraduate majors in physics, with a few double majors in computer science or in math. Students felt very welcome in the community and had a fairly strong sense of the professional community's regard for their research. Several expressed surprise that the work they did was as interesting to the broader community as it was, building confidence in their individual contributions.

Survey results indicate that research funding for CEU participants broke down approximately as follows: about 35% derived from REU programs, 19% from other sources of NSF funding (for example, RUI), 31% from DOE-supported university research programs, 8% from university support, and a final 7% unknown.

Perhaps the most informative data to emerge from the CEU survey regard the students' plans for graduate school and, more specifically, plans to pursue nuclear science. Seventy-seven percent of CEU participants indicated plans to pursue graduate studies in physics or chemistry (52% "definitely," 25% "probably"). An additional 9% said they would possibly pursue it, while 5% planned graduate studies in other fields. The remaining 9% planned something other than graduate school. Fully 90% reported that the CEU experience increased their interest in nuclear science (see Figure 2-7). As also shown in Figure 2-7, among those planning for graduate school, 40% reported they would definitely or probably pursue nuclear science, while 40% suggested they were not sure, but would consider nuclear science.

Based on these results, we conclude that the CEU experience positively influences both students' interest in the field of nuclear science and their plans to pursue graduate studies in the field. A summary estimate concludes that approximately 30% of CEU students probably plan to pursue graduate studies in nuclear science, with an additional 30% that are considering it a possibility. These numbers, as well as the evident increase of interest in nuclear science as a result of CEU participation, point to the continuing importance of this program to the nuclear science community.

In response to being asked about their favorite part of the CEU experience, students frequently mentioned being welcomed into the professional community without feeling belittled or insignificant, meeting other students from around the country that share common interests, seeing what the professional community is like,

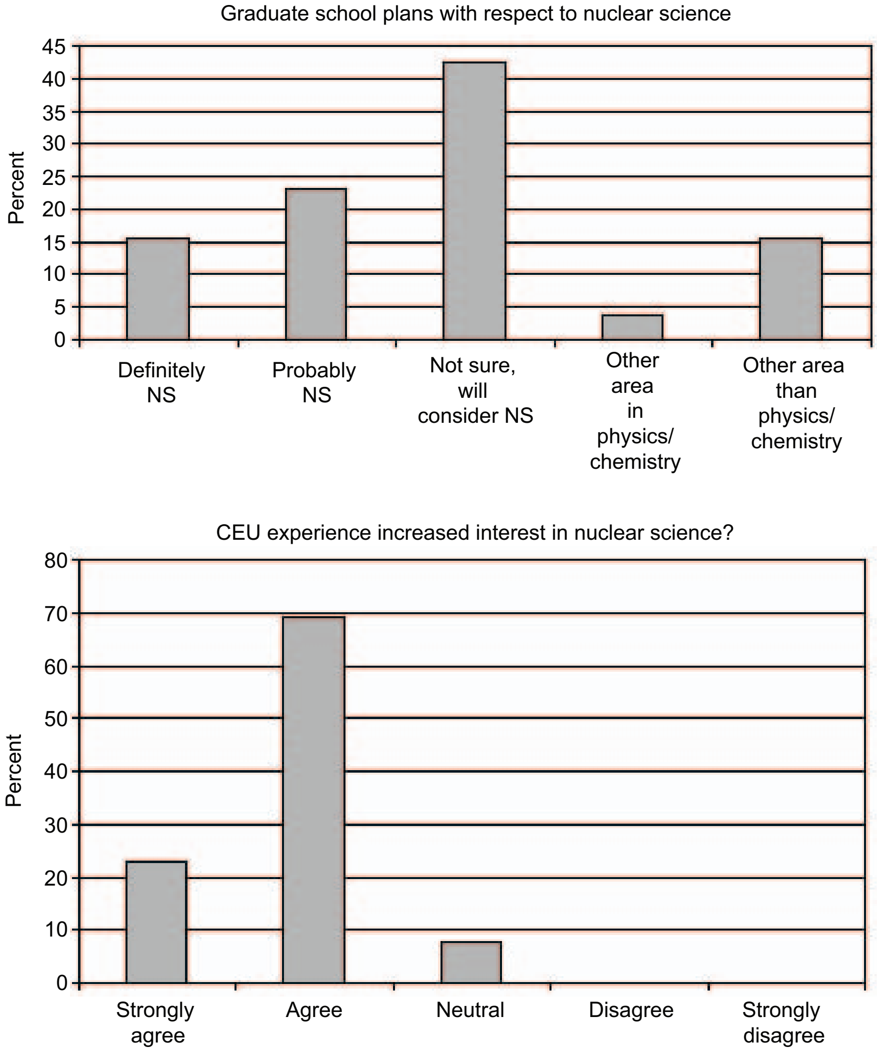


Figure 2-7. CEU student plans for graduate school in physics or chemistry, and the sense of increased interest as a result of the CEU experience.

attending advanced undergraduate-level nuclear physics seminars, getting a sense of future opportunities in research and of possible future collaborators, and participating in one-on-one communications with visitors at the undergraduate poster session. As one student put it, “The best part was watching physicists interact and seeing how passionate they are about their subject and how it consumes their whole lives.” And another: “It was a wonderful capstone to my REU experience, and it was invaluable to be able to experience a professional conference and to participate in a meaningful way.”

The opportunity provided by the CEU for undergraduate students pays very positive dividends for the community as a whole. In addition to introducing students to the broader field of nuclear science, it enables the community to offer them an “early welcome” as research colleagues, all of which helps further cement students’ interest in nuclear science.

Promoting the importance of undergraduate student involvement

Finally, we believe that an appropriate mechanism that will serve to heighten community awareness of the undergraduate issues discussed above, critical as they are to the future health and vitality of nuclear science, should be created, One way to establish this awareness is to publicly acknowledge and celebrate exceptional examples of undergraduate involvement and mentoring. We therefore recommend the establishment of a community-developed recognition award for undergraduate involvement and/or mentoring in nuclear science.

Conclusions and Recommendations

We strongly endorse the important role that the NSF REU and RUI programs and DOE university research grant support has played in motivating and training young scientists in nuclear science, as well as their support of the CEU program, which gives undergraduate students a venue for presenting research to and interacting with the professional community.

We recommend that the NSF and the DOE continue supporting research mentorship opportunities in nuclear science for undergraduate students through programs and research grant support. Additionally, we recommend that they consider expanding support if proposals for undergraduate student involvement in nuclear science research increase.

We recommend the establishment of a third summer school for nuclear chemistry, modeled largely after the two existing schools.

We commend the nuclear science community, and specifically the American Physical Society’s Division of Nuclear Physics, for its active and dedicated support of undergraduate research and for the quality of experiences it provides for the motivation and training of young scientists. Nonetheless, we wish to encourage an even deeper commitment among our colleagues to recruiting promising undergraduates into nuclear science.

We recommend that there be a concerted commitment by the nuclear science community to be more proactive in its recruitment of undergraduates into nuclear science, especially among underrepresented groups. We also recommend that the NSF and the DOE continue to be supportive of requests for recruitment and outreach support.

As an example of such activity, several REU programs have funds designated for the purpose of program promotion and recruitment—funds that could be used for travel to institutions with high numbers of students from underrepresented groups. For recruitment to be effective, it is essential that good working relationships between institutions be established, and that individuals with interest in these areas be identified and encouraged to build and maintain these ties. More broadly, we believe that a mechanism should be available to publicly acknowledge and celebrate individuals committed to recruiting, developing, and mentoring undergraduate students. Therefore,

We recommend that the Division of Nuclear Physics of the American Physical Society consider the establishment of a community-developed recognition award for individuals providing research opportunities and/or mentoring to undergraduates in nuclear science.

Finally, we are concerned about the low number of nuclear physics courses available across the broad spectrum of U.S. undergraduate physics programs, especially among the smaller undergraduate institutions that produce nearly half of all physics bachelor's degree recipients. We recognize that it can be especially difficult for these smaller physics programs, with limited staffing resources, to offer many courses beyond the basic core curriculum. A fifth recommendation aims to make additional resources available to these smaller institutions:

We recommend the establishment of an online nuclear science instructional materials database, for use in encouraging and enhancing the development of undergraduate nuclear science courses.

References

AIP 151.39: American Institute of Physics, "Enrollments and Degree Report," AIP Pub. R-151.39, August 2003.

AIP 211.31: American Institute of Physics, "Physics and Astronomy Senior Report: Classes of 1999 and 2000," AIP Pub. R-211.31, June 2002.

Clark: Sue Clark, Washington State University, program director, private communication.

NSAC 2002: The DOE/NSF Nuclear Science Advisory Committee, "Opportunities in Nuclear Science: A Long-Range Plan for the Next Decade," April 2002.

3. Graduate Education: A Survey of Students

Introduction

As part of our fact-finding process, we undertook an online survey of students currently seeking graduate degrees in nuclear science at U.S. universities. We contacted 627 graduate students by e-mail and, between December 2003 and March 2004, received 353 responses (56%).

The survey consisted of 93 questions, and we estimated that it should have taken about 30 minutes to complete. Students were asked general questions about their background, ethnicity, age, and citizenship status. They were also asked to evaluate their undergraduate experience as preparation for graduate school, their undergraduate research experience, and their current experiences in graduate school. Additional questions probed issues related to the students' quality of life. Finally, the students were asked about their plans after graduate school. Several questions allowed the students to provide brief essay-type responses.

In this chapter, we highlight the responses to several questions.

Gender, Age, Citizenship Status, and Ethnicity

An overview of the findings regarding the makeup of the graduate student population includes the following:

- Of those who responded, 286, or about 80%, were male; 67 (about 20%) were female. The male/female ratio was independent of citizenship status (U.S. citizens, 166/39; non-U.S. citizens, 120/28).
- Approximately 60% of the students were U.S. citizens.
- Approximately 70% were in experimental programs, 30% in theory.
- Most students expected to spend between five and six years in graduate school.
- The average age of the students was about 28 years.
- On average, non-U.S. citizens were older by about 1.5 years.
- The average age of U.S. females (about 26 years) was lower than either their U.S. male counterparts (27.5 years) or the average for the entire population (28 years). The age distribution is summarized in Table 3-1.

Table 3-1. Average age of male and female graduate student respondents, broken down according to citizenship status.

	All	U.S. Male	U.S. Female	Non-U.S. Male	Non-U.S. Female
Average Age	27.8	27.6	25.7	28.5	28.8

As shown in Table 3-2, the ethnic background of U.S. citizens in nuclear physics and nuclear chemistry is overwhelmingly Caucasian, a remarkable 94–95% among our respondents. Minority representation in the program appears tiny. We had no responses from Native Americans, while African Americans, Hispanics, and Asians/Pacific Islanders, taken together, numbered only 11. Of the male U.S. citizens who responded, six were of Asian or Pacific Island origin, two were Hispanic, and one was African American. We had two Asian/Pacific Islander female U.S. citizens respond to the survey.

Table 3-2. Ethnic background of the survey respondents. Students who were U.S. citizens were also overwhelmingly Caucasian.

	All	U.S. Male	U.S. Female	Non-U.S. Male	Non-U.S. Female
No. of respondents	353	166	39	120	28
African American	0.3%	0.6%	0.0%	0.0%	0.0%
American Indian/Alaskan Native	0.0%	0.0%	0.0%	0.0%	0.0%
Asian/Pacific Islander	22.0%	3.7%	5.4%	49.0%	42.0%
Caucasian	74.0%	94.0%	95.0%	45.0%	46.0%
Hispanic	3.5%	1.2%	0.0%	5.0%	12.0%

Clearly, U.S. minority populations are underrepresented in the graduate student population. This includes Americans of Asian descent, a fact that may be hidden by the large numbers of non-U.S. students from Asia.

Among non-U.S. students, the population is roughly equally split between whites (Europeans) and Asians, with a small percentage of Hispanics.

The Educational Experience

One question asked, “By the end of the 03–04 academic year, how many years of graduate study will you have completed?” The responses show that the percentage of U.S. women decreases in the later years of graduate school. Table 3-3 shows that, overall, the population of students was distributed fairly evenly from the second through the sixth years of study. However, the population of U.S. women peaked in the third year (31% of respondents) and dropped to about 8% in the sixth and subsequent years. This may be interpreted in (at least) two ways: Either more women are now joining the program, or women are leaving the program early. (Note, however, that the statistics for women are poor, and that non-U.S. women show a different pattern from U.S. women.)

Table 3-3. Graduate school experience of male, female, U.S., and non-U.S. respondents.

	All	U.S. Male	U.S. Female	Non-U.S. Male	Non-U.S. Female
No. of respondents	353	166	39	120	28
1 year	10%	11%	10%	9%	7%
2 years	16%	12%	20%	18%	21%
3 years	20%	18%	31%	20%	14%
4 years	20%	17%	15%	23%	25%
5 years	16%	18%	15%	17%	7%
6 years or more	18%	24%	8%	13%	25%

Additional questions sought to evaluate the quality of the respondents' undergraduate and ongoing graduate school experiences. Some of our findings are summarized in the following sections.

Undergraduate course work

Essentially all of the U.S. citizens who completed the survey started graduate school after completing their primary degrees (B.S. or B.A.); only about 5% had master's degrees. In contrast, over 50% of the foreign students had already completed master's degrees before commencing graduate studies in the U.S. Furthermore, the vast majority of students who responded (80% overall) had undergraduate majors in physics. Interestingly, we observed a small spike in the number of women chemists: Approximately 20% of the U.S. female respondents (6–7 students) majored in chemistry.

Table 3-4 illustrates the responses to the question, "Besides an introductory-level course did you take an undergraduate course with a primary focus on nuclear physics or nuclear chemistry?" Fewer than 30% of U.S. students had done so, in contrast to more than 60% of foreign students.

Table 3-4. Summary of responses to a question asking whether students had taken an advanced undergraduate course in nuclear physics or nuclear chemistry. The differences between U.S. and non-U.S. citizen responses are striking.

	All	U.S. Male	U.S. Female	Non-U.S. Male	Non-U.S. Female
No. of respondents	353	166	39	120	28
No	57%	72%	72%	35%	44%
Yes	43%	28%	28%	65%	56%

When asked to compare themselves with other physics/chemistry majors in their undergraduate classes, the responses from men and women, citizens and noncitizens, were similar, except that U.S. women ranked themselves somewhat lower on average.

A particularly interesting difference between the U.S. and non-U.S. citizens emerged when the students were asked to rank the adequacy of their undergraduate coursework as preparation for graduate school. Most U.S. citizens ranked their preparation as either average or above average, with a significant number (about 15%) saying they received below-average preparation; only about 20% said they had an excellent preparation for graduate school. In contrast, the majority of non-U.S. citizens said their preparation was excellent or above average; only about 15% ranked their preparation as average, and only about 2% as below average. Table 3-5 illustrates these results.

Table 3-5. Student evaluations of the adequacy of their undergraduate preparation for graduate school. Compared with U.S. citizens, more than twice as many foreign citizens ranked their preparation as excellent.

	All	U.S. Male	U.S. Female	Non-U.S. Male	Non-U.S. Female
No. of respondents	353	166	39	120	28
Excellent	31%	22%	21%	43%	42%
Above average	32%	28%	28%	38%	39%
Average	28%	35%	39%	18%	12%
Below average	10%	16%	13%	1%	8%

Similar attitudes emerged when U.S. citizens were asked to compare their preparation to that of foreign students, and vice versa. As shown in Table 3-6, only about 35% of the U.S. students felt they were as well prepared as their foreign counterparts when starting graduate school, whereas 85% of foreign students thought they were as well prepared as their U.S. counterparts. (Notably, about half of the U.S. students thought they had caught up in graduate school.)

Table 3-6. Student evaluations of their undergraduate preparation. U.S. students were asked if they were as well prepared as foreign-educated students, and vice versa.

	U.S. Male	U.S. Female	Non-U.S. Male	Non-U.S. Female
No. of respondents	166	39	120	28
Yes	36%	31%	85%	85%
No	64%	69%	15%	15%

The fact that many foreign students come to the U.S. already armed with master's degrees may help to explain some of these findings. However, when the responses from foreign students who came to the U.S. with B.S. degrees are examined, the trends are more or less the same.

In summary, U.S.-educated graduate students in nuclear science do not believe that their undergraduate curricula did as good a job in preparing them for graduate school as did the educational experiences of their foreign counterparts. (Almost all U.S. citizens in the survey were educated in the U.S., and almost all students who received their undergraduate degrees in the U.S. were U.S. citizens.) In addition, many U.S. students are never exposed to advanced ideas about nuclear science at the undergraduate level. Happily, many U.S. students feel that they had caught up in graduate school.

Accordingly, we believe that we should strive to strengthen the U.S. undergraduate curriculum and encourage U.S. colleges and universities to teach advanced undergraduate courses in nuclear science. We stress this point further in Chapters 2 and 6.

Undergraduate research experience

Undergraduate research appears to be very important, both as a means to motivate students to attend graduate school and as a recruiting tool for nuclear science.

Among the results of our survey, we found that

- Eighty-two percent of the students had research experience as an undergraduate. As shown in Table 3-7, 92% of U.S. female students had such experience. About 30% of all respondents had research experience in a non-nuclear field.
- Approximately 12% of respondents participated in the Research Experience for Undergraduates (REU) program in nuclear science; roughly another 20% participated in an REU program in a non-nuclear field.
- Almost half of the students came from undergraduate institutions with a research group in nuclear physics.

Almost all respondents agreed or strongly agreed that the undergraduate research experience positively affected their decisions to go to graduate school.

Table 3-7. Responses to a question asking whether students had had undergraduate research experience.

	All	U.S. Male	U.S. Female	Non-U.S. Male	Non-U.S. Female
No. of respondents	353	166	39	120	28
Yes	82%	87%	92%	75%	74%
No	18%	13%	8%	25%	26%

The graduate school experience

U.S. citizens do not rate themselves highly when asked to compare themselves academically to other graduate students in their class. As shown in Table 3-8, about half rank themselves as average, while only about 15% think they are in the top 10% of their graduate school class. In contrast, about 45% of foreign students rank themselves in the top 10% of their graduate school class, whereas only about 20% think they are average. It is perhaps noteworthy that 21% of U.S. female students rank themselves in the bottom 25% of their class—the only group to rank themselves this low.

Table 3-8. Student perceptions of their rank in comparison to other students in their class.

	All	U.S. Male	U.S. Female	Non-U.S. Male	Non-U.S. Female
No. of respondents	353	166	39	120	28
Top 10%	28%	17%	11%	46%	43%
Top 25%	28%	30%	18%	31%	18%
About average	39%	48%	47%	22%	39%
Bottom 25%	4%	4%	21%	1%	0%
Bottom 10%	1%	1%	1%	0%	0%

Approximately 85% of the student respondents worked for male advisers, and most (about 60%) worked for full professors. This clearly points to a lack of senior female role models in the nuclear science program. It also suggests that the faculty in nuclear science is aging (see Chapter 1). Most respondents carried out their research in small groups of three to six people, though U.S. female students seemed to prefer larger groups.

Many students were attracted to nuclear science by interactions with faculty (about 24%). For U.S. citizens, other important factors included an REU experience, the availability of an in-house experimental facility, and their preference for smaller research groups.

Graduate school life

When students were asked to rank the “best things” about their graduate school experience, the overwhelming winner (248 selected this box) turned out to be the research experience. In second place came the students’ adviser (193), closely followed by graduate student colleagues (152), advanced classes (158), and teachers/professors (157). We found very little difference in these rankings among the different categories of respondents.

The worst thing about graduate school life was said to be salary (112), followed closely by quality of life (i.e., no spare time, etc.) and advanced classes.

Regarding salary, almost 80% of the students thought they were paid enough to ensure an adequate standard of living and that their standard of living was about what they expected when they started graduate school. Nonetheless, the students' responses to questions about salary were particularly poignant (especially for married couples), and some are reproduced here:

- $1,500/month is not enough for a family of 4 in this area.
- ~50% goes towards housing and every year the housing goes up more than our pay raise.
- 2 kids + one on the way.
- After rent, utilities, food and car expenses, there is nothing left; I have accumulated debt during grad school.
- Barely surviving.
- Boston, renting, two with only one salary and my wife study with my money supporting.
- Cost of living in Berkeley, CA is extremely high.
- Can't afford health/car insurance.
- I can live like a rat, but my wife will not. Her job makes sure we don't.
- I have $2,000 [per year] to support my dependent teenage girl. . . . She needs much more to be leveled with others.
- I have trouble with the monthly bills on rent and food. I have to rely on credit cards.
- I support my mother, who does not work and is sick.
- My wife and I are both dependent on my salary. It is kind of short.
- We live well enough but we spend on credit hoping for the days of full employment.

We found that in 2003–2004, about 40% of students were supported by the DOE; other sources of support included the NSF (about 20%), teaching assistantships (about 15%), and other research support (about 15%).

The working environment for women

Overall, more than 60% of the students thought that the working environment for women was positive, 3% considered it negative, 17% said they "don't know," and 19% had no women in their groups. Interestingly, the women thought that their working environments were even better: Approximately 82% of U.S. women and more than 90% of foreign women graduate students ranked their working environments as positive, as shown in Table 3-9. Ten percent of U.S. women and 0% of foreign women ranked their working environments as negative; 8% and 3%, respectively, said they did not know.

Table 3-9. Student perceptions of the working environment for women.

	All	U.S. Male	U.S. Female	Non-U.S. Male	Non-U.S. Female
No. of respondents	353	166	39	120	28
Positive	61%	51%	82%	61%	96%
Negative	3%	2%	10%	2%	0%
Don't know	17%	22%	8%	16%	4%
No women in group	19%	25%	0%	22%	0%

The answers to the remainder of the "quality of life" questions reflect an overall happy attitude, suggesting that we are doing fairly well with our students: The students seem happy with their advisers, the other faculty in the group and department, the other graduate students, and so on. Almost 80% think the curriculum is appropriate and challenging.

When students expressed discouragement, the most common reason given was coursework, followed by personal problems and, interestingly, career prospects.

Career Goals

About 86% overall and 95% of U.S. students want to work in the U.S. Approximately 70% of foreign students want to work here.

About 60% of the U.S. students and about 30% of foreign students responded that they were undecided about their career goals. However, when asked what kind of work they hoped to do,

- About 40% of the students responded that they wanted to become university teachers or professors,
- About 25% wanted to do basic or applied research at a national laboratory,
- Very few (5–7%) wanted to go into industry (nuclear or non-nuclear), and
- About 25% were still "undecided."

For those who planned to continue in research after graduate school, the majority (60%) wanted to continue in the same field. About 7% wanted to switch to another subfield of physics, while 10% wanted to leave physics altogether.

We also asked the students to rank the importance of several job preparation skills in the doctoral educational program. The results, which are summarized in Table 3-10, indicate that the graduate students considered teamwork, collaboration with others, and building communication and presentation skills as very important (about 60%) or fairly important (about 30%). Their opinions seem to be somewhat

Table 3-10. Student ratings of skills gained in graduate school.

	Very important	Fairly important	Not too important	Not important at all
Organizational skills	26%	41%	26%	7%
Communication skills	61%	28%	4%	7%
Grant writing/career development	17%	36%	32%	15%
Teamwork	59%	29%	6%	6%
Collaboration	63%	28%	4%	5%
Interdisciplinary research	29%	39%	27%	5%

more ambivalent toward grant-writing seminars, interdisciplinary research, and learning managerial or organizational skills. For example, only 17% overall thought that attending grant-writing workshops was very important; about the same percentage (15%) thought it not important at all.

Summary and Conclusions

We reached the following four key conclusions, based on the results of the graduate student survey:

- The representation of U.S. minorities (African Americans, Hispanics, and Asian Americans) in the program is tiny. While women now represent about 20% of the graduate student population, they also remain underrepresented. We should strive to increase the representation of women and ethnic minorities in the program.
- We must strive to strengthen the undergraduate curriculum and, in particular, to ensure that advanced courses in nuclear science are offered to our undergraduate physics majors in U.S. institutions. The U.S. graduate students who responded to the survey consistently ranked themselves lower than their foreign counterparts, both in terms of their undergraduate preparation for graduate school and in terms of their class ranking in graduate school. Very few U.S. students come to graduate school having had advanced coursework in nuclear science. Students commonly choose to work in fields they are familiar with as undergraduates. Therefore, if we are to continue to attract the best and brightest undergraduate students to professional careers in nuclear science, we must look to enhance the undergraduate curriculum.
- Approximately 18% of the students in our survey had already spent six or more years in graduate school. About 9% had already spent five or more years doing research. The average time to degree is long, and we should seek ways to shorten it.

- Foreign students represent about 40% of the graduate student population. Approximately 70% of these students want to make a home and a career in the U.S. Typically, these students represent the best and the brightest from their home countries; they also are international ambassadors of friendship. Over the years, the U.S. has greatly benefited from this steady influx of talent, and we should strive to ensure that the U.S. continues to welcome foreign students.

4. Postdoctoral Training: A Survey of Fellows

Introduction

To assess the effectiveness of the nation's investment in postdoctoral training and to help us understand the factors influencing a successful career in nuclear science, we conducted a Web-based survey of postdoctoral fellows currently working in the field between February 15 and March 15, 2004. The survey included a comprehensive set of 104 questions addressing "Career Path and Demographic Background" (25 questions), "Evaluation of Doctoral Education and Experience" (20), "Usefulness of Your Doctoral Education" (8), "Family and Career" (12), and "Economic, Social, and Environmental Factors" (39). In addition, we asked eight open-ended questions concerning "Recommendations and Opinions."

We distributed the survey to 352 postdoctoral fellows, approximately 271 of whom registered as having begun the survey. Of those, 225 (64%) answered the entire survey (except the open-ended questions, which some did not answer). One hundred eighty-five respondents (53%) fully completed the survey and provided responses to the open-ended questions. The following sections discuss the main conclusions from each part of the survey.

Demographics and Career Paths

The gender and citizenship demographics, details of citizenship status, and ethnic background for those responding to the survey are shown in Tables 4-1 through 4-3.

Table 4-1. Gender and citizenship demographics for survey respondents.

Women	Men	U.S. Ph.D.	Non-U.S. Ph.D.	U.S. Citizen	Non-U.S. Citizen
14%	86%	47%	53%	29%	71%

Table 4-2. Citizenship status of survey respondents.

	All	Women	Men	U.S. Ph.D.	Non-U.S. Ph.D.	U.S. Citizen	Non-U.S. Citizen
U.S. Citizen, Native Born	27%	28%	26%	60%	1%	92%	0%
U.S. Citizen, Naturalized	2%	0%	3%	5%	0%	8%	0%
Permanent Resident (GC)	6%	6%	6%	5%	5%	0%	9%
Temporary Resident	59%	63%	58%	28%	84%	0%	82%
Non-U.S. Resid. Outside U.S.	5%	3%	6%	1%	9%	0%	8%
Other	1%	0%	1%	1%	1%	0%	1%

Table 4-3. Ethnic background of survey respondents.

	All	Women	Men	U.S. Citizen	Non-U.S. Citizen
American Indian/Alaskan Native	1%	0%	1%	3%	0%
Asian or Pacific Islander	20%	28%	19%	5%	27%
Black	1%	0%	1%	0%	1%
Hispanic	2%	0%	2%	0%	3%
White	76%	72%	77%	92%	69%

The age demographic for those responding to the survey is shown in Figure 4-1 for women and men. Table 4-4 provides the average ages at the time of the survey and at the time of the respondents' first postdoctoral positions, for several subgroups of respondents.

The distribution of the number of postdoctoral positions that have been held is shown in Figure 4-2, and the average number of positions held for several subpopulations is indicated in Table 4-5.

Figure 4-1. Age distributions for male and female survey respondents.

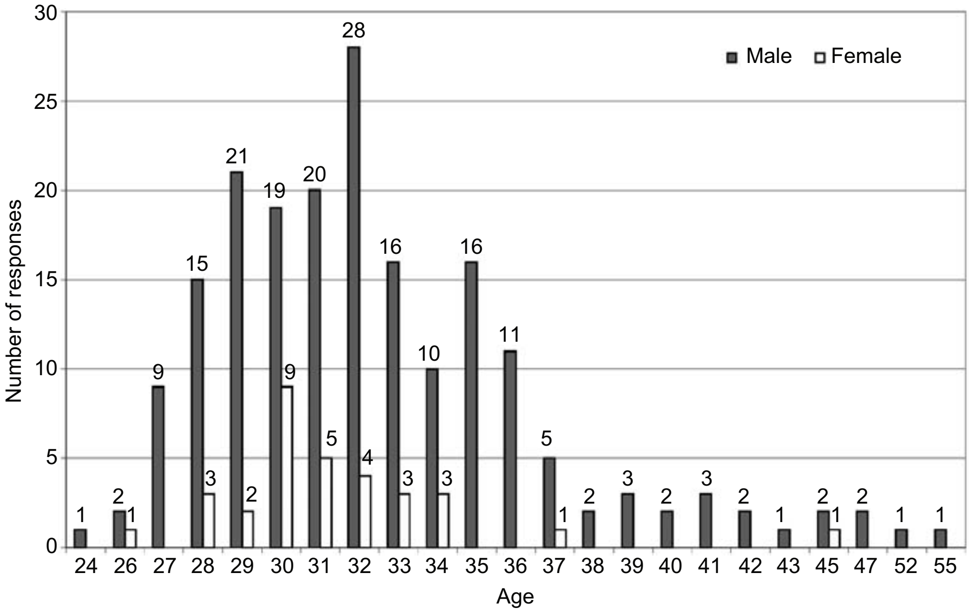


Table 4-4. The average age for several subpopulations of postdoctoral fellows.

	All	Female	Male	U.S. Ph.D.	Non-U.S. Ph.D.	U.S. Citizen	Non-U.S. Citizen
Average age	32.4	31.4	32.6	32.1	32.5	31.7	32.7
Average age at time of first postdoc	29.5	29.2	29.6	29.6	29.4	29.1	29.7

Figure 4-2. Distribution of the number of postdoctoral positions held for various subpopulations.

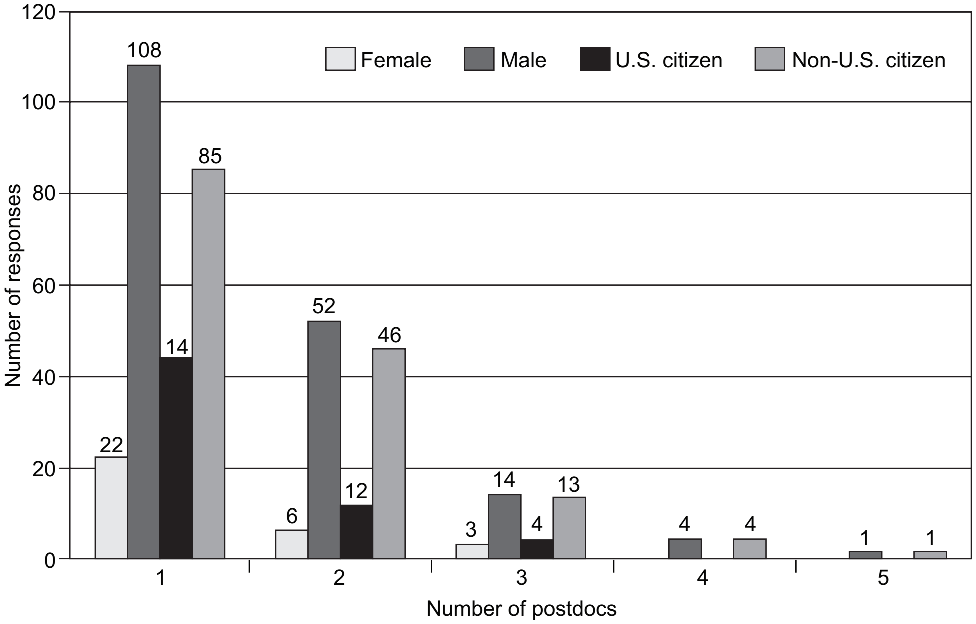


Table 4-5. The average number of postdoctoral positions held by several subpopulations of fellows.

	All	Female	Male	U.S. Citizen	Non-U.S. Citizen
Average No. of Postdoctoral Positions Held	1.5	1.3	1.5	1.3	1.6

The above data show that the percentage of U.S. citizens in the present population is 29%. About 50% of the postdoctoral fellows received their Ph.D.'s in the U.S., suggesting that the opportunity for advanced training in nuclear science in the U.S. is competitive with educational programs in other countries. The percentage of women in the survey population is 14%, lower than the percentage of women in the total graduate student population (20%), but higher than the percentage of women who responded to the Ph.D.'s 5–10 Years Later survey (12%). This suggests a hopeful trend toward a gradual increase in the number of women postdoctoral fellows in nuclear science. There is essentially no ethnic diversity in the U.S. postdoctoral population. The percentage of nonwhite fellows in the non-U.S. citizen population is significantly higher, owing to a sizable population of Asian postdoctoral fellows from Japan, India, China, and South Korea—in descending order of numbers of fellows.

The "age" and "number of positions held" demographics show that, on average, most respondents have held 1.5 postdoctoral fellowships. They began their first one about 2.6 years before responding to our survey. At the time they began their first postdoc, women were, on average, slightly younger than men, and U.S. citizens slightly younger than non-U.S. citizens. The age distribution for both men and women is approximately Gaussian below the age of 38, with an average age of about 32 years. It has a tail, accounting for about 10% of the total population, extending from the age of 38 to age 55. About 95% of these older postdoctoral fellows were male, and 90% of them were non-U.S. citizens. There is no evidence, however, that this tail represents people who have stayed overly long at the postdoctoral level. The distribution of ages at the time of the first postdoc shows a similar tail (with the same gender and citizenship demographics). That is, the two distributions are approximately the same, one displaced from the other by about 2.6 years.

The percentage of experimental and theoretical postdoctoral fellows is shown in Table 4-6. All 30 female postdocs who responded to this question indicated that they were experimentalists. The corresponding percentage for men was 68%. The percentage of non-U.S. citizens who indicated they were theorists was somewhat greater (31%) than the corresponding percentage of U.S. citizens (17%).

When the survey respondents entered the field of nuclear science, their career goals were overwhelmingly (78%) to become a university professor and/or perform basic research in an academic or national laboratory setting, as shown in Table 4-7. Further, as shown in Table 4-8, after several years in the field, the percentage of those who wish to continue in the same direction is even larger (85% overall, 94%

Table 4-6. The percentage of experimental and theoretical postdoctoral fellows.

	All	Women	Men	U.S. Citizens	Non-U.S. Citizens
Experimentalist	73%	100%	68%	83%	69%
Theorist	27%	0%	32%	17%	31%

Table 4-7. Career goals of postdoctoral fellows upon entering the field of nuclear science.

	All	Women	Men	U.S. Citizen	Non-U.S. Citizen
To be a professor	37%	41%	36%	51%	31%
Academic or nat. lab researcher	41%	41%	41%	25%	47%
Researcher in BGN	3%	3%	2%	5%	2%
Administrator/ manager	0%	0%	0%	0%	0%
Work independently (freelance)	0%	0%	0%	0%	0%
Start a business	0%	0%	1%	1%	0%
No formulated goal	17%	12%	18%	17%	18%
Other	2%	3%	2%	1%	2%

for women). This expectation is strikingly at variance with data from the Ph.D.'s 5–10 Years Later survey, which shows that only 62% of men and 83% of women found jobs in higher education, or at a national laboratory upon entering the workforce after being postdoctoral fellows. The remainder took jobs in business, government, or nonprofit organizations. The percentage of men and women 5–10 years after their Ph.D.'s who are currently employed in higher education or at a national

Table 4-8. Current career goals of postdoctoral fellows.

	All	Women	Men	U.S. Citizen	Non-U.S. Citizen
To be a professor	34%	53%	31%	43%	31%
Academic or nat. lab researcher	51%	41%	53%	35%	57%
Researcher in BGN	4%	0%	5%	6%	4%
Administrator/ manager	1%	0%	1%	0%	1%
Work independently (freelance)	0%	0%	0%	2%	0%
Start a business	1%	0%	1%	2%	1%
No formulated goal	4%	3%	4%	1%	4%
Other	5%	3%	5%	11%	2%

laboratory is even lower (61% and 75%, respectively). These data indicate that, with respect to careers, there is a large mismatch between expectations and reality for 30–40% of the postdoctoral fellows in nuclear science. The fact that the desire to find jobs at universities or at national laboratories remains strong after significant time in the field suggests that the postdoctoral population is largely unaware of this mismatch, and that postdocs do not pursue or receive counseling, training, or job experience that would afford access to the full spectrum of available career opportunities. At the same time, as discussed below, the single largest concern for our survey respondents was the prospect of permanent employment. This concern far outweighed any other. A sizable percentage of those responding (10–15%) indicated they would not recommend a career in nuclear science to an incoming graduate student precisely because of the current long-term employment outlook.

The areas of nuclear science in which respondents worked at the time of the survey are shown in Table 4-9. Twenty-eight percent worked in relativistic heavy ions, 29% in nuclear structure or nuclear reactions, 12% in medium-energy nuclear science (including hadronic physics), and 9% in nuclear astrophysics.

The work styles of postdoctoral fellows are shown in Table 4-10: 41% of survey respondents indicated that they worked in research teams of 3–6 people, 14% in teams of 7–10; 24% worked primarily alone; and 12% worked mostly with their supervisors.

Table 4-9. Areas of current research among postdoctoral fellows.

	All	Women	Men	U.S. Ph.D.	Non-U.S. Ph.D.	U.S. Citizen	Non-U.S. Citizen
Nuclear Structure	21%	29%	19%	15%	24%	13%	24%
Nuclear Reactions	8%	10%	8%	9%	8%	9%	7%
Medium Energy	12%	13%	13%	13%	10%	13%	13%
Relativistic Heavy Ions	28%	32%	27%	26%	31%	22%	30%
Nuclear Astrophysics	9%	7%	9%	15%	5%	16%	6%
Nuclear Chemistry	1%	0%	1%	0%	2%	0%	1%
Fundamental Nuclear Science	6%	3%	6%	7%	5%	7%	5%
Accelerator Nuclear Science	5%	3%	5%	3%	5%	2%	6%
Applied Nuclear Science	0%	0%	1%	0%	1%	0%	1%
Other	10%	3%	11%	12%	9%	18%	7%

Table 4-10. The current work styles of postdoctoral fellows.

	All	Women	Men	U.S. Ph.D.	Non-U.S. Ph.D.	U.S. Citizen	Non-U.S. Citizen
I work primarily by myself.	24%	13%	26%	30%	20%	23%	24%
I work mostly with my supervisor.	12%	7%	13%	12%	14%	12%	13%
I work in a res. team of 3–6.	41%	50%	39%	42%	39%	45%	40%
I work in a res. team of 7–10.	14%	20%	13%	11%	15%	15%	13%
I work in a res. team of 11–20.	3%	3%	3%	1%	4%	2%	3%
I work in a res. team of >20.	6%	7%	6%	4%	8%	3%	7%

When asked the advantages and disadvantages of their individual or team research experience, the top responses in each category were the following:

Advantages	**Indiv research***	**Team research***
Working in a large team; learning things quickly	20%	54%
Freedom; ability to perform independent research	41%	16%
Working with a small team of good people	2%	14%
Working on exciting science/technical developments	5%	4%
Good visibility; chance to network and give talks	12%	6%
Other	20%	6%
Disadvantages		
Being isolated; not enough interaction with others	68%	27%
Poor leadership; poor management; poor mentoring	9%	12%
Too much work; not enough time to do things right	9%	17%
Too much competition/friction with co-workers	0%	20%
Not enough visibility; not enough independence	0%	7%
Other	14%	17%

*Fellows who worked by themselves or primarily with their supervisors were asked about advantages and disadvantages of “individual research”; those who worked in groups of three or more were asked about “team research.”

Survey respondents were asked to indicate the average number of professional meetings attended in the last year, as well as the average number of oral presentations made and the number of publications in journals or proceedings over the same period. The results are shown in Table 4-11. The average number of oral presentations given by U.S. citizens was significantly lower than the corresponding average for non-U.S. citizens.

Table 4-11. The number of professional meetings attended and papers given in the last year by survey respondents.

	All	Female	Male	U.S. Ph.D.	Non-U.S. Ph.D.	U.S. Citizen	Non-U.S. Citizen
Average Prof. Meetings	2.3	2.5	2.3	2.3	2.4	2.1	2.5
Average No. of Talks	2.5	2.4	2.5	2.4	2.5	1.7	2.7
Average No. of Papers	5.8	6.3	5.7	5.2	6.6	5.4	6

Evaluation of Doctoral Education and Experience

The areas of nuclear science in which our survey respondents received their doctoral training is shown in Table 4-12. Thirty-four percent indicated nuclear structure or nuclear reactions as the area of specialty, 24% were trained in relativistic heavy ions, and 10% indicated medium-energy nuclear science (including hadronic physics).

Table 4-12. Areas of nuclear science in which postdoctoral fellows received their Ph.D.'s.

	All	Women	Men	U.S. Ph.D.	Non-U.S. Ph.D.	U.S. Citizen	Non-U.S. Citizen
Nuclear Structure	22%	35%	21%	19%	26%	19%	24%
Nuclear Reactions	12%	17%	11%	10%	14%	10%	13%
Medium Energy	10%	11%	10%	10%	8%	8%	11%
Relativistic Heavy Ions	24%	24%	24%	25%	25%	22%	25%
Nuclear Astrophysics	4%	0%	5%	8%	1%	7%	3%
Nuclear Chemistry	1%	0%	1%	0%	2%	0%	1%
Fundamental Nuclear Science	5%	3%	5%	5%	4%	3%	5%
Accelerator Nuclear Science	3%	3%	3%	2%	4%	0%	5%
Applied Nuclear Science	2%	0%	2%	0%	3%	0%	2%
Other	17%	7%	18%	21%	13%	31%	11%

Table 4-13 indicates the research sites (university or national laboratory) where most of the respondents' dissertation research was carried out. The results show that universities and national laboratories share positions of roughly equal prominence in providing research environments for doctoral research in nuclear science.

Table 4-13. The sites where postdoctoral fellows completed most of their dissertation research.

	All	Women	Men	U.S. Ph.D	Non-U.S. Ph.D	U.S. Citizen	Non-U.S. Citizen
At my home university	42%	29%	44%	41%	42%	37%	44%
Away from my univ. at a national lab even though I spent most time at my home univ.	9%	7%	10%	10%	6%	12%	8%
Away from my home univ. at a national lab where I stayed for at least 3 months	32%	50%	28%	34%	30%	35%	30%
Equally at my home univ. and a national lab although most time was at my univ.	3%	0%	4%	2%	6%	3%	4%
Equally at my home univ. and a national lab where I spent at least 3 months.	6%	7%	6%	6%	7%	7%	6%
At my home university, which has a direct affiliation with (e.g., manages) a natl. lab.	8%	7%	8%	7%	9%	6%	8%

The number of postdoctoral fellows who completed a master's thesis involving original research is indicated in Table 4-14. The percentage of non-U.S. citizens who did so was approximately four times that of U.S. citizens. Possible factors influencing this result are the differences between U.S. educational systems and those of other countries. In the U.S., a master's degree involving original research is typically not required as part of doctoral training.

Table 4-14. Percentage of postdocs who completed a master's thesis involving original research.

	All	Female	Male	U.S. Ph.D.	Non-U.S. Ph.D.	U.S. Citizen	Non-U.S. Citizen
Yes	50%	47%	51%	26%	73%	17%	65%
No	50%	53%	49%	74%	27%	83%	35%

Table 4-15 shows the percentage of postdoctoral fellows who indicated they had practical "hands-on" experience, outside an academic setting, in nuclear science or a related field, before or during graduate school. American citizens were significantly more likely than non-U.S. citizens to have had such experience.

Table 4-15. The percentage of postdocs with "hands-on" experience outside an academic setting before or during graduate school.

	All	Female	Male	U.S. Ph.D.	Non-U.S. Ph.D.	U.S. Citizen	Non-U.S. Citizen
Yes	26%	27%	26%	33%	19%	39%	21%
No	74%	73%	74%	67%	81%	61%	79%

Table 4-16 indicates the work styles of survey respondents during graduate school. The results show that the percentage of people who worked primarily with their supervisors (28%) during their graduate training is more than twice the corresponding percentage for the current work styles of postdocs (12%; see Table 4-10).

Table 4-16. The work styles of postdoctoral fellows during their graduate study.

	All	Women	Men	U.S. Ph.D.	Non-U.S. Ph.D.	U.S. Citizen	Non-U.S. Citizen
I work primarily by myself.	23%	16%	24%	24%	25%	32%	20%
I work mostly with my supervisor.	28%	20%	29%	26%	27%	22%	30%
I work in a res. team of 3–6.	36%	37%	36%	38%	38%	37%	36%
I work in a res. team of 7–10.	8%	17%	7%	9%	6%	8%	8%
I work in a res. team of 11–20.	1%	3%	1%	1%	1%	1%	1%
I work in a res. team of >20.	4%	7%	3%	2%	3%	0%	5%

When asked the advantages and disadvantages of their individual or team research experiences during their graduate training, the top responses in each category were the following:

Advantages	Indiv research*	Team research*
Working and interacting with a team	19%	34%
Good supervision; good leadership; good mentoring	32%	12%
Independence; the ability to do original research	22%	11%
Working in a small group of talented people	8%	18%
Gaining knowledge; learning how to do research	11%	16%
Other	8%	9%
Disadvantages		
Poor leadership; poor management; poor mentoring	32%	41%
Not enough interaction with team members and collaborators	20%	24%
Having to focus narrowly; time constraint to get Ph.D.	24%	18%
Having to learn how to work in large collaborations	4%	12%
Other	20%	5%

*Fellows who worked by themselves or primarily with their supervisors were asked about advantages and disadvantages of "individual research"; those who worked in groups of three or more were asked about "team research."

Table 4-17 indicates the average number of professional meetings attended by survey respondents during graduate school, as well as the average number of talks and journal publications.

Table 4-17. Professional meetings attended and papers or talks given during graduate school by current postdoctoral fellows.

	All	Female	Male	U.S. Ph.D.	Non-U.S. Ph.D.	U.S. Citizen	Non-U.S. Citizen
Average Prof. Meetings Attended	5.4	6.0	5.3	4.9	6.0	4.7	5.7
Average No. of Oral Presentations	4.5	4.2	4.6	4.2	5.0	3.7	4.9
Average No. of Papers in Journals or Proceedings	9.0	8.7	9.0	8.6	9.3	8.6	9.1

To assess how postdoctoral fellows judge the usefulness of their doctoral education, we asked survey respondents whether, given their experience, they would choose the same career path again. The results are shown in Table 4-18: 67% indicated they would still get a Ph.D. in nuclear science, and 19% said they would get a Ph.D. in a different subfield of physics or chemistry.

Table 4-18. What postdocs indicated they would do if they had to do it over again.

	All	Women	Men	U.S. Citizen	Non-U.S. Citizen
I would still get a Ph.D. in nuclear science.	67%	60%	69%	66%	69%
I would get a Ph.D. in a different subfield.	19%	20%	19%	26%	16%
I would get a Ph.D. in a different field.	6%	7%	6%	5%	6%
I would get a professional degree (M.D., J.D., etc.)	3%	7%	2%	2%	2%
I would get a professional master's (M.B.A, M.F.A., etc.)	3%	3%	2%	1%	3%
I would get an academic master's (M.A., M.S., etc.)	1%	3%	0%	0%	2%
I would not get a graduate degree.	1%	0%	2%	0%	2%

Among the 19% who would get a Ph.D. in another subfield, the most common reasons given for their feelings were the following:

Lack of job/career prospects; better prospects elsewhere	58%
Other scientific area is more interesting	19%
Too much time/investment required for too little return	17%
Environment in large collaborations	2%
Other	4%

As to what subfields might be chosen, the most popular areas indicated by those who said they would consider a degree in a different subfield were condensed-matter physics, and cosmology and astrophysics, as shown in Table 4-19.

Table 4-19. Preferences of postdocs who indicated they should have sought a Ph.D. in a different subfield of physics or chemistry.

Subfield	Percent
Condensed-Matter Physics	31%
Cosmology/Astrophysics	26%
Medical/Biophysics	17%
High-Energy Physics	12%
Other, Various	14%

For postdocs who indicated they should have chosen a different field (6% of the total), 50% said they favored a Ph.D. in computer science, and 50% engineering.

Asked about their feelings concerning the usefulness of completing a Ph.D. in nuclear science, almost all indicated that it was probably or definitely worth the effort. Table 4-20 shows details of the responses.

Table 4-20. Postdocs' opinions about the usefulness of a nuclear science Ph.D.

	All	Women	Men	U.S. Citizen	Non-U.S. Citizen
It was definitely worth the effort.	66%	83%	63%	57%	70%
It was probably worth the effort.	31%	17%	33%	40%	27%
It was probably not worth the effort.	2%	0%	3%	3%	2%
It was definitely not worth the effort.	1%	0%	1%	0%	1%

In response to a question concerning other ways, in addition to preparing for a career in nuclear science, that their doctoral education was useful, the top three responses are the following:

Development of a broad range of skills (programming, paper writing, etc.)	28%
Opportunity to network and broaden scientific perspectives	21%
Fulfillment of career goals	18%

Family and Career

Family matters

Among our respondents, 73% of male and 66% of female postdoctoral fellows were married or in a committed relationship. As shown in Table 4-21, there was a significant difference between these populations with respect to the education of the spouse or partner. Women were significantly more likely to have partners holding advanced degrees.

Table 4-21. The highest degrees obtained by the spouses or partners of postdoctoral fellows.

	Women	Men
Bachelor’s	0%	30%
Master's	22%	38%
Ph.D., M.D., or J.D.	78%	30%
Other	0%	2%

As shown in Table 4-22, women in a committed relationship were also significantly more likely to have spouses or partners trained in nuclear science. Furthermore, as shown in Table 4-23, female postdoctoral fellows were much more likely to have spouses or partners currently working full time.

Together, these observations suggest that female postdoctoral fellows may experience different career-related stresses in their personal relationships than do men. In particular, female postdocs are much more likely to have spouses or partners with advanced degrees in nuclear science who are concurrently working full time. It is reasonable to infer that, for individuals in such relationships, significant stress arises from the difficulty of finding two career positions in nuclear science that match the capabilities and interests of both partners, in the same geographical area. As this circumstance is significantly more common among female postdocs and their partners, it is reasonable to project that, on average, women are more likely to experience conflict between career and relationships than are men.

Table 4-24 indicates the percentage of survey respondents who lived in the same geographical areas as their spouses or partners. Women were somewhat less likely than men to live near their spouses or partners, and non-U.S. citizens were significantly less likely than U.S. citizens to live in the same areas as their spouses or partners. This latter finding might be explained by the short-term nature of most postdoctoral appointments. Many non-U.S. Ph.D.’s might come to the U.S. for their postdocs, simply leaving their spouses or partners in their native countries.

Table 4-22. The fields of spouses' or partners' education.

	Women	Men
Nuclear Science	57%	10%
Other Natural Science	17%	17%
Education	0%	9%
Engineering	9%	13%
Fine Arts	4%	3%
Humanities	4%	9%
Social or Behavioral Science	0%	8%
Business Management	0%	9%
Law	0%	4%
Medicine	4%	14%
Other	5%	4%

Table 4-23. Spouses' or partners' current employment status.

	All	Women	Men	U.S. Citizen	Non-U.S. Citizen
Full Time	44%	68%	40%	52%	40%
Part Time	8%	0%	9%	15%	6%
Not Employed	30%	5%	34%	22%	33%
Student	14%	23%	12%	9%	16%
Retired	0%	0%	1%	2%	0%
Other	4%	4%	4%	0%	5%

Table 4-24. Percentage of postdocs living in the same geographic areas as their spouses or partners.

	All	Women	Men	U.S. Citizen	Non-U.S. Citizen
Yes	75%	55%	79%	91%	68%
No	25%	45%	21%	9%	32%

The percentage of postdoctoral fellows who indicated that they had children is shown in Table 4-25. The average number of children for these postdocs was 1.3; the average age of the children was about five years.

Table 4-25. Percentage of postdocs having children, stepchildren, or adopted children.

	All	Women	Men	U.S. Citizen	Non-U.S. Citizen
Yes	31%	21%	33%	28%	32%
No	69%	79%	67%	72%	68%

As shown in Table 4-26, 43% of men and 46% of women indicated that, at some time, family issues ("marriage," "children," and "care for relatives" were given as examples) affected their careers or the careers of their spouses.

Table 4-26. Percentage of postdocs who indicated that family issues affected their careers or those of their spouses or partners.

	All	Women	Men	U.S. Citizen	Non-U.S. Citizen
Yes	43%	46%	43%	61%	35%
No	57%	54%	57%	39%	65%

The top four reasons given to explain how family issues had affected careers were the following:

My career was compromised in order to find two positions together	38%
My spouse's career was compromised in order to find two positions together	35%
My spouse gave up his/her career to care for children	13%
Our relationship was damaged/destroyed because we could not find two positions together	7%

Table 4-27 shows the other side of the conflict: 41% of postdocs also indicated that, at some time, career affected family decisions.

Table 4-27: Percentage of postdocs indicating career issues affected family decisions.

	All	Women	Men	U.S. Citizen	Non-U.S. Citizen
Yes	41%	50%	40%	49%	38%
No	59%	50%	60%	51%	62%

The top four reasons given to explain these impacts were the following:

One or both of our careers were compromised in order to find two positions together	32%
We delayed starting a family/having children due to instability of employment	27%
Our relationship was damaged/destroyed because we could not find two positions together	11%
One or both of us needed to move for a new job	10%

Economic, social, and environmental factors

The distribution of compensation is shown in Figure 4-3 for men and women, and in Figure 4-4 for U.S. citizens and non-U.S. citizens. The average compensations for the principal subpopulations are shown in Table 4-28.

The average annual compensation for postdoctoral fellows is about $44,500. This average is roughly constant for all subpopulations, though it is somewhat higher for U.S. citizens than for non-U.S. citizens. The distribution of annual salaries is approximately Gaussian between $32,000 and $56,000, with tails at both the high and low ends. The total number of fellows in the tail at the low end of the distribution, comprising mostly male non-U.S. citizens, is about 2.3% of the total. The number in the tail on the high side is about 10% of the total and is composed primarily of men (75%), 27% of whom are U.S. citizens.

Although the general picture of postdoc salaries is acceptable to good, the disparity for fellows in the tail at the low end of the distribution is a concern. A way to address this would be for the field of nuclear science to endorse a minimum salary

Figure 4-3. Distribution of compensation for male and female postdoctoral fellows.

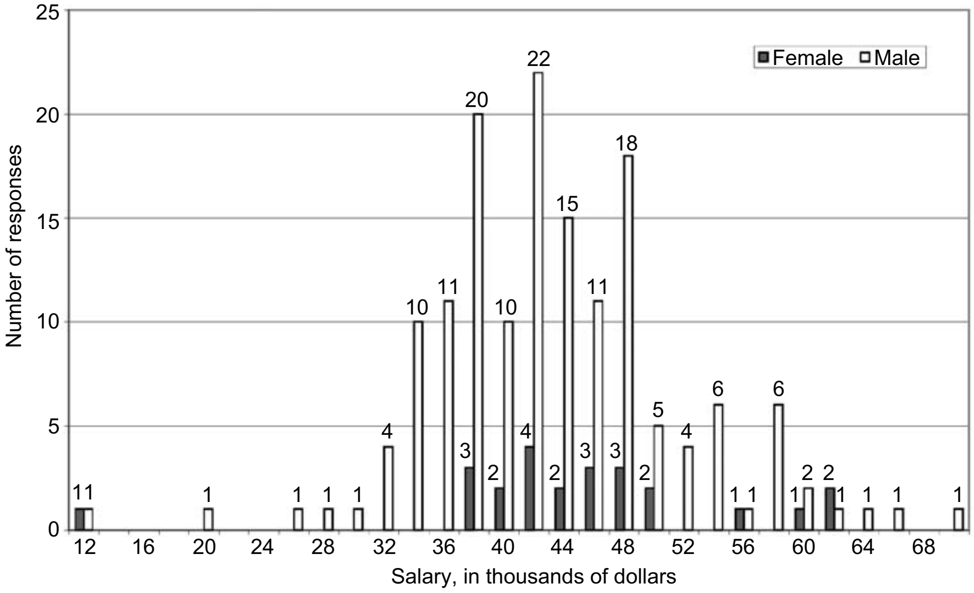


Figure 4-4. Distribution of compensation for U.S. citizens and non-U.S. citizens.

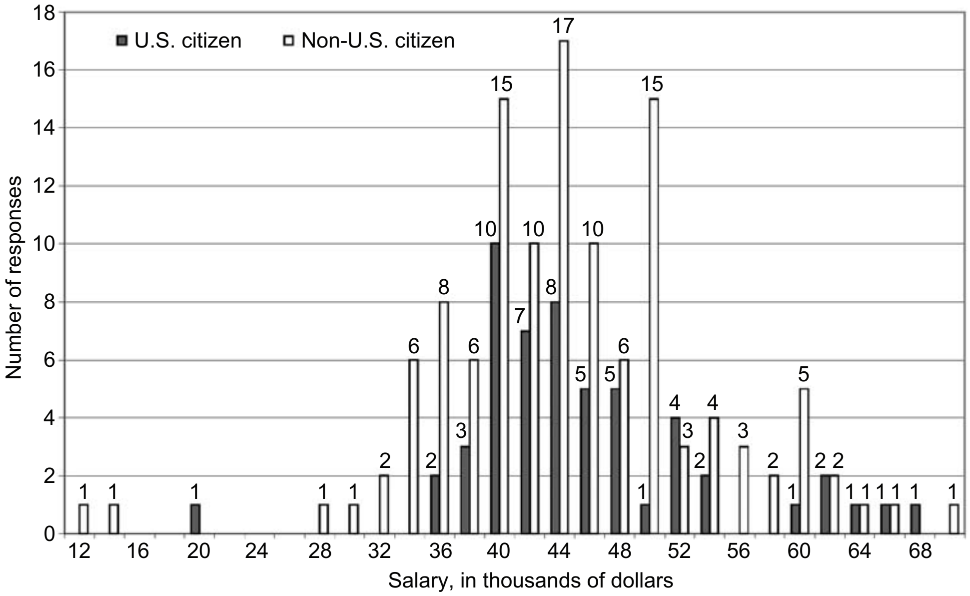


Table 4-28. Average annual compensation for postdoctoral fellows, in thousands of dollars.

	All	Women	Men	U.S. Ph.D.	Non-U.S. Ph.D.	U.S. Citizen	Non-U.S. Citizen
Average Salary	44.5	44.3	44.5	45.5	44.3	46.2	43.7

scale, such as that established by the National Institutes of Health (NIH) (currently about $36,000 per year for new postdocs), as the minimum expected salary nationally.

The survey posed additional questions concerning the level of satisfaction with the respondents' current compensation and its importance in determining a future career path. The results are shown in Tables 4-29 and 4-30.

Table 4-29. Feelings of postdocs regarding their current salaries.

	All	Women	Men	U.S. Citizen	Non-U.S. Citizen
Satisfied	32%	47%	29%	27%	34%
Adequate	47%	50%	46%	49%	46%
Expected but not adequate	15%	0%	18%	20%	13%
Unreasonably low	6%	3%	7%	4%	7%

The vast majority of postdoctoral fellows (79%) were either satisfied with their salaries or felt they were adequate. Fifteen percent felt their current level of compensation was about that expected for a postdoc, but nevertheless inadequate to main-

Table 4-30. Responses regarding the importance of salary in determining future career paths.

	All	Women	Men	U.S. Citizen	Non-U.S. Citizen
Important but not a determining factor	84%	79%	84%	75%	87%
Overriding consideration that may decide future career path	16%	21%	16%	25%	13%

tain a reasonable standard of living. This percentage differed for women (0%) and men (18%). Six percent of those surveyed indicated that their salaries were unreasonably low, in rough agreement with the distributions shown in Figures 4-3 and 4-4, considering the number of fellows in the tails at the low ends of those distributions.

Table 4-30 indicates that, for most postdocs (84%), salary was an important, but not determining, consideration in their future career choices. Sixteen percent indicated that salary was an overriding concern that may determine their future career path. A comparison of the responses of women in Tables 4-29 and 4-30 shows that, even though significantly more women than men felt their current salaries were good or adequate, 21% of women felt salary to be an overriding consideration in their career choices. This is somewhat higher than the corresponding percentage for men (16%).

The percentage of postdoctoral fellows who indicated that their employers provided them with health and dental insurance is indicated in Tables 4-31 and 4-32, together with the average annual cost of both for all fellows who indicated they had coverage. Fourteen percent of postdoctoral fellows do not have employer-provided health

Table 4-31. Percentage of postdoctoral fellows whose employers provided health insurance, and average annual cost.

	All	Women	Men	U.S. Citizen	Non-U.S. Citizen
Yes	86%	80%	91%	90%	89%
No	14%	20%	9%	10%	11%
Average Annual Cost	$1,450	$1,200	$1,500	$1,350	$1,475

Table 4-32. Percentage of postdoctoral fellows whose employers provided dental insurance, and average annual

	All	Women	Men	U.S. Citizen	Non-U.S. Citizen
Yes	73%	67%	75%	78%	71%
No	27%	33%	25%	22%	29%
Average Annual Cost	$310	$490	$280	$270	$330

insurance; 27% do not have employer-provided dental insurance. The average amount respondents paid for health insurance was about 3.3% of the average postdoc salary.

Twenty-eight percent of the U.S. Ph.D.'s surveyed indicated they acquired significant debt completing their Ph.D. degree. The average debt incurred was about $20,600, with a root-mean-square deviation of about $14,000. Factors contributing to incurred debt included tuition (7%), housing and food (43%), family support (24%), cost during transition to postdoc (13%), and other (13%). Only 4% of non-U.S. Ph.D.'s incurred debt during their doctoral training, perhaps indicating a difference in the level of tuition support in other countries.

Additional survey questions concerned "quality of life" and environmental factors. The respondents were asked whether they strongly agreed, agreed, had no opinion, disagreed, or strongly disagreed with a series of statements. They were also given the option to respond that the question was not relevant for them (that is, to indicate a nonresponse). The results are shown in Table 4-33, which indicates the "mean" response to each statement for each of the indicated subpopulations. Numbers below 3 thus indicate a positive response; numbers above 3 indicate a negative response. As the table shows, most postdocs appear to have had generally positive feelings about their postdoctoral experiences. In general they felt they were treated ethically, that their advisers treated everyone fairly, and that their advisers took time to discuss the science behind the projects they worked on. Respondents also felt their advisers cared about their development, encouraged and supported them to go to conferences, and communicated expectations and feedback clearly. Most also felt a sense of community with their group.

The most negative—albeit not *strongly* negative—response was to the statement that they received useful training in organization, management, and other areas of career development. The near-neutral response to this statement may indicate that the respondents felt they are acquiring career development skills at an adequate level, but that their advisers did not emphasize this aspect of their training. We also note, however, that the average number of postdoctoral positions that had been held by the respondents was 1.5, suggesting that most who responded were at a relatively early stage of their careers and may not yet have held the type of position that would make the importance of these skills fully apparent.

A final statement in this series was directed to women. Thirty-three percent agreed or strongly agreed that they were at a large disadvantage, as women, in the field of nuclear science; 20% indicated they had no opinion; and 47% disagreed or strongly disagreed. The reasons given by those who felt they were at a large disadvantage are shown in Table 4-34.

Women who felt they were not treated as peers indicated that this feeling elicited emotions ranging from frustration and anger to self-doubt. Women who felt a lack of accommodation for their maternal responsibilities expressed feelings of constant conflict between family and career.

Table 4-33. Responses to questions related to social, environmental, and quality of life issues. The numbers indicate the mean response to each statement (strongly agree = 1; agree = 2; no opinion = 3; disagree = 4; strongly disagree = 5).

	All	Women	Men	U.S. Citizen	Non-U.S. Citizen
The person I work for takes time to discuss the science behind my work.	2.03	2.23	1.99	1.94	2.08
The person I work for cares about my development of or learning needed skills.	2.19	2.00	2.23	2.26	2.16
I am treated ethically/get recognition for my achievements.	1.99	2.10	1.97	2.00	1.99
The person I work for treats everyone fairly.	1.97	1.97	1.97	2.01	1.94
I feel a sense of community with my group.	2.26	2.45	2.23	2.47	2.19
I feel a sense of community with my group is important	1.71	1.60	1.73	1.67	1.73
The person I work for encourages/supports my attending conferences	2.10	1.96	2.10	2.04	2.02
In my job I get useful training in org., management, and other career development	3.11	3.04	3.12	2.84	3.24
The person I work for communicates expectations and feedback clearly.	2.20	2.00	2.24	2.27	2.20
The department I work in cares about postdoc issues or listens to feedback.	2.29	2.50	2.25	2.83	2.67
The person I work for encourages me to develop my own research plan.	2.80	2.93	2.78	3.13	2.67
The institution I work for provides help with family/personal responsibilities.	2.62	2.84	2.58	2.96	2.92
The institution I work for provides access to a gym or health facility.	2.29	2.00	2.35	2.51	2.20

Table 4-34. Responses given by women who felt they were at a large disadvantage in the field of nuclear science. Seventy-three percent of this group were U.S. citizens.

Response	Total	U.S. Citizen	Non-U.S. Citizen
Women are not treated as scientific peers.	60%	62%	56%
No allowance is made for the need to carry out maternal responsibilities.	40%	38%	44%

Open-Ended Questions

The last section of the survey consisted of eight open-ended questions. These questions, together with the four top responses to each, are indicated below.

	Question: How did you choose to study nuclear science?
31%	Interest/excitement about the science
23%	Wish to continue this direction based on undergraduate research experience/lectures
12%	The influence of adviser or another important figure
7%	Accidentally

	Question: How would you get others interested in nuclear science?
24%	Outreach: tours, popular lectures on fulfillment of this career/its societal importance
13%	Dissemination of information on major scientific advances and their cross-disciplinary impact
11%	I wouldn't
10%	Through strong / exciting undergraduate programs in nuclear science

	Question: What advice would you give to beginning graduate students in nuclear science?
24%	Learn/develop/broaden your skills as much as possible; work hard; be the best
17%	Learn about/plan now for a career outside nuclear science and investigate all the possibilities
13%	Look at the long-term prospects/lifestyle and decide if you really want it and really like it
8%	Choose your adviser/topic carefully; work for someone you respect and who respects you

	Question: What recommendation would you offer doctoral programs today?
15%	No idea
14%	Focus on important/exciting areas relevant for society; advertise; look modern and attractive
9%	Provide more/stronger career guidance and job planning/placement help
9%	Promote more cross-disciplinary training and cross fertilization

	Question: What would have helped you with your first job search?
26%	More publications / opportunities to present my work; more contact with potential employers
17%	Nothing
7%	More help from adviser
7%	Better knowledge about opportunities in nuclear science and in other fields

	Question: What aspects of your doctoral experience are you most pleased with?
23%	Experience working on a quality team with talented people
22%	Independence and ability to do independent, original research
18%	The knowledge, confidence, experience, and skills gained
13%	Personal achievement; personal satisfaction

	Question: What aspects of your doctoral experience are you most disappointed with?
19%	The uncertain future; unavailability of jobs; lack of job stability
11%	Nothing thus far
11%	Lack of respect; lack of intellectual independence
7%	Low salary; lack of benefits

	Question: What else do you think we should know?
22%	Nothing to add
15%	The job situation is horrible; we should not train new people until it is fixed
13%	The survey was good /useful
7%	The visa problem is severe and must be fixed

Summary and Outlook

From the responses to the survey of postdoctoral fellows, we conclude that in the U.S., forefront research programs at universities and national laboratories, as well as state-of-the-art facilities with world-class capabilities, provide an attractive opportunity for doctoral training. This conclusion is supported by the observation that, although only 29% of current postdoctoral fellows are U.S. citizens who received their degrees in the U.S., 25% of the non-U.S. citizens making up the remaining 71% of the postdoc population also received their Ph.D.'s in the U.S. This indicates that the opportunity for advanced training in nuclear science in the U.S. is competitive and attractive, bringing many foreign students and postdocs into the U.S. program. Universities and national laboratories play roles of equal prominence in providing research environments for Ph.D. research and postdoctoral training in nuclear science.

Overall, the postdoctoral community is very positive about the postdoctoral experience and the usefulness of getting a Ph.D. in nuclear science, despite significant hardship in some cases, owing to stresses on career and family that result from the temporary nature of employment and the level of financial compensation. These hardships appear to be accepted as "rites of passage" on the road to a successful career and a permanent position in nuclear science. The vast majority of postdoctoral fellows indicated they are satisfied with their salary or feel it is adequate. Most further indicated that salary is an important consideration, but not a determining factor, in their deliberations about future career paths. Nonetheless, there is a significant disparity for fellows at the low end of the salary distribution that should be addressed by the adoption of a minimum salary scale for new postdocs, such as that established by the National Institutes of Health (currently about $36,000 per year).

In general, postdoctoral fellows felt they were treated ethically and that their advisers provided balanced and constructive guidance. Most felt a strong sense of community with their groups. Respondents were less positive—but not strongly negative—about whether they were receiving adequate training in organization, management, and other areas of career development.

Not surprisingly, perhaps, female postdoctoral fellows appeared to experience different career-related stress in their personal and family relationships than do men. Specifically, far more female than male respondents had spouses or partners with advanced degrees in nuclear science and with full-time jobs. It is reasonable to infer that for postdocs in such relationships, significant stresses might arise from the difficulty of finding two career positions that are close to each other and that match the capabilities and interests of both partners. As this circumstance is significantly more probable for female postdocs and their partners, it is reasonable to project that, on average, women are significantly more likely than men to experience conflict between careers and personal relationships. Approximately 30% of the female respondents also indicated they feel they are at a large disadvantage in the field of nuclear science. Two reasons were expressed for this opinion: that they were not treated as scientific peers and that no allowance was made for maternal responsibilities.

The survey uncovered some differences in the graduate training experience for U.S. and non-U.S. citizens. U.S. citizens were much more likely to have had practical "hands-on" experience outside an academic setting before or during graduate school and much less likely to have done a master's thesis involving original research. It is not obvious from the survey what impacts these differences may have.

The overwhelming majority of postdoctoral fellows entered the field of nuclear science to become university professors and/or to perform basic research in an academic or national laboratory setting. Among those who had spent several years in the field, the percentage wishing to pursue this direction was even greater. This expectation is strikingly at variance with the reality revealed by data from the survey of Ph.D.'s five to ten years after their degrees, which shows that slightly fewer than two-thirds eventually find a job at a university or a national laboratory—and not all of these jobs are in academic research. This suggests a large mismatch between career expectations and the likely reality for 30–40% of the postdoctoral fellows in the field. The fact that the desire to find a job in academe continues unabated after significant time in the field suggests that most postdocs are unaware of this reality and do not pursue or receive counseling, training, or job experiences that would afford access to the full spectrum of available career opportunities—opportunities that may ultimately need to be considered. At the same time, the single largest concern for the postdoctoral population is the eventual prospect of permanent employment. Concern about this far outweighs any other concern expressed. Indeed, a sizable percentage (10–15%) of those responding indicated they would not recommend a career in nuclear science to an incoming graduate student precisely because of the current long-term employment outlook.

This concern about future employment and the expectation-reality mismatch are particularly worrisome in an era of declining university programs and faculty positions in nuclear science, both perhaps consequences of the impression held by many that nuclear science is a "mature" field. The outlook for attracting good students and postdoctoral fellows may not be as bright as it has been in the past. The community of nuclear science researchers is a unique and precious national resource. Prudence and duty call for action to see that it is not eroded.

We are also troubled by the lack of diversity (there is effectively no ethnic diversity among U.S. citizens in the field of nuclear science) and the low percentage of women, compared with the situations in other scientific fields [SED 2000] and in scientific communities in other developed countries [Wu 2000]. The U.S. cannot remain competitive technologically, economically, or in matters of national defense without using the full intellectual capacity of a diverse workforce.

When Henry Rowland was asked in the late nineteenth century what he intended to do about his graduate students, his response was, "I shall neglect them, of course" [Grauer 2000]. In an era when modern physics was in its infancy and the number of university positions could be counted on two hands, it was not unreasonable to leave the future of the field to natural selection. By contrast, in the field of nuclear science today, the challenge of responding to the concerns identified above—and thus sustaining a scientifically and technologically advanced workforce to meet the nation's needs and maintain world leadership—requires commitment and stewardship.

In light of our findings, and as discussed in detail in Chapters 6 and 7, we therefore recommend a renewed and strengthened commitment by the nuclear science community to mentoring the next generation of nuclear scientists, to increasing ethnic and gender diversity, to providing effective career guidance to help ensure realistic expectations, and to reducing the time to degree.

References

Grauer 2000: Neil Grauer, "Pioneers of Scholarship: The Six Who Built Hopkins," *Johns Hopkins Magazine*, April 2000 (*http://www.jhu.edu/~jhumag/0400web/31.html*).

SED 2000: T.B. Hoffer et al., "Doctorate Recipients from United States Universities, Summary Report 2000: Survey of Earned Doctorates" (National Opinion Research Center, Chicago, 2000).

Wu 2002: Ling-An Wu, "Chinese Women in Science," presentation at IUPAP Conference, Paris, March 2002 (*http://www.if.ufrgs.br/iupap/*).

5. Five to Ten Years Later: A Survey of Recent Ph.D.'s

Introduction

To complete our documentation of the effectiveness of the present educational activities supported by the NSF and the DOE and to follow nuclear science Ph.D.'s beyond the postdoctoral period and into the first years of their careers, we conducted a third comprehensive survey, complementing those summarized in the previous chapters. This Web-based survey was sent to nuclear science Ph.D.'s who graduated between July 1, 1992, and June 30, 1998. The questionnaire was divided into six sections: (i) your overall career path from the time you received your Ph.D. until the present and your demographic background; (ii) the search for your first job after receiving the Ph.D.; (iii) your retrospective evaluation of your doctoral education; (iv) your assessment of the usefulness of your doctoral degree; (v) the intersection of family and career; and (vi) your recommendations and opinions (a set of seven "open-ended" questions on careers in nuclear science, and on advice to current graduate students and current doctoral programs).

A data run from the Survey of Earned Doctorates [Sui] provided the institutions and the number of their nuclear physics or nuclear chemistry graduates for the 585 reported Ph.D.'s during the above six-year period. We obtained correct and current e-mail addresses for 412 of these Ph.D.'s from their doctoral degree supervisors (or by other methods—see Appendix C, where we present more details of this survey). Responses from 251 of these Ph.D.'s—61% of those for whom we had e-mail addresses—were obtained between mid-December 2003 and May 4, 2004. Among those who were U.S. citizens at Ph.D. completion, the response rates for native-born[1] and non-native-born Ph.D.'s appear to be similar, though the latter was somewhat lower. Though we made efforts to contact non-U.S. citizens who had returned to their home countries or other foreign destinations, the survey probably underrepresents this group of Ph.D.'s.

Characteristics of Respondents

The mean age of the survey respondents was 38.5 years. Twelve percent of them were women, which is essentially the same percentage as in the survey population.[2] Table 5-1 presents the ethnic background among native-born U.S. citizens.[3]

As can be seen from this table, there are very few native-born ethnic minorities among the nuclear science Ph.D.'s.

Table 5-2 then presents the citizenship of the respondents at the time of the survey and at Ph.D. completion.[4]

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[1] Due to the Tiananmen Square protests in 1989, Chinese graduate students on temporary visas were allowed to readily obtain permanent residency (green cards). Since there are a significant number of these students who obtained Ph.D.'s during the time of this survey, it is necessary to look at native-born U.S. citizens for some comparisons.

[2] The Survey of Earned Doctorates data for this six-year survey period reports that 11% were women.

[3] As one goes through the various tables and figures, the number of respondents answering the particular question being addressed frequently changes.

[4] The Survey of Earned Doctorates data for this six-year survey period reports that 62% were U.S. citizens and 38% were on temporary or permanent visas.

Table 5-1. Ethnic backgrounds among respondents who were native-born U.S. citizens.

U.S. Citizen (Native-born)	N	Percent
American Indian or Alaskan Native	1	0.6
Asian or Pacific Islander	2	1.2
Black	2	1.2
Chicano or Latino	1	0.6
White	145	90.1
Mixed race/ethnicity	10	6.2

Table 5-2. Citizenship of respondents, at Ph.D. completion and at the time of the survey.

	Current		At Ph.D.	
Citizenship	N	Percent	N	Percent
U.S. citizen, native-born	165	67.1	165	67.3
U.S. citizen, naturalized	20	8.1	7	2.9
Permanent U.S. resident (green card holder)	27	11.0	16	6.5
Temporary U.S. resident	11	4.5	44	18.0
Citizen of another country, and currently residing outside the U.S.	19	7.7	9	3.7
Other (e.g., dual citizenship)	4	1.6	4	1.6

As expected, between the time of the Ph.D. and the time of the survey, the number of temporary residents in the U.S. decreased, and the number of citizens from other countries residing outside the U.S. increased. The substantial current total of naturalized U.S. citizens and permanent U.S. residents is in part a consequence of the Tiananmen Square protests and the U.S. response in easing the requirements for Chinese students to obtain "green cards." Twenty-two of the current 47 naturalized U.S. citizens or permanent U.S. residents are Asian/Pacific Islander.

The Postdoctoral Experience

One of the key purposes of this survey was to characterize the postdoctoral experience for nuclear science Ph.D.'s (how many took postdocs? how long did they spend as postdocs?) before entering the job market and to learn their reasons for taking a postdoc. (The survey cohort of nuclear science Ph.D.'s had a median registered time to the degree of 7.0 years. This datum and those appearing in footnotes 3 and 5 were obtained from a special data run from the Survey of Earned Doctorates [Welch]). To place these results in a broader context, comparisons will be made in this section (and some later sections) to a similar national study called *Ph.D.'s—Ten Years Later* [Nerad and Cerny] which surveyed six disciplines,[5] two of which, biochemistry and mathematics,[6] had a significant fraction of their Ph.D.'s taking postdoctoral appointments.

Our survey showed that 70% of the nuclear science Ph.D.'s held at least one postdoctoral appointment; the comparable numbers for biochemistry and mathematics were 86% and 31%, respectively. Table 5-3 compares the number of postdoctoral positions and the average total time in postdoctoral positions among these three disciplines.

Table 5-3. Number of postdoctoral positions and average total time in postdoctoral positions for three disciplines. The table entries reflect the experiences of Ph.D.'s who held at least one postdoctoral position.

	Biochemistry (86%)		**Mathematics (31%)**		**Nuclear Science (70%)**	
Postdoctoral Appointments	**Percent**	**Mean Total Years**	**Percent**	**Mean Total Years**	**Percent**	**Mean Total Years**
One	60	3.0	60	1.8	61	2.3
Two	31	4.5	29	3.1	32	4.5
Three	7	6.9	8	4.7	6	5.9
Four	1	8.5	3	6.8	1	7.9
Five	1	–	0	–	0	–

In all three cases shown in Table 5-3, about 60% of the Ph.D.'s had one postdoctoral appointment, about 30% took two appointments, and 7–11% had three or more postdocs. The biochemists and nuclear scientists who took two postdocs did so for a mean total time of 4.5 years. When one looks at the distribution by gender in these data for nuclear science, roughly the same percentage of women as men took postdocs, and each accepted an average of 1.5 postdocs, but the mean time spent as postdocs for the women was about seven months shorter than for the men, 2.7 years compared with 3.3 years.

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[5] This survey was conducted on the cohorts who received their Ph.D.'s between July 1982 and June 1985; the other four disciplines were computer science, electrical engineering, English, and political science.

[6] In mathematics, the postdocs are typically called Visiting Assistant Professors.

Table 5-4 presents the data for the environment of the first and second postdoctoral appointments taken in nuclear science.

As expected, this table shows that the vast majority of the postdocs were taken either at universities or at national laboratories. There were no postdocs in business or industry and very few in government or at medical schools or other nonprofit organizations. The individuals who took postdocs outside the U.S. predominantly went to accelerator laboratories or theoretical institutes for the first postdoc, with the addition of a few university appointments for the second postdoc.

Table 5-4. Environment for first and second postdoctoral positions, for nuclear science Ph.D.'s.

Environment	First Postdoc	Second Postdoc
University	50%	48%
National Lab	39%	33%
Business/Industry	0%	0%
Government	1%	2%
Medical School/Hospital	3%	2%
Other Nonprofit Organization	1%	0%
Outside U.S.	7%	15%

Finally, Table 5-5 looks at the major factors involved in choosing the first and last postdocs and compares the responses in the nuclear science survey to the earlier one involving biochemists. As we saw in Table 5-3, above, an even higher percentage of biochemistry Ph.D.'s take "almost mandatory" postdocs, but biochemistry is a discipline in which recent Ph.D. production is seen as excessive in the context of the available job market in academe and biotechnology [Triggle and Miller]. This situation was beginning to manifest itself even at the time of the *Ph.D.'s—Ten Years Later* study. This report does not argue that nuclear science is over-producing Ph.D.'s for its broadly based "traditional job market" (and, in fact, we recommend a modest increase in Ph.D. production; see Chapter 1); however, a number of responses to the nuclear science survey came from individuals who did not obtain the job in academe or the national laboratories that they had anticipated. Nonetheless, these individuals are, in fact, employed in components of the nuclear science "traditional job market"; thus, the nuclear science responses may be fruitfully compared to the job market–related responses of the biochemists (here and later in the chapter).

Striking parallels appear in Table 5-5: The largest percentage of both biochemists and nuclear scientists evaluated taking the first postdoc and the last postdoc as "nec-

Table 5-5. Major factors in the choice of first and last postdoctoral positions, for biochemistry and nuclear science Ph.D.'s. Multiple answers were permitted.

	Biochemistry		Nuclear Science	
Reason	First Postdoc	Last Postdoc	First Postdoc	Last Postdoc
Necessary step	75%	55%	73%	58%
Training in another subfield or area	42%	44%	21%	18%
Additional training in subfield	38%	18%	40%	24%
Work with a specific person	32%	36%	15%	21%
Only acceptable employment	10%	22%	27%	21%

essary steps." (Furthermore, for both first and last postdocs, the percentages were essentially independent of discipline.) The desire for "additional training in [their] subfield" also elicited parallel responses. Finally, more than 20% of the nuclear science Ph.D.'s felt that the first and the last postdocs were the "only acceptable employment," a percentage that was mirrored only for the last postdoc among the biochemists. For discussion later in this chapter, it is important that we try to understand the source of the view that a postdoc was the "only acceptable" job.

Employment data indicate that adequate numbers of permanent positions outside academia and the national laboratories have been available. Had the respondents been led to believe (perhaps by their perception of the views of their faculty mentors) that the only acceptable job—a job they must continue to seek—was a position involving fundamental nuclear science research? If so, their views were at dramatic variance with what has been the realistic "traditional job market" for Ph.D. nuclear scientists for many decades.

The Initial Career Path

Aspirations and reality

In this section, it is particularly useful to separate the career path outcomes for nuclear science experimentalists (78% of the respondents) from those for theorists (22%). We also wish to define a category called BGN for jobs in business (or industry), in government, or with nonprofit organizations. (Most of our survey results on the intersection of family and career appears in Chapter 7 and will not be repeated here.)

Figures 5-1 and 5-2 show the respondents' career goals at the beginning and at the end of their Ph.D. programs.

Initially, the respondents looked strongly to careers as professors or researchers in national laboratories or in academe, with fewer than 10% of the experimentalists

Figure 5-1. Career goals for experimentalists and theorists, at the beginning of graduate school.

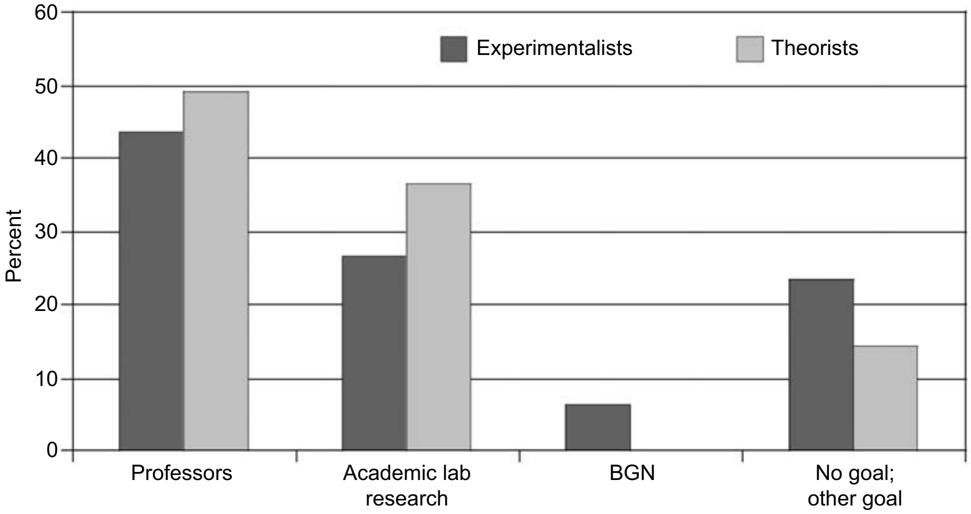
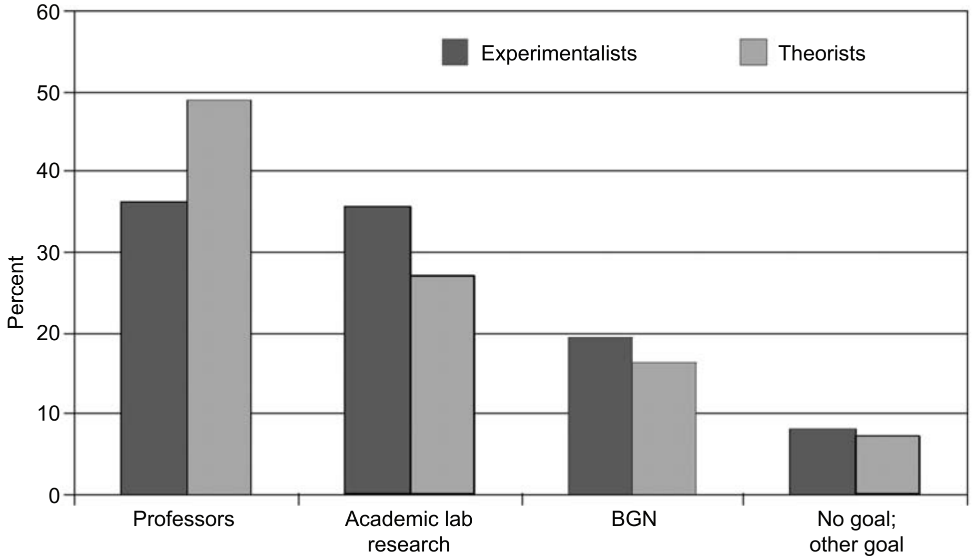


Figure 5-2. Career goals for experimentalists and theorists, at the conclusion of graduate school.



(and no theorists) interested in careers in BGN. By the end of graduate school, nearly 50% of the theorists and 36% of the experimentalists (down from 44%) still wanted to be professors; 36% of the experimentalists and 27% of the theorists sought research careers in the national laboratories or in academe. Also, by the time they received their Ph.D.'s, 20% of the experimentalists and 16% of the theorists were interested in careers in BGN; fewer than 10% remained undecided.

In contrast, Tables 5-6 and 5-7 show the first job titles and the current (December 2003 to May 2004) job titles for the respondents. Thirteen individuals are not tabulated in Table 5-7, since they were still postdocs,[7] and another thirteen[8] did not respond with their current job titles. Our best understanding of the survey data is that all of the respondents are currently employed.

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[7] These included six experimentalists (3% of the total experimentalists) and seven theorists (13%).

[8] These included nine experimentalists (5% of the total experimentalists) and four theorists (7%).

Table 5-6. First job titles reported by respondents.

	Experimentalists N = 182*		Theorists N = 46	
First Job	**N**	**Percent**	**N**	**Percent**
Faculty (tenured and tenure-track)	28	15	11	24
Non-tenure-track faculty	27	15	10	22
National laboratory researcher	48	26	8	17
Other academic/national lab	17	10	2	4
BGN	60	33	15	33

*2 Experimentalists were not in the workforce

Table 5-7. Job titles at the time of the survey, as reported by respondents. Individuals who were still postdocs are not included here.

	Experimentalists N = 178*		Theorists N = 44*	
Current Job	**N**	**Percent**	**N**	**Percent**
Faculty (tenured and tenure-track)	46	26	11	25
Non-tenure-track faculty	8	4	7	16
National laboratory researcher	44	25	7	16
Other academic/national lab	15	8	1	2
BGN	65	37	18	41

*Some did not respond about current job titles

Focusing on the current job titles, we find that about 25% of both the experimentalists and the theorists are tenured or tenure-track faculty, 25% of the experimentalists and 16% of the theorists are at national laboratories, and 37% of the experimentalists and 41% of the theorists are working in BGN. The most significant changes between the first job and the current job for experimentalists are the increase of the tenured and tenure-track faculty (from 15% to 26%) and the corresponding decrease in the non-tenure-track faculty (from 15% to 4%). For theorists, the biggest change is the increase in the number of those in BGN (from 33% to 41%).

Table 5-8 compares the current job spectrum for those who took one or more postdoctoral appointments with those who did not take such an appointment.

Table 5-8. Current positions of respondents who held one or more postdocs and those who did not.

	Postdoc (N = 156)		No Postdoc (N = 69)	
Current Job	**N**	**Percent**	**N**	**Percent**
Faculty (tenured and tenure-track)	38	24	19	28
Non-tenure-track faculty	11	7	4	6
National laboratory researcher	46	29	5	7
Other academic/national lab	12	8	5	7
BGN	49	31	36	52

In the discussion of Table 5-8, and in several subsequent discussions, we will limit the employment categories to (i) faculty (tenure-track and tenured), (ii) national laboratory researcher, and (iii) BGN, owing to the poor statistics for individuals employed as "non-tenure-track faculty" or in "other academic/national lab" positions.

Table 5-8 shows that about a quarter of the survey respondents were in faculty positions, whether or not they had had postdoctoral experience. However, three-quarters (14 of 19) of those who did not do a postdoc had faculty positions in colleges or universities that do not independently grant Ph.D.'s (and the great majority of these individuals were native-born U.S. citizens). An almost equal number (13) of the respondents who had held a postdoc also hold current positions in these teaching-oriented institutions. With regard to those individuals taking positions at national laboratories, most (90%) had been postdocs. Finally, 52% of those not doing a postdoc were currently employed in BGN, compared with 31% of those doing one or more postdocs.

Table 5-9 illustrates the job titles for the respondents currently employed in BGN. The job spectrum is presented in descending order, from the most to the least frequent responses. Science and engineering research and development, unrelated to nuclear or medical fields, was the largest category, followed by software engineering. The "nontraditional" job category of finance (investment banking) follows, with a return to the "traditional job market" categories of nuclear science research and development, medical instrumentation research and development, and radiation or medical physics in the next three places.

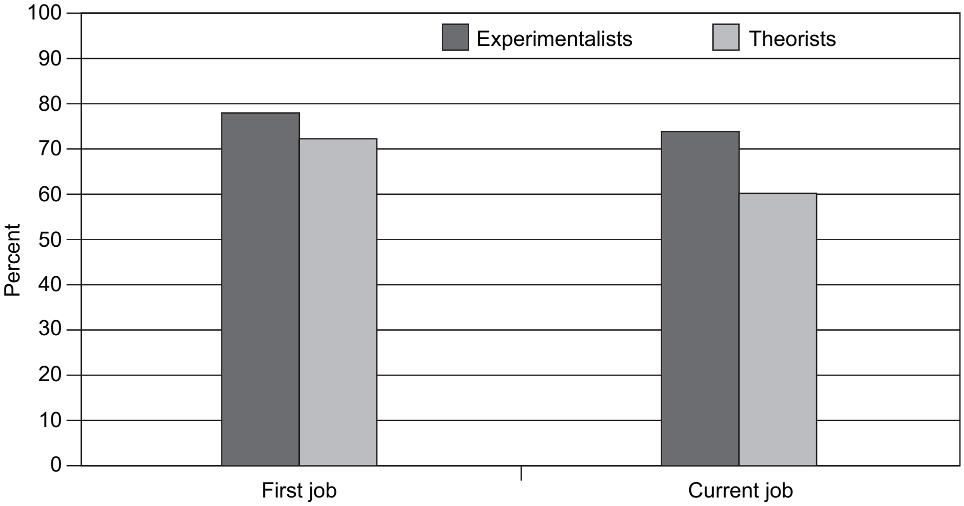
We then looked at the percentages of our respondents who had achieved the goal they sought at the end of graduate school: employment at a university or college, or at a national laboratory (this analysis included those who were non-tenure-track faculty or held "other academic/national lab" positions). These results are shown in Figure 5-3 for both the first job and the job held at the time of the survey.

Table 5-9. Current job titles of respondents employed in business, government, or the nonprofit sector. The numbers indicate numbers of responses.

• Science or Engineering R&D (not nuclear, not medical) (17) • Software Engineer (11) • Finance (8) • Nuclear Science R&D (6) • Radiation Physics / Medical Physics (5) • Top Executive (CEO, COO, CFO) (4)	• General Management (3) • Manufacturing/Engineering/Management Information Systems (3) • High School Teaching (3) • Technical Support (3) • Consulting (2) • Legal (2) • Small Business Owner (2) • Other (6)
Total 80	

This figure shows that 78% of the experimentalists and 72% of the theorists had an initial job in academe or at a national laboratory, but that the percentages for the current job had fallen to 74% and 60%, respectively. This mismatch of career goals and (at least) early career outcomes suggests that some of these respondents may be the source of negative comments about Ph.D. education in nuclear science, which we will come to later. It is also noteworthy[9] that of those in academe, 21% felt that their current jobs were "in a different field," rather than being "in nuclear science or in a related field"; the corresponding number for those at a national laboratory was 13%.

Figure 5-3. Percentages of respondents who achieved the career goal they sought at the end of graduate school: an academic or national laboratory job.



Choices and reasons

Table 5-10 presents the survey respondents' views of faculty expectations for their careers. The exact wording of this question was, "Describe the expectations of faculty in your department during your doctoral education regarding your professional development." Respondents were allowed multiple choices among the five options given in the table. The results are tabulated as the percentage of the 234 respondents who chose a particular option. Sixty-three percent of the respondents

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[9] See Table 1-1 in Chapter 1 (Demographics).

Table 5-10. Faculty expectations regarding professional careers. Survey participants were permitted multiple responses.

	N	Percent of Respondents* (N = 234)
Faculty encouraged pursuit of academic careers at research universities	148	63
Faculty encouraged pursuit of academic careers at 4-year colleges	45	19
Faculty encouraged pursuit of national laboratory careers	101	43
Faculty encouraged pursuit of careers in BGN sector	28	12
Faculty did not have specific expectations about career choices	95	41

* Respondents chose all that applied

felt that faculty encouraged careers at research universities, 43% felt that they encouraged careers at national laboratories, and 41% said that the faculty did not have any specific career expectations. Nineteen percent of the respondents said that the faculty encouraged careers at four-year colleges, and only 12% responded that the faculty encouraged careers in the BGN sector. This last number is in stark contrast to the early career outcomes: 37% of the experimentalists and 41% of the theorists were working in the BGN sector five to ten years after their Ph.D.'s

A quotation from Roman Czujko, Director of the Statistical Research Center of the American Institute of Physics, seems appropriate in this context [Czujko]:

> Physics departments are isolated from the world outside of academe. Many physics departments are still driven by the dominant goal of adding to the knowledge base, that is, conducting basic research and preparing students to become the next generation of basic researchers. Too few faculty understand the remarkable diversity of careers commonly pursued by people with physics degrees. Too few departments have modified their curriculum to address the needs of the majority of their students, that is, those students who do not become Ph.D.'s conducting basic research.

Finally, Table 5-11 lists the factors of most importance to our survey respondents in choosing their current jobs. The ten most important factors (1 = most important) are shown separately for faculty (tenure-track and tenured), national laboratory researchers, and BGN employees. We based the rank on the percentage of respondents who assessed a factor as being either "very important" or "fairly important"; the other possible responses were "not too important," "not important at all," and "not applicable."

When interpreting some of the results in this table, it is useful to know that the top ten factors range from 96–100% down to about 80% for both faculty and the national laboratory researchers; whereas it goes down to about 50% for those in

Table 5-11. Factors in the choice of current jobs. The rank order was determined by the number of times respondents answered "very important" or "fairly important."

	Rank		
Factors	**Tenured/ Tenure-Track**	**National Lab**	**BGN**
Congenial Work Environment	1	3	5
Good Opportunity to Teach	1		
Job Security	3	3	7
Autonomy of Work	3		5
Good Health and Retirement Benefits	5	3	4
Opportunity to Contribute to Society	5	3	9
Good Geographic Location	5	9	3
Good Salary/Compensation	8	1	1
Good Career Growth Opportunities	8	1	2
Use of my Doctoral Education	10	9	10
Good Environment for Raising Children		3	
Good Equipment, Experimental Space or Other Resources		8	
Good Opportunity to Do Research		9	
Sufficient Time for Leisure, Family, Interests			8

BGN. As would be expected, the faculty rated a good opportunity to teach, a congenial work environment, job security, and autonomy of work highly. The national laboratory researchers rated good salary and good career growth highly, with a number of other factors in third place, including (like the faculty) a congenial work environment and job security. Those employed in BGN likewise rated good salary and good career growth opportunities the highest, followed by good geographic location (89%) and good health and retirement benefits (71%).

Usefulness of the Doctoral Education

Was it worth it?

How did our survey respondents appraise their doctoral education? Would they do a Ph.D. again, was it worth the effort, what job preparation skills had they learned? Table 5-12 shows the responses to the question, "Knowing what you know now, if

Table 5-12. Responses to the question, "If you had it to do over, would you get a Ph.D.?"

Response	Biochem. (N = 613)	Math (N = 676)	Elect. Eng. (N = 460)	Nuc. Sci. (N = 235)
Yes: Same Field				58%
{Total}	{69%}	{79%}	{79%}	{75%}
Yes: Different Subfield				17%
Yes: Different Field	9%	14%	10%	13%
No: M.D./J.D.	16%	5%	7%	5%
No: Master's Degree	5%	2%	5%	5%
No Graduate Degree	1%	1%	0%	2%

you had to do it over again, would you get a Ph.D.?" For comparison, the table also shows responses from biochemistry, electrical engineering,[10] and mathematics from the *Ph.D.'s—Ten Years Later* study.

In this table, nuclear science, mathematics, and electrical engineering show the same trends in their responses, with 75–79% reporting that they would have done a Ph.D. in the same field,[11] with another 10–14% reporting that they would have chosen a different field for the Ph.D. A total of 8% to 12% would have sought professional degrees, master's degrees, or no graduate degree. By contrast, only 69% of the biochemists would have again obtained a Ph.D., with 16% reporting that they would have sought an M.D. or J.D. instead. (Almost all of this 16% would have sought an M.D., which reflects their view of the relative job markets.) The preferred different fields for the Ph.D. named by the nuclear scientists were, first, computer science or electrical engineering (tie); second, biology or biomedical physics (tie); and third, materials science.

In the nuclear science survey only, respondents who said they would stay in the same field for the Ph.D. were also asked whether they would have chosen the same or a different subfield of physics or chemistry. Here, 23% of those who would have again chosen physics for the Ph.D. would have changed into a different subfield.[12] The preferred different subfields of physics in this survey were, first, astrophysics or particle physics (tie); second, atomic physics, biophysics, or solid-state physics (tie); and third, quantum optics.

Table 5-13 presents similar data for nuclear science only, sorted by the current job of the respondents, as discussed above. Those with careers in BGN clearly differ

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[10] Data from electrical engineering have good statistics for some of these tables and provide another comparison point.

[11] When the responses were looked at by gender, women were slightly more likely to say they would again pursue a Ph.D. in the same field. In nuclear science, 79% of the women offered this response.

[12] Similar responses to this type of question about changing to another subfield also appeared in the postdoctoral fellow survey.

Table 5-13. Responses by nuclear scientists in different current jobs to the question, "If you had it to do over, would you get a Ph.D.?"

	Percent		
Responses	**Tenured/ Tenure-Track (N=57)**	**National Lab (N=46)**	**BGN (N=82)**
Yes: Same Field	65%	79%	42%
Yes: Different Subfield	18%	13%	23%
Yes: Different Field	9%	4%	18%
No: M.D./J.D.	5%	2%	6%
No: Master's Degree	2%	0%	10%
No Graduate Degree	2%	2%	1%

from those in either faculty or national laboratory positions; a higher percentage of BGN employees would have gone into a different field or would have obtained a master's degree.

Was completing a Ph.D. worth the effort to the respondents? Table 5-14 presents these results for the same four disciplines that were contrasted in Table 5-12. Here we see that acquiring a Ph.D. was "worth the effort"—obtained by summing "definitely worth" and "probably worth"—for 97–98% of the respondents in mathematics and electrical engineering, 93% in biochemistry, and 90% in nuclear science, the lowest of the four. Correspondingly, nuclear science had 10% of its respondents reporting that obtaining the Ph.D. was "probably not worth" the effort.

It is interesting to look further into whether respondents felt the Ph.D. was "worth the effort." Table 5-15 breaks down the favorable responses for experimentalists and theorists according to their current jobs. A remarkable 100% of the theorists responded that obtaining a Ph.D. was worth the effort, regardless of the current

Table 5-14. Feelings about completing a Ph.D.: Was it worth the effort? Entries in the "worth" column represent the totals of "definitely worth" and "probably worth."

Major Field	**Definitely Worth**	**Probably Worth**	**Worth**	**Probably Not Worth**
Biochemistry	72%	21%	93%	7%
Electrical Engineering	80%	18%	98%	2%
Mathematics	81%	16%	97%	3%
Nuclear Science	68%	22%	90%	10%†

† 3 men responded "definitely not worth the effort"

Table 5-15. Percentage of experimentalists and theorists in different jobs who felt that getting a Ph.D. was definitely or probably worth the effort.

	Experimentalists		Theorists	
Current Job	**N**	**Percent**	**N**	**Percent**
Tenured/ Tenure-Track	42	91	11	100
National Lab	40	98	5	100
BGN	51	84	18	100

job. The most satisfied experimentalists were those in the national laboratories, followed by faculty, and then by those in BGN jobs.

Assessments that the Ph.D. was "worth the effort" imply that the respondents' education was adequate to allow them to find employment and prepared them to be effective in their current jobs. It is quite significant that 84% of the 51 experimentalists and all of the 18 theorists whose current jobs are in BGN felt that this was the case. Hence, overall, it appears that the current educational system is providing the needed expertise and allowing graduates to find employment that uses their skills. Indeed, more than half of the nuclear science Ph.D.'s are hired in areas outside nuclear science.

Job preparation skills

As discussed in more detail in Chapter 6, the 1995 report by the Committee on Science, Engineering and Public Policy of the National Academies recommended a number of actions to revitalize the doctoral training of scientists and engineers and to increase its effectiveness [COSEPUP]. In particular, the report discussed the importance of a number of job skills that would be needed in the workplace and that should be included in doctoral education. These included working in a team, collaboration with another person, undertaking interdisciplinary research or study, learning organizational or managerial skills, developing communications and presentation skills, and attending grant-writing and career development workshops.

The survey respondents were asked to evaluate how important several "job preparation skills should be to doctoral education in nuclear science," on a scale running from "very important" to "not important at all." Figures 5-4 and 5-5 display the responses.

From these figures, we see that more than 90% of the respondents thought that communication skills, collaboration, and teamwork were either "very important" or "fairly important" in doctoral education (with 70% responding that communication skills were "very important"). In addition, more than 80% of the respondents thought that interdisciplinary research and organizational skills were important, and about 70% felt that grant-writing and career development workshops were

Figure 5-4. Respondents' evaluations of several job preparation skills.

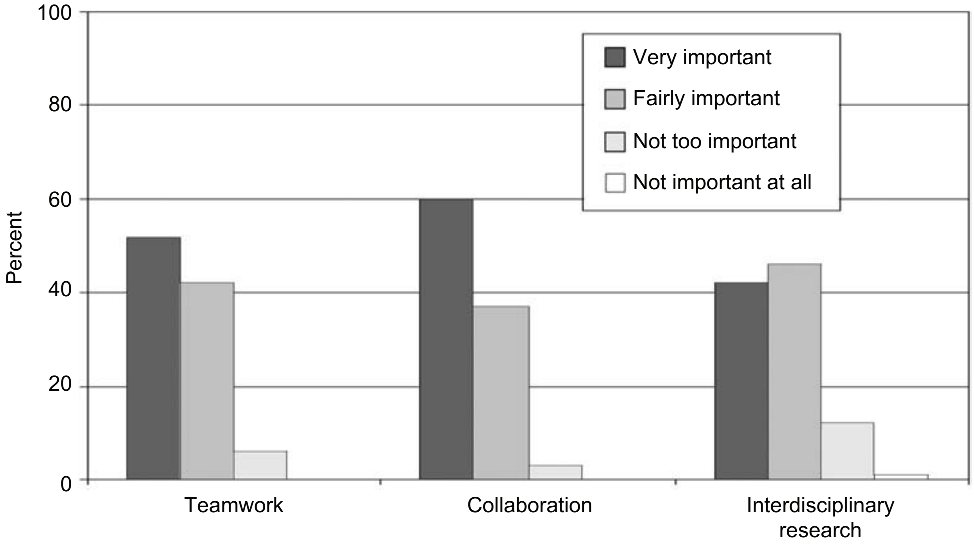
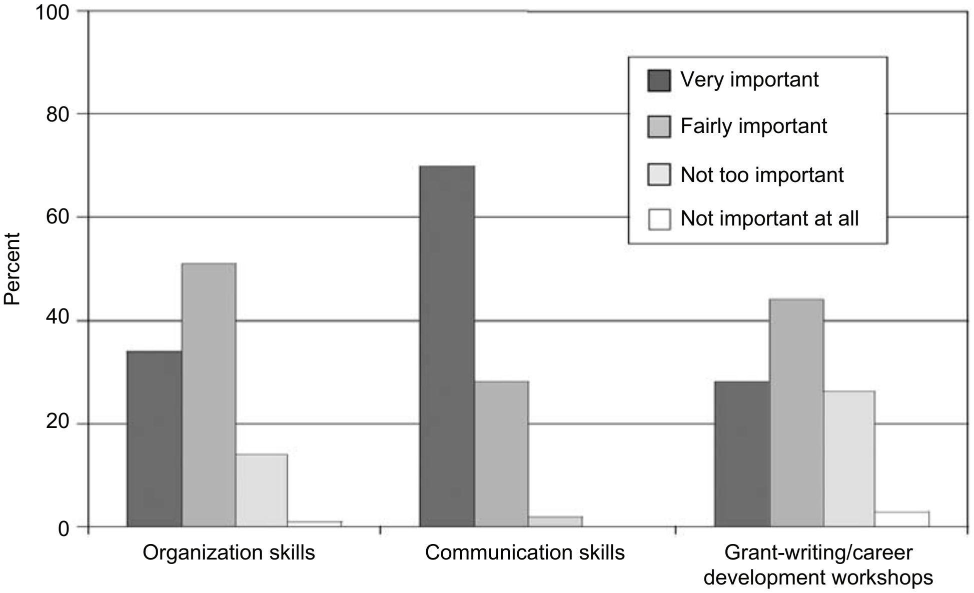


Figure 5-5. Respondents' evaluations of several job preparation skills.



important.[13] These responses are certainly in line with the National Academies recommendations (unfortunately, the survey did not then go on to ask whether their particular Ph.D. program provided these job placement skills).

Finally, the survey asked the respondents to choose among a number of different ways that some people find their doctoral education useful, regardless of the field in which they got their Ph.D. The highest ranking items were the following (as sums of the responses[14] "strongly agree" and "somewhat agree"):

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[13] The graduate student survey responses to a similar question essentially paralleled these results, with the percentages viewing a particular skill as "important" summing to 6–9% less for the three most highly rated skills and about 20% less for the three lower-rated skills.

[14] This question had five possible responses : strongly agree, somewhat agree, neither agree nor disagree, somewhat disagree, and strongly disagree.

“It led me to more analytical and critical thinking.”	95%
“It satisfied me intellectually.”[15]	90%
“It made me more disciplined in my thinking.”[16]	89%
“It helped me figure out how to find relevant information.”[17]	84%
“It helped me develop my communication skills (verbal, written and presentation).”	81%
“It increased my perseverance so that I could stay on the same project or problem for much longer than before.”	73%
“It made other people respect me more.”	64%
“It increased my self confidence.”	63%
“It served as a ‘union card,’ helping me to be accepted in many kinds of jobs.”[18]	55%
“It provided contacts that later helped me professionally.”	54%

The first of these items had the highest score for “strongly agree,” 72%. For the final three of these items, the sum of the responses “somewhat disagree” and “strongly disagree” was more than 10%: 23% did not feel that it served as a “union card,” 22% did not believe that it provided useful professional contacts, and 12% did not think that acquiring a Ph.D. increased self-confidence.

Doctoral Education and the Graduate School Experience

In this section, we look at several of the essential elements of the Ph.D. programs in nuclear science. Figures 5-6 through 5-8 present respondents’ evaluations of what we might call the “academic effectiveness” of the Ph.D. programs—the curriculum of the Ph.D. programs, the quality of graduate-level teaching in these programs, and the quality of the research experience, respectively.

These results, scored from poor (1) to excellent (4), show quite a high average rating in Figure 5-8 for the quality of the research experience (3.47), with the quality of the curriculum and the quality of graduate-level teaching scoring lower, around 3.0 in each case. This indicates that more faculty effort might be put into these latter two areas. Looking at these data another way, the quality of the research

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[15] This response had the second highest score for “strongly agree,” 60%. Seventy-two percent of theorists and 56% of experimentalists strongly agreed (differences of 15% or greater will be noted).

[16] This response had the third highest score for “strongly agree,” 55% (68% of theorists and 51% of experimentalists).

[17] This response had the fourth highest score for “strongly agree,” 43%. All other scores for “strongly agree” were less than 40%.

[18] Forty-one percent of women and 25% of men “strongly agreed.”

Figure 5-6: Evaluations of the Ph.D. curriculum.

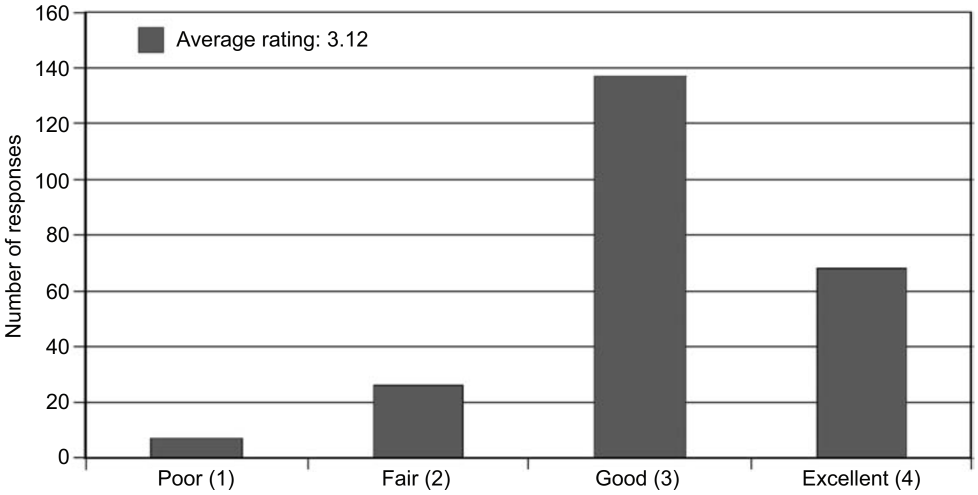


Figure 5-7. Evaluations of graduate-level teaching by faculty.

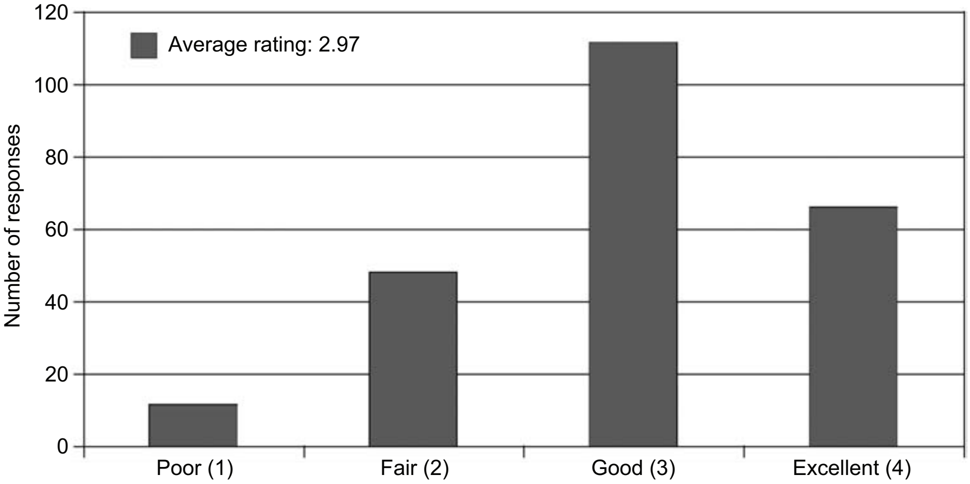
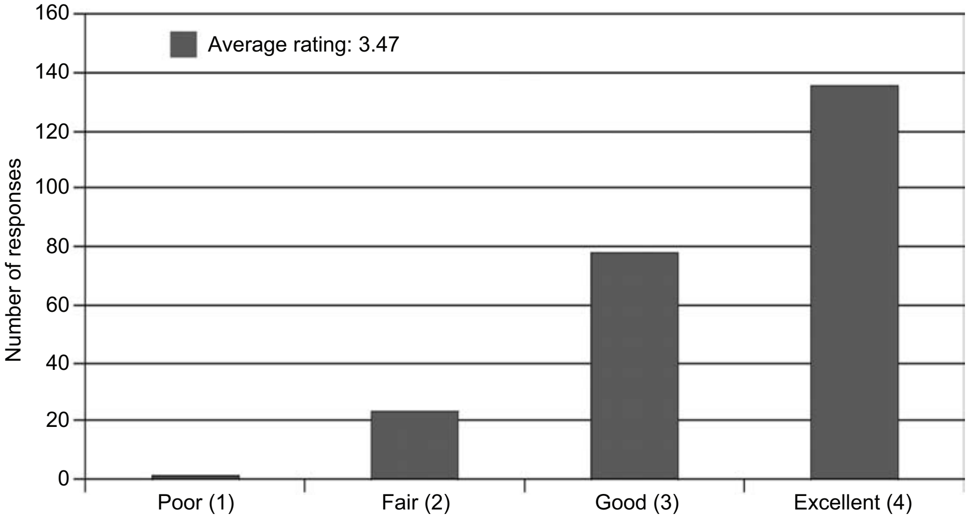


Figure 5-8: Evaluations of the graduate research experience.



experience was rated as excellent by 57% of the respondents, while the quality of the curriculum and the graduate-level teaching were rated as excellent by only half as many, 28% of respondents. Five percent of the respondents judged the quality of graduate-level teaching as poor; only one individual rated the research experience as poor.

Figures 5-9 and 5-10 present evaluations of what might be described as the "research mentoring effectiveness" of the Ph.D. programs—the quality of faculty advice in developing the dissertation topic and the quality of guidance in helping to complete the Ph.D. The average ratings in both cases lie between the low and high average ratings of Figures 5-7 and 5-8, respectively. Fifty percent of respondents evaluated the quality of the guidance provided by the dissertation adviser in helping them complete their Ph.D.'s as excellent; 46% rated the quality of advice in developing the dissertation topic as excellent. Six percent felt the quality of faculty guidance in assisting them to complete the Ph.D. was poor.

Figure 5-9: Evaluations of the quality of advice in developing respondents' dissertation topics.

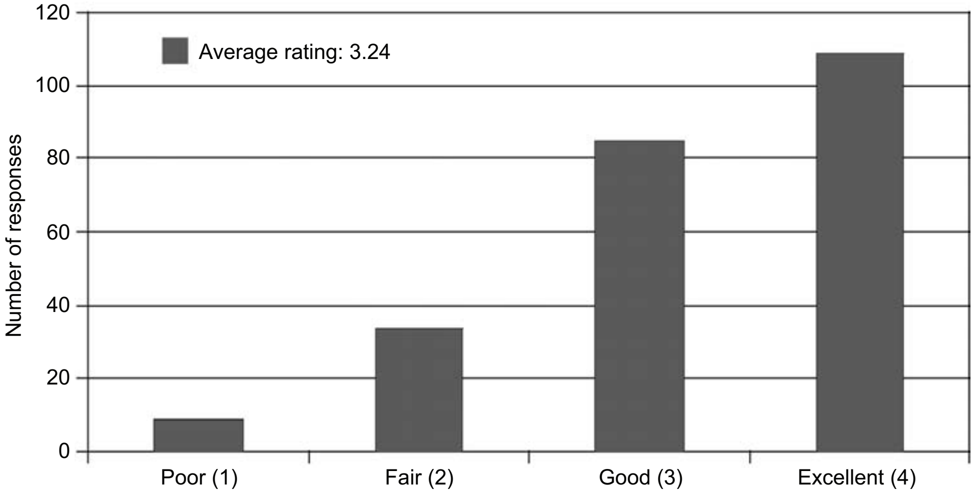
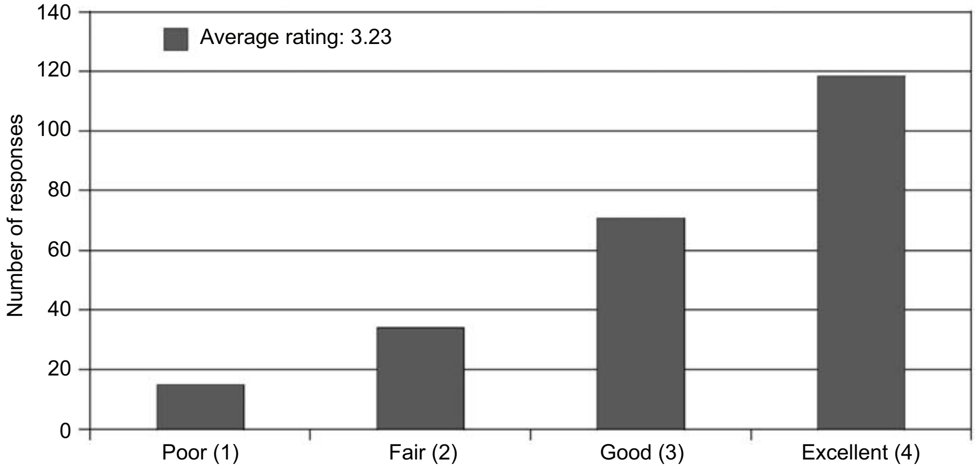


Figure 5-10: Evaluations of the quality of guidance provided in helping complete the Ph.D.



Taking these results together, we conclude that the quality of the research experience is highly valued, while some additional faculty effort might go into other components of the Ph.D. program, particularly into graduate-level teaching.

Turning now to the funding picture for doctoral education in nuclear science, we found that, at one time or another, 40% of the respondents had fellowships, 79% held teaching assistantships, and 96% held research assistantships. The funding sources for the research assistantships was 40% from the NSF, 32% from the DOE, 18% from the universities, and 10% from a combination of agency (or research foundation) and university support. Table 5-16 summarizes the duration of the several types of support.

Table 5-16. Percentage of students receiving different kinds of support for various lengths of time. Each row sums to 100%.

	Duration in Years						
Type of Support	0.5	1	1.5	2	3	4	5 or more
Fellowships	8%	30%	3%	27%	16%	4%	2%
Teaching Assistantships	10%	30%	11%	30%	9%	2%	8%
Research Assistantships	1%	2%	2%	10%	19%	24%	43%

Sixty-eight percent of the individuals with fellowship support were covered for two years or less, and another 30% had three or four years of fellowship support. The most common duration for teaching assistantships was either one or two years (30% each). For the 96% holding research assistantships, 24% held them for four years and 43% for five or more years.

Other facets of the respondents' research experiences include research specialty, work style, and the location of the doctoral research. The respondents' areas of research specialty are given in Table 5-17. The four most prevalent research specialties accounted for 76% of the responses: nuclear structure, medium-energy nuclear science, nuclear reactions, and relativistic heavy ions.

As regards the work style, 22% of the respondents had worked primarily alone, 25% primarily with their research supervisors, and 52% in research teams. Among this last group, 53% had worked in research teams of 3–6 people (including the respondent and the Ph.D. supervisor), 29% in teams of 7–10, 10% in teams of 11–20, and 8% in teams of more than 20.

Finally, where did the respondents conduct their research? Fifty-nine percent conducted most of their dissertation research at their home universities, while 28% did most of their research away from their home schools. Among the latter group, 65% spent at least three months away from their home universities. The remaining 13% of respondents conducted about equal amounts of research at and away from their home universities; of these, just over 60% spent at least three months away.

Table 5-17. Areas of research reported by respondents.

	N	Percent
Nuclear structure	62	26
Medium-energy nuclear science	50	21
Nuclear reactions	36	15
Relativistic heavy ions	32	14
Fundamental nuclear science	22	9
Nuclear astrophysics	20	9
Nuclear chemistry	6	3
Accelerator nuclear science	5	2
Applied nuclear science	2	1
Total	**235**	**100**

Advice from Nuclear Science Ph.D.'s 5–10 Years Later

An essential aspect of this survey was seven open-ended questions, which concluded the questionnaire. The responses to five of these questions follow:

1. What advice would you offer to graduate students who are just beginning studies in nuclear science?

This question elicited 171 responses, although it was near the end of a long survey. The results are shown in Table 5-18, gathered into the most common responses.

Table 5-18. Respondents' advice to beginning doctoral students.

Open-Ended Questions: Most Cited of 171 Responses	**N**	**Percent**
Strongly reconsider a Ph.D. in nuclear physics	41	24
Continue only if you "love" it*	18	
Don't/Choose alternative field/Bad job market	23	
Be interdisciplinary/breadth	23	13
Focus/define your goals	17	10
Work hard	16	9
Keep options open/flexibility	16	9

* Job market-related

Of great concern to the subcommittee was the fact that the most frequent "advice"—from 41 of the respondents to this question—was that beginning doctoral students should strongly reconsider a Ph.D. in nuclear physics. This advice took two major forms: (i) there is no job in nuclear science in your future, so you should continue only if it is your "calling" and you cannot be content otherwise; and (ii) nuclear physics is a field with no job prospects in sight—get out while you can.[19]

Examples of specific comments include:

> If you don't absolutely love this stuff, do something else. Academic research is all about sacrifice. You'll work less and find more job openings, money, flexibility, etc. doing just about anything else.
>
> If it is not a case of "I am compelled/driven to study in this field," I would say find something more useful, i.e., something to make you more employable.
>
> Quit and do something else. If you are smart enough for nuclear physics, you can find something else that will give you a much better life.
>
> Think about the practical applications of your Ph.D. work. Will you be needed by an employer when you graduate? Consider switching to a more useful discipline, such as EE.
>
> I would advise students that there is not a sure path from the Ph.D. to a faculty job at a major university or lab, even for the very qualified.

Other important advice to beginning graduate students (offered much less frequently) was to strive for a broad background with interdisciplinary interests, to focus and define goals early, to work hard, and to be flexible.

2. What recommendations would you offer doctoral programs in nuclear science today?

This question received 152 responses; the results are shown in Table 5-19, again gathered into the most common responses. Again, one recommendation dominated the others by nearly a factor of two. The respondents felt that they needed much more assistance in career planning and guidance than they had received, particularly about careers in BGN jobs.

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[19] As noted earlier, our best understanding of the survey data is that all of the respondents are currently employed.

Table 5-19. Respondents' recommendations for doctoral programs.

Open-Ended Questions: Most Cited of 152 Responses	**N**	**Percent**
Provide career planning and guidance, especially about BGN	34	22
Work for breadth and interdisciplinary skills	20	13
Develop skills that the marketplace needs	18	12
Improve image of field/keep current/be active	11	7
Better mentoring and advising; address individual needs/goals	11	7
Shorten the time to the Ph.D.	10	7
Honesty/realism about the job market	8	5

Several specific comments follow:

> Mentoring is extremely important. Also, in general, faculty has contacts with other people at Ph.D.-granting academic institutions. Faculty needs to be aware that many (most) students won't end up at research institutions. Faculty really have an obligation to at least make some effort to develop contacts with people in business, industry and non-research institutions. Keeping in touch with alumni could be quite helpful.
>
> Provide better guidance/contacts for non-academic career paths. This requires that the Ph.D. advisers do a little extra work here.
>
> Teach marketable technical skills. Encourage employers to hire Ph.D.'s. Better networking with the private business-industrial sectors. Need to work much harder at employment opportunities for the Ph.D.'s. They are generally very smart and motivated people who would help most any employer.
>
> Better and earlier advice on career paths and positions.
>
> Many students seem to feel that if they get a Ph.D. but do not go on to a university or national lab job then they have failed. It would be good to try to change this culture.

Of the other six listed recommendations, most of them can also be related to career issues: doctoral programs should work for breadth and interdisciplinary reach; these programs should help graduate students develop skills that the marketplace needs; the graduate students need better mentoring, including addressing their goals as individuals; and departments should be honest and realistic about the state of the job market in discussions with the graduate students. The other two recommendations reflect some respondents' concerns that the doctoral program that they went through was not as active as it should have been and that the time to the Ph.D. was too long.

3. How did you decide to choose to study nuclear science?

The most frequent answers to this question were similar to those elicited in the postdoctoral survey: The respondents got involved because they had been inspired by good undergraduate or summer research experiences; they had developed a general interest in nuclear science, enjoyed the work, and wanted to continue; they had been guided into nuclear science as an undergraduate by a professor or other mentor; or as a graduate student, they had been inspired by, influenced by, or wanted to work with a specific professor.

4. How would you get others interested in nuclear science?

Here are a few representative quotes:

> That's a tough one. I recently taught a general physics course for non-science majors and I gave them some readings about women in physics. Most of the students were shocked at how few women (and minorities) there were. One student (a communications major) said: "You guys have a major public relations problem." I do agree. It seems to me that we need to do a better job (somehow) of getting the word out. NASA has always done a lot of outreach, and I think we need to do something along these lines.
>
> More (good) exposure in the popular press. For too many people, even the word nuclear evokes a very negative response. Unless people think of nuclear science as something other than working to create weapons of mass destruction, we will be fighting an uphill battle.
>
> It is my belief that other career paths that have been followed should be highlighted to illustrate that if you do not get that premier faculty position, you will still have an interesting and technically challenging career.
>
> Market all the related fields and applications. Physicists are the worst at marketing their own.

5. Do you think that additional incentives are needed to increase the number of U.S. bachelor's degree holders who are going into doctoral programs in nuclear science? If so, what might those incentives be?

We received 168 responses to this question. Of greatest concern to us was that the job market–related "advice" given here was even more negative than that received in response to the first question, above. There, 24% of the respondents felt that beginning doctoral students should strongly reconsider a career in nuclear science; here, 38% were definitely against any incentives to enter a doctoral program in nuclear science, 56% of the respondents thought that additional incentives (of a broad range of types) could be useful, and 6% “did not have an opinion.” A conviction that the job market was poor for nuclear science Ph.D.’s was the dominant reason for the negative responses.

Negative responses included the following:

> Why on earth would we want to encourage people to go into nuclear science, when the ones in it can’t find jobs?
>
> God, no! There aren’t enough good jobs out there as it is. . . . why sentence another generation of idealistic young students to the eternal hellish round of postdoc after postdoc.
>
> No. I don’t think that we need more Ph.D. scientists. Although I think this is a valuable learning experience, the truth of the matter is that most people “hope” to go on to academic and/or research careers and there just [aren’t] that many available.

In addition, even many of the favorable answers were actually based on a better job market:

> Yes. Jobs calling out for nuclear scientists would be a big incentive.
>
> Yes, but only if more “real” (non-postdoc) jobs can become available.

The above results were independent of gender and citizenship; theorists were somewhat more negative (44%) than experimentalists (36%); and the largest difference was between those employed in BGN (48% negative) and those employed in academe or the national laboratories (31%). We again see the effects of inadequate career advising for our doctoral students, particularly with regard to job placement outside academe and the national laboratories.

Summary and Conclusions

This survey has provided us with a snapshot of the initial career paths of nuclear science Ph.D.’s, as well as their retrospective views on their doctoral education. The responses from women (12% of the total) were representative of their presence in the survey population, and there were very few ethnic minorities among the 67% of the respondents who were native-born U.S. citizens. This continuing issue of the low participation rate of women and the very low participation rate of underrepresented minorities was also observed in the surveys of current graduate students and postdocs. Clearly, the nuclear science community is going to have to initiate some major actions to become more inclusive. The survey additionally found that 64% of the women had spouses or partners who also had doctorates (or M.D.’s or J.D.’s). The career search for women thus becomes more difficult, as two professional jobs in the same geographic area must be sought. University departments and national laboratory divisions need to become more aware of the increasing number of dual-career professionals and develop innovative policies to accommodate them.

We found that 70% of the respondents had held at least one postdoctoral appointment. Roughly the same percentage of men and women took postdocs, and each accepted an average of 1.5 positions. Ninety-five percent of the first postdoctoral appointments were taken either at universities or at national laboratories in the U.S. or abroad. A mean time of 3.3 years was spent in these postdocs, which, when added to the median registered time to the Ph.D. for the survey cohort of 7.0 years, means the "typical" total elapsed time from the beginning of graduate school to the first job is more than ten years. This time is a barrier to attracting the best people into the field, is unnecessarily long for many career paths, and hinders the intellectual independence of nuclear scientists at the most creative period in their careers. This total time should be shortened. It also poses an especially serious hurdle to financially disadvantaged students, who may feel strong pressures to become productive wage earners.

In looking at initial career paths, we distinguished between nuclear science experimentalists (78%) and theorists (22%). We also defined a category called BGN for jobs in business or industry, in government, or with nonprofit organizations. At the end of the Ph.D. process, 36% of the experimentalists wanted to be professors, 36% wanted a research career in the national laboratories or academe, 20% were interested in BGN, and some were still undecided. The corresponding numbers for theorists were professors, nearly 50%; nuclear science researchers, 27%; and BGN, 16%. In contrast to these goals, we found about one-quarter of both the experimentalists and the theorists currently working as tenured or tenure-track faculty, 25% of the experimentalists and 16% of the theorists as national laboratory researchers, and 37% of the experimentalists and 41% of the theorists in BGN.[20]

Unfortunately, the high expectations (about 75% of respondents) of a career in academe or the national laboratories for both experimentalists and theorists was in direct conflict with the reality of the "traditional job market" for physics (or nuclear science), in which one-third to one-half of the Ph.D.'s ultimately work outside physics (or nuclear science). In fact, only 70 of 195 respondents (36%) reported a current job in nuclear science[21] in academe or the national laboratories. The respondents whose jobs are outside of "academic" nuclear science represent an important national resource with its concomitant transfer of knowledge and techniques. The overwhelming majority of respondents viewed their nuclear science Ph.D.'s as valuable, since it has given them special skills. However, a number of "mixed messages" in answers to other questions in the survey indicates that proper career advising has not taken place.

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[20] Twelve percent of the experimentalists and 18% of the theorists are working as "non-tenure-track faculty" or in "other academic/national laboratory" positions.

[21] The question was "Is your current job in nuclear science, in a related field, or in a different field."

Fifty-eight percent of the survey respondents said that they would get a Ph.D. in nuclear science again, while 17% would choose a different subfield of physics or chemistry.[22] Another 13% would pursue a Ph.D. in another field, and 12% would seek a M.D., J.D., or master's degree, or no advanced degree at all. The respondents at the national laboratories were the most satisfied with their Ph.D.'s in nuclear science (79%), followed by those in tenured or tenure-track positions (65%); as might be expected, fewer of those working in BGN (only 42%) would again seek a Ph.D. in nuclear science. However, when asked whether completing the Ph.D. was worth the effort, 90% of all respondents—and a remarkable 100% of the theorists[23] —said that it was "definitely worth" or "probably worth" the effort. When we look at the overall retrospective evaluation of the various elements of doctoral training, the quality of the research experience was the most highly rated, with 57% of the respondents viewing it as having been "excellent" and 33% as "good." This assessment by most that the Ph.D. was "worth the effort," and the similar 90% assessment that the doctoral research experience was "excellent" or "good," leads us to infer that these respondents felt their doctoral education had prepared them to be effective in their current jobs. (It is also interesting to note that the item rated highest by the respondents in the list of possible ways that a doctoral education could be useful was "It led me to more analytical and critical thinking.") Overall, it would appear that obtaining the Ph.D. in nuclear science had provided the necessary skills for these graduates to find suitable employment.

As far as we can tell, all the respondents were employed at the time of the survey. Nonetheless, three of the open-ended questions—the advice to beginning doctoral students, the recommendations they would offer to doctoral programs, and the question regarding additional incentives to increase the number of doctoral students in nuclear science—elicited a significant number of negative responses, owing to the respondents' perception of a poor job market for nuclear science Ph.D.'s.

Earlier in this chapter, Table 5-9 presented the current job titles for 80 of the respondents who reported being employed in BGN. Apart from the new category of jobs in finance, held by 10% of these respondents, the spectrum of current jobs in this table broadly represents the "traditional job market" for the last four decades for nuclear science Ph.D.'s who did not take jobs in academe or the national laboratories. We agree with the respondents who provided recommendations to the doctoral programs related to this issue of employment: Students need much better mentoring and much more assistance in career planning and guidance, particularly about careers in business, in government, and with nonprofit organizations. In addition, the physics and chemistry faculty should be honest and realistic about the state of the job market, particularly for graduate students just choosing their research specialty. It would be very valuable for departments to provide, for example, an annual meeting devoted to an analysis of what jobs their previous Ph.D.'s

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[22] This total of 75% who would get a Ph.D. again in the same field (physics or chemistry) is comparable to the results from the similar survey that 79% of the electrical engineers or mathematicians would again get Ph.D.'s in their respective fields.

[23] Eleven theorists were in tenured or tenure-track positions, 5 were researchers at national laboratories, and 18 were in BGN.

held five years after graduation, as well as to have a seminar every fourth semester or so, in which outside speakers discuss how they view their careers in BGN or in non–basic research positions in the national laboratories.

References

COSEPUP: "Reshaping the Graduate Education of Scientists and Engineers," Committee on Science, Engineering, and Public Policy, National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, National Academy Press (Washington, DC, 1995).

Czujko: Roman Czujko, in "Scientists and Engineers for the New Millennium: Renewing the Human Resource," Daryl F. Chubin and Willie Pearson, Jr., Eds., a collection of the Commission on Professionals in Science and Technology, March 2001, p. 23.

Nerad and Cerny: Maresi Nerad and Joseph Cerny, "Postdoctoral Patterns, Career Advancement and Problems," *Science* **285**, 1533 (1999).

Sui: Judi Sui, Graduate Division, University of California, Berkeley, CA, private communication, 2003.

Triggle and Miller: David J. Triggle and Kenneth W. Miller, "Doctoral Education: Another Tragedy of the Commons?" *J. Pharm. Ed.* **66**, 287 (2002).

Welch: Vince Welch, National Opinion Research Center, University of Chicago, Chicago, IL, private communication, 2004. Results from a special data run from the SED files.

6. Enhancing Graduate and Postdoctoral Education

Introduction

The purpose of graduate student and postdoctoral education is to prepare and enable these early-career scholars to participate in forefront basic research in all areas of nuclear science, both experimental and theoretical. At the same time, the community has a shared responsibility to provide a supportive climate for students and postdocs, and to prepare these apprentice scholars for careers beyond their current positions. Such careers might include not only opportunities to build on the basic research these scientists pursued as graduate students or postdocs, or to teach at colleges and universities, but also positions that rely on their knowledge and the tools of nuclear science in solving important problems in homeland and national security, nuclear medicine, energy, applied nuclear technology, and accelerator science.

The main goal in graduate education in nuclear science is to provide the general background in physics or chemistry and the enhanced knowledge in nuclear science that will enable graduate students to pursue research in a specific subfield, using theoretical or experimental tools. To be successful, graduate students must develop the ability to solve complex problems and must have the tools to work on all aspects of a specific problem, in particular, their dissertation project. Most need computational skills, and many, especially experimentalists, develop a multitude of hardware skills, including facility with electronics, detector operations and development, and often accelerator operations. To be effective as scientists and in all of their possible career paths, graduate students need to develop both oral and written communication skills.

However, there are challenges in graduate education that need to be addressed. Central to these concerns is the need to provide the training for graduate students that will prepare them for the full spectrum of career opportunities available to them.

Graduate and Postdoctoral Education in Nuclear Science

The challenges

The first challenge is to ensure that nuclear scientists are prepared for careers in basic research. A recent NSAC report [NSAC 2003] looked at our current system of preparing the next generation of nuclear theorists and proposed opportunities at Centers of Excellence and Topical Study Centers to supplement the training of these students, who are traditionally trained at a single university. There are also challenges for experimentalists who are members of large collaborations, yet who need to be trained broadly in hardware and software techniques, as well as the fundamental science questions they are helping to answer. Furthermore, all students and postdocs need guidance in developing scientific leadership skills, as well as the communication skills they will need if they are to disseminate their research results effectively.

Second, we must also ensure that nuclear scientists are prepared for careers in education, since they will become the educators of future generations of scientists—in particular, nuclear scientists. Most of the positions in physics and chemistry education are outside the major research universities. But even research universities demand faculty members who are talented, dedicated instructors, prepared to teach physics or chemistry to a broad spectrum of students and to excite them about career opportunities in science.

A third challenge is to provide graduate students and postdocs with the background and tools they need to tackle and solve the important problems in related areas, from homeland and national security to accelerator science.

And finally is the challenge of outreach, a challenge that overlaps broadly with the messages of other chapters in this report. We must do more to attract students, including women and members of traditionally underrepresented groups, to the excitement of nuclear science research, and to prepare them for careers in higher education and basic and applied research. While about 3,800 bachelor's degrees in physics were awarded in the U.S. in 1995, only about 50 nuclear science Ph.D.'s per year were awarded to U.S. citizens in 2000–2002, a reflection of the challenge the community faces in attracting high school students and undergraduates to the field.

To address these challenges will require a shared commitment by the entire community of nuclear scientists. With over 40% of recent Ph.D.'s having done at least some of their research away from their home university, and with over 25% having spent at least three months off campus (see Chapter 5), the responsibility for graduate education extends beyond the home university to the national laboratories, the funding agencies, and the professional societies.

The current situation

Table 6-1 (from our *Ph.D.'s 5–10 Years Later* survey) breaks down the current positions of U.S. nuclear scientists five to ten years after their Ph.D. degrees and thus reflects the actual careers of today's nuclear scientists. In this cohort of recent

Table 6-1. Current job titles of nuclear scientists five to ten years after receiving Ph.D.'s.

	Experimentalists N = 178*		**Theorists N = 44***	
	N	**%**	**N**	**%**
Tenured and tenure-track faculty	46	26	11	25
Non-tenure-track faculty	8	4	7	16
National laboratory researcher	44	25	7	16
Other academic or national lab position	15	8	1	2
Business, govt, or nonprofit position	65	37	18	41

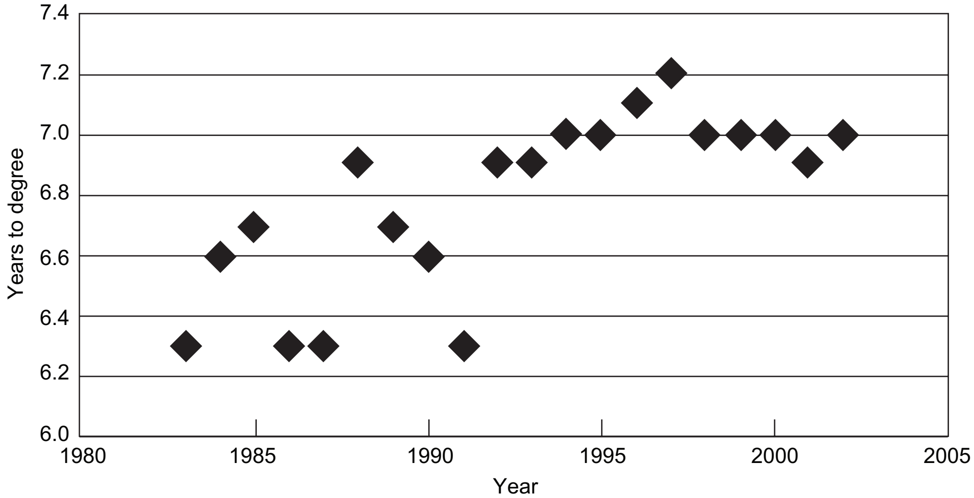
*Some of the 251 survey respondents did not provide current job titles.

Ph.D.'s, 37% of the experimentalists and 41% of the theorists hold positions outside basic research and higher education, a pattern that has characterized nuclear science for decades. While these recent Ph.D.'s feel overwhelmingly (83%) that their current job is related to their doctoral education, 46% feel that their current job is not in nuclear science or a related field. Only about 60% of theorists and 75% of experimentalists have careers that match the aspirations they held as they were leaving graduate school. In this context, the results of our graduate student and postdoctoral fellow surveys (Chapters 3 and 4, respectively) are especially notable: Most current graduate students and 85% of postdocs aspire to positions at colleges or universities and/or positions in basic research. And fewer than one-third of current postdocs feel they are getting useful career development training. These data underscore the need to prepare current graduate students and postdocs for realistic, yet challenging, career opportunities.

There are also concerns, shared by scientists and leaders in graduate education, that the time between entering graduate school and being recognized as an independent scientist is generally too long. This long time to independence also characterizes the nuclear science community. Figure 6-1 presents the median registered time to the Ph.D., from entry into graduate school to receipt of the Ph.D., for nuclear physics and nuclear chemistry combined. For the latest five-year period for which data are available (1998–2002), the median is seven years. Figure 6-2 shows the percentage distribution of this time to degree for these doctoral recipients.

In addition, 70% of recent Ph.D.'s took at least one postdoctoral position; the mean time that these individuals spent as postdocs was 3.3 years. Therefore, the respondents in our Ph.D.'s 5–10 Years Later survey spent over ten years between entry into graduate school and potentially permanent positions. Current postdocs are in their early 30s, most (72%) are in committed relationships, and many (31%) are starting to have families.

Figure 6-1. Median registered time to degree for nuclear science Ph.D. recipients.



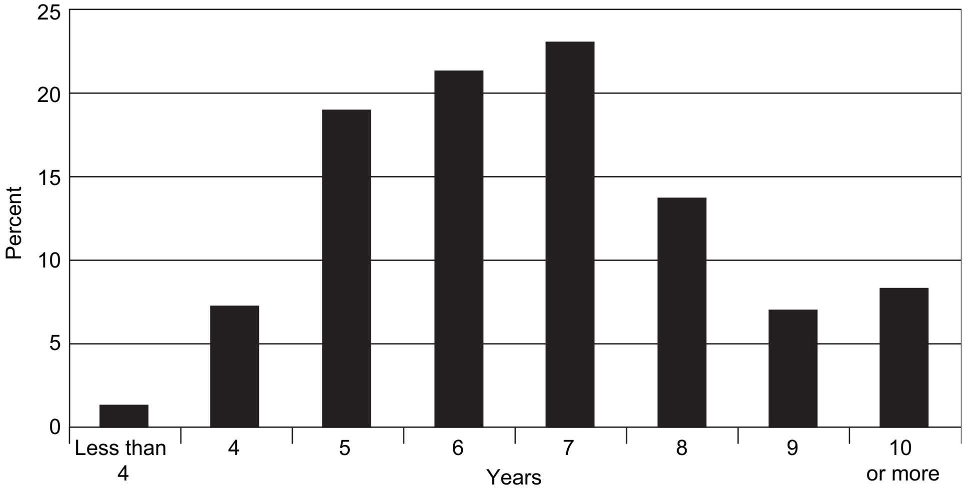


Figure 6-2. Percentage distribution of time to degree for nuclear science Ph.D. recipients, 1998–2002.

National concerns

In 1995 the Committee on Science, Engineering, and Public Policy (COSEPUP) of the National Academies recommended actions that could serve to revitalize doctoral programs for scientists and engineers [COSEPUP 1995]. Many of these recommendations remain vital and address ongoing concerns in nuclear science graduate education. The primary recommendation of this report was to "offer a broader range of academic options," to take into account the reality that many career opportunities for Ph.D.'s are outside the academy and basic research.

In addition, the COSEPUP report recognized that the time to degree (and the time to first employment) should be controlled, recognizing that it was too long, even in 1995. While the report emphasized that excellence in research must be maintained, it noted that "the primary objective of graduate education is the education of students." As the report stated: "The value of such activities as working as highly specialized research assistants on faculty research projects and as teaching assistants should be judged according to the extent to which they contribute to a student's education. . . . Each institution is urged to set its own standards for time to degree and to enforce them." Similar concerns have been raised by professional societies. In 1995 the chairs of physics departments across the U.S. met at a workshop jointly hosted by the American Physical Society (APS) and the American Association of Physics Teachers (AAPT). One of their recommendations was that "departments should make vigorous efforts to decrease the time to completion of a Ph.D., which . . . has risen by an average of 2.5 years over the past 30 years" [APS/AAPT]. In particular, these leaders in physics education recommended that "funding agencies should consider various means of encouraging timely completion of degrees."

In 2000, another COSEPUP report outlined principles that should guide the postdoctoral experience and recommended ten action points. These action points included the following [COSEPUP 2000]:

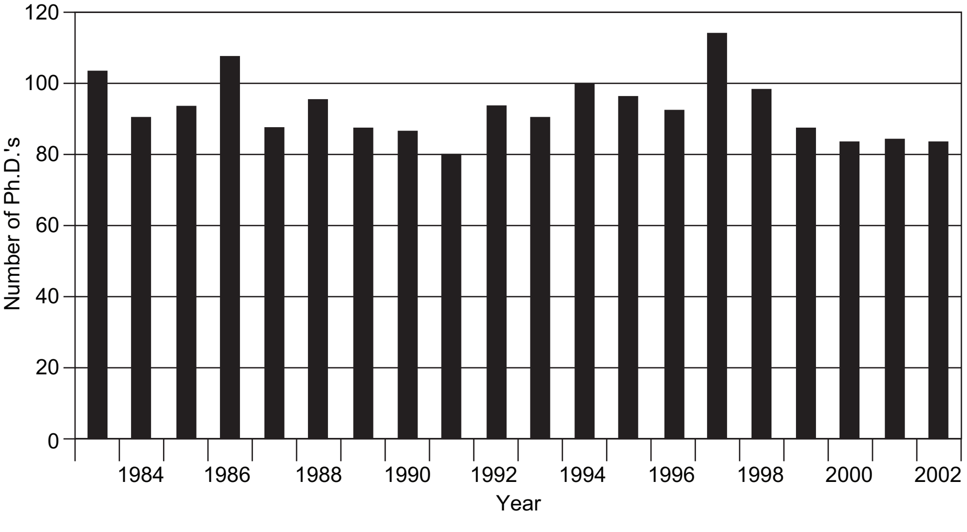
- Set limits for total time of a postdoc appointment (of approximately five years, summing time at all institutions), with clearly described exceptions as appropriate.

- Provide substantive career guidance to improve postdocs' ability to prepare for regular employment.
- Improve the quality of data . . . for the population of postdocs in relation to employment prospects in research.
- Take steps to improve the transition of postdocs to regular career positions.

The Association of American Universities (AAU), representing the leading research universities in the U.S. and Canada, presented similar recommendations in 1998 [AAU]. A recent article that presents a broad perspective on current issues in graduate education also points to "increasingly prolonged postdoctoral positions" [Triggle and Miller].

Another issue is training sufficient numbers of graduate students to meet the needs of the nation for trained nuclear scientists, especially outside basic research and education. Figure 6-3 shows the number of Ph.D.'s awarded in nuclear physics and nuclear chemistry between 1983 and 2002 [SED 2002]. In the last three years, only 83–84 Ph.D.'s were granted in nuclear science. As summarized in Chapter 1, concerns have been expressed that the U.S. is not producing a sufficient number of Ph.D.'s in highly technical areas, including nuclear science, to meet the nation's needs. In particular, there has been considerable interest in the need to train more nuclear chemists and engineers [NERAC]. These concerns point to the need for a modest increase in the production of nuclear science Ph.D.'s, with the aim of returning it to the levels of the early 1990s. Increasing the number of U.S.-citizen nuclear science Ph.D.'s will require interventions in the college years to encourage more undergraduates to pursue research and advanced studies in nuclear science. It will also require that nuclear scientists convey the vitality of their field and a sense of the exciting opportunities for forefront research to a larger number of graduate students in physics and chemistry, and to faculty members in these departments at research universities.

Figure 6-3. Number of nuclear science Ph.D.'s awarded, 1983–2002.



Possible Solutions: National Initiatives in Graduate and Postdoctoral Education

Our surveys indicate a largely satisfied population of students and young nuclear scientists. Opportunities to participate in undergraduate research and conferences received high marks from participants and are paying dividends. Graduate students report their experiences in largely positive terms, and most postdocs would choose the same career paths if they had it to do over. Most respondents to the Ph.D.'s 5–10 Years Later survey similarly report satisfaction with their experiences and with the choices they made. Throughout the educational process, students appear to be gaining most of the skills essential to work successfully as nuclear scientists, educators, and contributors in related fields. Nonetheless, as we have indicated here, challenges remain. We point to some possible solutions below.

Attracting the best and the brightest

The key to attracting physics and chemistry students is to provide them with research opportunities early in their careers: academic-year or summer research opportunities as undergraduates; after their bachelor's degrees and before matriculating as graduate students; and in their first year of graduate studies, before they choose a research field and mentor.

The Nuclear Chemistry Summer School has been for many years a model for attracting undergraduates with strong backgrounds in chemistry and physics to consider research in nuclear chemistry. This intensive six- to eight-week program for talented juniors exposes the undergraduates to nuclear chemistry through classroom and laboratory experiences. Several current leaders in nuclear chemistry are graduates of these summer schools, underscoring their potential to attract capable undergraduates to our field.

The Research Experience for Undergraduates (REU) program, supported directly by the NSF, and the support of undergraduates by grants to individual NSF or DOE investigators have also proven to be highly successful ways to engage undergraduates in nuclear science research. The Conference Experience for Undergraduates (CEU) at the annual Division of Nuclear Physics meeting of the APS complements research exposure with a special opportunity for undergraduates to be introduced to the broader research community, the "nuclear family." However, only a small fraction of the undergraduates who participate in any of these research activities pursue graduate studies in nuclear science, often drifting into other subfields of physics or chemistry for their advanced degrees. A coordinated effort to retain these undergraduates in nuclear science is needed if we are to realize the goal of increasing by about 20% the number of U.S. Ph.D.'s awarded annually in nuclear science.

One way to attract the most talented graduate students is by recruiting them with fellowship support—support that is especially critical in the first years of graduate study. In general, graduate students in their first year of study should have the freedom to focus on their coursework and begin to explore research interests, without needing to teach in the classroom or be restricted to a specific research project of a faculty supervisor. The NSF has a long tradition of providing such prestigious support: Graduate Research Fellows receive three years of support, with generous stipends and a cost of education allowance. Only a small fraction (about 15% in recent years) of NSF awards go to graduate students in physics or chemistry; most go to life sciences or engineering students [Chang and Freeman]. No recent NSF awards have gone to students in nuclear science. A similar fellowship program sponsored by the Office of Science (the DOE currently has no such program) would help attract the most talented graduate students for studies in the physical sciences, allowing them the flexibility in their first year of study to explore research opportunities and, in particular, the forefront opportunities in nuclear science. Such a fellowship program in the areas of physical science critical to the DOE's mission was recommended by the Secretary of Energy Advisory Board in 2003 [SEAB].

An alternate route to enhance the visibility of nuclear science is to develop highly selective postdoctoral fellowships. This is a successful model, as demonstrated in astrophysics, where Hubble Fellowships (*http://www.stsci.edu/stsci/hubblefellow.html*), in particular, are recognized by students and faculty in many of the physical sciences, not only in astronomy and astrophysics. A prestigious postdoctoral fellowship program would help attract the best and the brightest of graduate students to studies in nuclear science, retain them as highly visible postdoctoral scholars, and enhance their attractiveness as they prepare for faculty positions at top universities and colleges, or for leadership positions in our national laboratories. Developing such prestigious postdoctoral positions was endorsed by NSAC as one of its nuclear theory report recommendations in 2003 [NSAC 2003].

Reducing the time to the first job

The National Academies [COSEPUP 1995, 2000], leading research universities [AAU], and professional societies [e.g., APS/AAPT] have been leaders in calling for shortening the time to a Ph.D. degree and reducing the time spent in postdoctoral positions.

Best practices in graduate education show that getting graduate students engaged in research early in their careers and vigorously reviewing progress, at least annually, are keys to shortening time to degree. Chemistry Ph.D. students usually spend about one year on coursework, often participating in rotations through research groups during that first year. Therefore, by the first summer, chemistry students are participating in research that builds towards a dissertation. By coupling this with rigorous annual reviews, a nominal five-year Ph.D. program is readily attainable. Physics graduate students often spend one and a half to two years taking courses. Still, they can start to participate in research during their first summer, and with rigorous annual reviews, the time to degree can be reduced by a full year [Cizewski].

Following the COSEPUP recommendations [COSEPUP 2000], as well as those of a special committee of the AAU, institutions across the U.S. are limiting the total time for postdoctoral appointments. The University of California system, for example, has implemented a policy that postdoctoral appointments be made for a period of up to three years, with reappointments permissible up to a total of five years, including time spent in postdoctoral status at other institutions [UC].

Preparing future faculty in nuclear science

Many faculty positions in physics and chemistry are outside the major research universities, in four-year colleges or universities that do not offer Ph.D.'s in physics and chemistry. Major research universities are also increasingly concerned about enhancing undergraduate education, bringing student-centered, collaborative learning into their classrooms and laboratories. Prestigious awards for junior faculty, such as the NSF CAREER awards, require an innovative teaching component in the proposal.

Preparing to be instructors should be part of the training of graduate students and postdocs, since a large fraction aspire to, and many attain, faculty positions. See *Paths to the Professoriate* for strategies aimed at enriching preparations for future faculty [Wulff and Austin]. While many graduate students spend a year (or more) as teaching assistants, colleges and universities are expecting that new faculty bring experience as lecturers or in other leadership roles in the classroom or laboratory. Many universities have established Preparing Future Faculty programs (*http://www.preparing-faculty.org*) that combine training as future faculty members with service as instructors outside the traditional university classroom or laboratory (e.g., working in small or community colleges or working with students at risk). It is appropriate for research mentors to encourage graduate students and postdocs to obtain and enhance teaching experiences, recognizing that careers in higher education, broadly defined, are realistic aspirations.

Preparing students for a broad range of careers

The surveys of current graduate students, postdocs, and nuclear scientists five to ten years after their Ph.D.'s all point to the mismatch between career aspirations and realistic careers for many of our early-career nuclear scientists. Many national studies, such as those by COSEPUP, reinforce the need for shared responsibilities in providing realistic career advice, together with the tools to be successful in a broad range of careers:

- Graduate students and postdocs should become aware of the broad range of career opportunities and develop the skills they need to be successful.
- Faculty and research mentors should themselves become more supportive of and familiar with career options and the skills graduate students and postdocs need to become successful.
- Professional societies can help by communicating trends in careers and the skills needed for success.
- Funding agencies should require placement reporting to help ensure that investigators recognize their responsibility for career mentoring and that they are aware of the range of careers pursued by their former students and postdocs.

Training grants that broadly prepare graduate students for research are one way to attract and support the most talented graduate students, and to prepare them for interdisciplinary and applied research. This model is extensively employed in the life sciences, supported by the National Institutes of Health (NIH). Likewise, in recent years, the NSF has supported the Integrative Graduate Education and Research Traineeship (IGERT) program of training grants (*www.nsf.gov/home/crssprgm/igert/start.htm*). These are highly competitive grants, with none to date awarded in nuclear science. However, there is a great need to train nuclear scientists, especially to meet the challenges in applied science that serve the missions of the DOE. In 2003, SEAB also recommended that training grant projects, especially in nuclear science, be initiated to meet these needs [SEAB]. Such projects would help train nuclear scientists to meet applied needs, rather than focusing on basic research in nuclear science. Therefore, we recognize that it may not be appropriate that funding for such training grants come from the basic science divisions, including the Office of Nuclear Physics within the DOE.

Enhancing diversity in nuclear science

Ethnic minorities and women are not well represented in the nuclear science community. This deprives the community of significant intellectual capacity, as well as limiting the breadth of experiences among those active in the field. The lack of full participation by women and minorities is not an issue for nuclear science alone, as discussed in detail in Chapter 7.

The NIH, through the Minority Opportunities in Research (MORE) program of the National Institute of General Medical Sciences (*http://www.nigms.nih.gov/minority/*), has a long tradition of programs to recruit and retain underrepresented minorities in the research efforts of the biomedical sciences. The NIH supports scholarships for minority undergraduates and fellowships for minority graduate students. It also supports “pipeline” projects that provide a continuum of opportunities to attract, educate, and retain underrepresented minorities in the research enterprise. This continuum often starts with summer research programs for undergraduates that provide stipends, housing, and travel expenses for eight- to ten-week experiences. The undergraduates participate in forefront research, and regular academic enrichment activities include guidance on how to prepare for Graduate Record Examinations, write a personal statement, and develop more effective presentation skills.

In addition, the NIH has developed two programs to smooth the transition from undergraduate experiences to full-time graduate studies. The first is a “bridge” program in which students with weaker undergraduate science backgrounds participate in a research-based M.S. degree program and a two- to three-year transition to a Ph.D. program. Students in bridge programs often spend one or two years in residence during the academic year at a university that does not grant Ph.D.’s in the sciences, taking advanced undergraduate or graduate courses (external bridge program). They do research at a research university during the summers and, by the second or third year, are fully engaged (at the level of a first-year Ph.D. student) in coursework and research at the research university. Upon satisfactory completion of qualifying examinations, they are automatically enrolled in the Ph.D. program. Alternatively, students can enroll in an internal bridge program, where M.S. degree studies are conducted at the research university.

The second transitional program is a postbaccalaureate experience in a laboratory environment. Before applying to a Ph.D. program, recent graduates work in a laboratory, usually supported as a technician, for one or two years while taking advanced undergraduate or graduate courses.

The NSF also has a tradition of programs to enhance the opportunities in science for members of underrepresented groups, including women (*www.ehr.nsf.gov/*). The more recent program is the Alliance for Graduate Education and the Professoriate (AGEP), in which consortia of both research-intensive and minority-serving universities partner in mentoring and preparing underrepresented minorities for academic careers in the sciences, math, and engineering. Each consortium proposes its own interventions to recruit, educate, and retain these early-career scientists on the path toward academic careers. Many of these consortia have undergraduate research programs, complemented by efforts to recruit and retain graduate students. Some consortia also include postdoctoral scholars, providing them with research opportunities at prominent universities and enhancing their preparation for careers in the academy.

Both the NSF and the NIH sponsor research opportunities directed at minority-serving institutions to complement the above programs, which are usually focused at majority-serving universities.

Several other consortia are dedicated to enhancing the participation of underrepresented minorities and women in the physical sciences, complementing activities supported by the NIH and the NSF. The National Physical Science Consortium (NPSC), for example, provides up to six years of fellowship support for women and underrepresented minorities studying in the physical sciences, biochemistry, and computer science (*http://www.npsc.org/*). Similarly, the Consortium for Graduate Degrees for Minorities in Engineering (GEM) provides fellowships for master's degree studies in engineering, and Ph.D. studies in engineering and the natural and physical sciences (*http://was.nd.edu/gem/gemwebapp/gem_00_000.htm*). In both programs, students have the opportunity to conduct research in academic, national, and industrial laboratories. Among laboratories with a nuclear science component, sponsors of the NPSC include Los Alamos and Lawrence Livermore national laboratories; sponsors of GEM include Argonne, Brookhaven, Los Alamos, and Oak Ridge national laboratories, Fermi National Accelerator Laboratory, and the Stanford Linear Accelerator Center. The Ronald E. McNair Post-Baccalaureate Achievement Program, funded by the Department of Education, provides research support and academic enrichment programs for undergraduates from disadvantaged backgrounds (*http://www.ed.gov/programs/triomcnair/index.html*). Eligible applicants are first-generation college students or students from ethnic minorities. The goal is to increase the participation of students from disadvantaged backgrounds in graduate education and to enhance their success in obtaining Ph.D. degrees.

Conclusions and Recommendations

The median registered time from entry into graduate school to a Ph.D. in nuclear physics or nuclear chemistry has been seven years over the last five reporting periods (1998–2002). Then, 70% of the Ph.D.'s take one or more (almost mandatory) postdoctoral positions lasting an average of 3.3 years. Therefore, ten-plus years pass before the "typical" nuclear science Ph.D. has a first job. This is too long. Not only can it deter career-minded students who might instead choose to pursue a different advanced degree, but it also deprives the U.S. of the independent intellectual contributions of these accomplished young scientists during a creative time of their lives. We believe that the time to the Ph.D. should be shortened to five and a half or six years

We also recognize the value and importance of the postdoctoral experience for many newly minted Ph.D.'s. However, we urge principal investigators to evaluate the total time being spent by their postdocs during this stage of their careers and to make sure that these individuals are receiving the training they need to enhance their subsequent career prospects.

As a first step toward reducing the overall time to the first job,

We recommend that the nuclear science community assume greater responsibility for shortening the median time to the Ph.D. degree.

The following activities should be among those considered to realize this goal:

- Nuclear science faculty should conscientiously monitor the progress of their graduate students toward the Ph.D. degree.
- Recognizing that a high-quality Ph.D. program contains, in addition to research, various scholarly components such as coursework, qualifying examinations, and in some cases serving as a teaching assistant, nuclear science faculty should work with their departmental colleagues to optimize these components for their students' education. In doing this, individual graduate students' needs and goals should be taken into account.
- Nuclear science faculty should identify new ways to engage graduate students in research early in their graduate careers.
- The funding agencies should be apprised of graduate students' progress in their research and toward their degrees, and work to help faculty toward the goal of optimizing the educational experience and reducing the time to completion of the Ph.D. degree. Monitoring the placement of graduate students after their Ph.D. work, as well as the attrition of those who do not finish, will also provide important data to improve overall graduate student education.

In recent years there has been a tremendous increase in the number of graduate students in the life sciences, while the number of talented students in the physical sciences has not increased, even though the scientific challenges are great and the need for scientists in the physical sciences continues to grow. The consequent need to increase the number of young Americans pursuing careers in the physical sciences and engineering was explicitly underscored in the Secretary of Energy Advisory Board's 2003 report, which recommended new undergraduate, graduate, and postdoctoral fellowship programs [SEAB].

We strongly endorse the Secretary of Energy Advisory Board's 2003 recommendation that new, prestigious graduate student fellowships be developed by the Office of Science in the areas of physical sciences, including nuclear science, that are critical to the missions of the DOE.

We also strongly endorse the accompanying recommendation that new training grant opportunities in nuclear science be established.

Prestigious fellowships would serve to attract the brightest graduate students for study in the physical sciences, including nuclear science, in areas critical to the missions of the DOE, providing them with the flexibility to prepare for research in their subfield of choice. The training grants in nuclear science could, in particular, prepare undergraduate and graduate students and postdoctoral scholars for careers at the DOE and at DOE-supported national laboratories that require expertise in nuclear science and its applications.

There are relatively few ways in which nuclear scientists early in their careers are recognized for their accomplishments and potential, and even fewer ways in which this recognition extends beyond the nuclear science community. Prestigious postdoctoral awards in other physical sciences have served to meet both of these challenges. With similar postdoctoral fellowships in nuclear science, the visibility of nuclear science would be enhanced, encouraging undergraduate and graduate students to pursue such studies, and colleges and universities would be able to identify the top candidates for faculty positions.

The establishment of prestigious postdoctoral positions would also support a recommendation of the NSAC theory subcommittee [NSAC 2003].

We recommend that prestigious postdoctoral fellowships in nuclear science be established, with funding from the NSF and the DOE.

We recognize that the funding agencies will ultimately define the logistics to realize these prestigious opportunities. A reasonable approach to implementing this recommendation might be 12 two-year fellowships. In this approach, six of these fellowships would be awarded annually, typically with three each to theorists and experimentalists. Eligible applicants would have no more than two years of previous postdoctoral experience. At least initially, preference would be given to applicants with Ph.D.'s from U.S. universities. Compensation would be significantly above the standard stipend in nuclear science and would include an institutional payment to provide health benefits and a research account to provide some research independence for the recipient. The fellows could use their awards at any U.S. university or national laboratory; however, an effort should be made to limit the number of these prestigious scholars at a single host institution.

The mechanism for nomination of candidates for prestigious graduate student and postdoctoral fellowships should encourage the participation of both men and women of all ethnic backgrounds.

References

AAU: Association of American Universities, Postdoctoral Education Committee Report, May 1998 (*http://www.aau.edu/reports/PostDocRpt.html*).

APS/AAPT: "Physics 1995: Physics Graduate Education for Diverse Career Options," Workshop for Physics Department Chairs, APS and AAPT (*http://www.aps.org/jobs/dcc/conf95/index.cfm*).

Chang and Freeman: T. Chang and R. Freeman, presentation at NSF workshop, "Understanding the Impact of Policies Governing the Support of Graduate Student and Postdoctorate Education and Training in the Sciences and Engineering," June 2004.

Cizewski: J. A. Cizewski, "Mentoring Graduate Students in Physics and Astronomy at Rutgers University," *Bull. Am. Phys. Soc.*, April 2002.

COSEPUP 1995: "Reshaping the Graduate Education of Scientists and Engineers," Committee on Science, Engineering, and Public Policy, National Academy of Sciences, National Academy of Engineering, and Institute of Medicine (National Academy Press, Washington, DC, 1995).

COSEPUP 2000: "Enhancing the Postdoctoral Experience for Scientists and Engineers: A Guide for Postdoctoral Scholars, Advisers, Institutions, Funding Organizations, and Disciplinary Societies," Committee on Science, Engineering, and Public Policy, National Academy of Sciences, National Academy of Engineering, and Institute of Medicine (National Academy Press, Washington, DC, 2000).

NERAC: "The Future of Nuclear Engineering Programs and University Research and Training Factors," Nuclear Energy Research Advisory Committee, Task Force report (2000).

NSAC 2003: "A Vision for Nuclear Theory," NSAC Report, October 2003.

NSF 2002: National Science Foundation, "Survey of Earned Doctorates," 2002.

SEAB: "Critical Choices: Science, Energy, and Security," Final Report of the Secretary of Energy Advisory Board's Task Force on the Future of Science Programs at the Department of Energy, accepted by the Board in 2003.

SED 2002: T. B. Hoffer et al., "Doctorate Recipients from United States Universities, Summary Report 2002: Survey of Earned Doctorates" (National Opinion Research Center, Chicago, 2002).

Triggle and Miller: D. J. Triggle and K. W. Miller, “Doctoral Education: Another Tragedy of the Commons?” *J. Pharm. Ed*. **66**, 287 (2002).

UC: “Postdoctoral Education at the University of California.” report of the UC Council of Graduate Deans (*http://ogsr.ucsd.edu/reports/postdoc_report/intro.htm*).

Wulff and Austin: Donald H. Wulff and Ann E. Austin, *Paths to the Professoriate*, Jossey-Bass Higher and Adult Education Series (John Wiley, San Francisco, 2004).

7. Moving toward a More Diverse Workforce

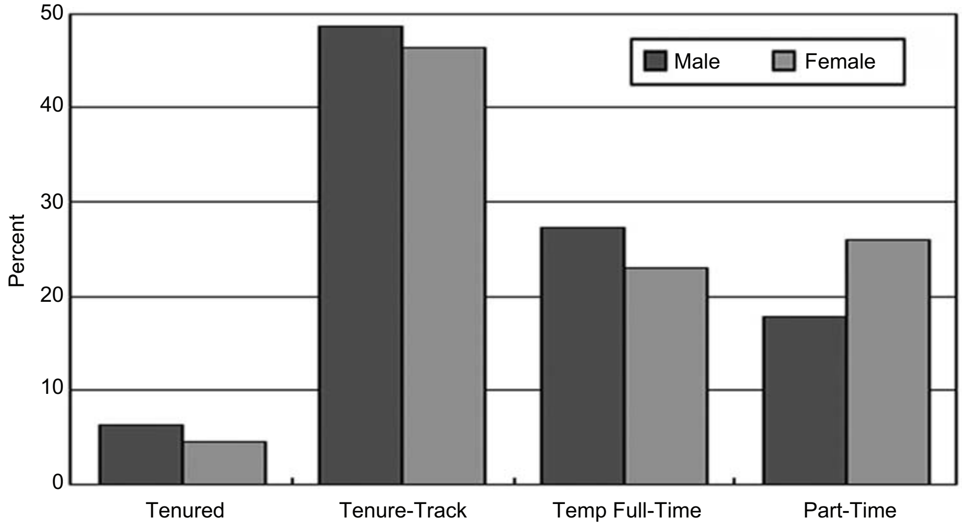
Introduction and Overview

Ethnic minorities and women are not well represented in the nuclear science community. This deprives the field of significant intellectual capacity, as well as limiting the breadth of experiences among those active in the field. The lack of full participation by women and minorities is not an issue for nuclear science alone. The need to increase the participation of these groups in the sciences generally and in engineering has been well documented [Thom, Long, NSF 03-312]. The participation of women in the sciences is increasing, but not uniformly across all disciplines. Recent increases in the number of women getting Ph.D.'s in the biological sciences have not been matched by advances for women in the physical sciences. Even among the physical sciences, the inclusion rates are not equal [SED 2000]. Despite some advances in the numbers of women with Ph.D.'s, women and ethnic minorities remain poorly represented among faculty. In 2002, as shown in Table 7-1, only 10% of the faculty in physics departments were women [AIP 2002]. Moreover, the representation of women at the full professor rank and at Ph.D.-granting universities is small. Figure 7-1 shows that many of the women who are getting academic jobs are getting them at smaller institutions, in non-tenure-track positions, and in part-time positions [AIP 2002]. The situation for underrepresented ethnic minorities is much worse. The percentage of Hispanic and African American faculty in physics departments was 2.0% and 1.8%, respectively, in 2000; see Table 7-2 [AIP 2000]. In this regard, physics departments lag behind the general academic community.

Table 7-1. Percentage of faculty positions in physics held by women in 1994, 1998, and 2002.

	1994 Percent	1998 Percent	2002 Percent
Academic Rank			
Full Professor	3	3	5
Associate Professor	8	10	11
Assistant Professor	12	17	16
Other Ranks	8	13	15
Type of Department			
Ph.D.	5	6	7
Master's	7	9	13
Bachelor's	7	11	14
Overall	6	8	10

Figure 7-1. Employment status of male and female new physics faculty in 2002.



This lack of representation of women and minorities among the faculty is often viewed as a pipeline issue. This, in turn, is often used as an excuse for us in higher education to say that we inherited the problem, absolving us of any responsibility to fix it. While total parity does not exist in math and science education at the elementary, middle, and high school levels, the pipeline becomes further clogged beyond high school graduation: during the undergraduate years, in graduate school, at the postdoctoral level, and in finding permanent full-time employment. Addressing the issues at these levels is certainly the nuclear science community's responsibility.

Table 7-2. Race and ethnicity of physics faculty in 1996 and 2000, as compared with all disciplines in 1995.

	Physics		**All Disciplines**
	1996	**2000**	**1995**
African American	1.5	1.8	5.0
Asian	10.1	9.9	5.1
Hispanic	1.4	2.0	2.4
White	85.3	84.2	86.7
Other	1.8	2.0	0.8

Assessing the Pipeline Issue

The high school picture

Over the past decade, the number of students taking physics in high school has increased dramatically, producing an increase in the number of bachelor's degrees awarded [Mulvey and Nicholson]. Concurrently with the increase in students taking high school physics, there has been an increase in the participation of women and minorities [Neuschatz and McFarling]. In 2001, 22% of African American high school graduates and 21% of Hispanic students had taken physics, compared with 33% of white students and 47% of Asian students. As shown in Figure 7-2, these numbers represent at least a 10% increase for each of these groups since 1990 [Neuschatz and McFarling]. These increases are encouraging, particularly when we consider the low number of ethnic minority high school physics teachers (only about 4% in 1997) who can serve as role models. Nonetheless, continued increases in the number of minority students who are taking high school physics courses and higher-level mathematics courses (precalculus and calculus) are critical to increasing the diversity in the physics community. The outreach center proposed in Chapter 8 should be charged with running outreach programs that inspire and encourage minority students to consider physics as a possible career choice and that provide early guidance on how they should prepare themselves academically for such a career. At the same time, as shown in Figure 7-3, the participation of women in high school physics classes has increased to a point near parity. In summary, although work remains to be done at the high school level, these numbers point clearly to obstructions in the pipeline further along.

Beyond high school

As an example of these obstructions, we note that, although for the past decade the percentage of women in high school physics has been over 40% (see Figure 7-3),

Figure 7-2. Percentage of high school graduates who took physics, by ethnic category.

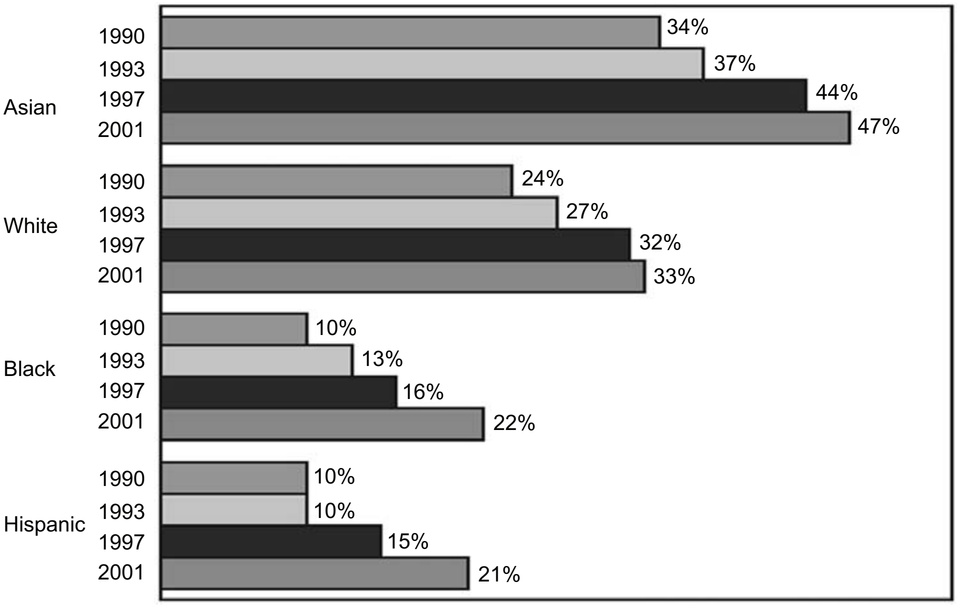
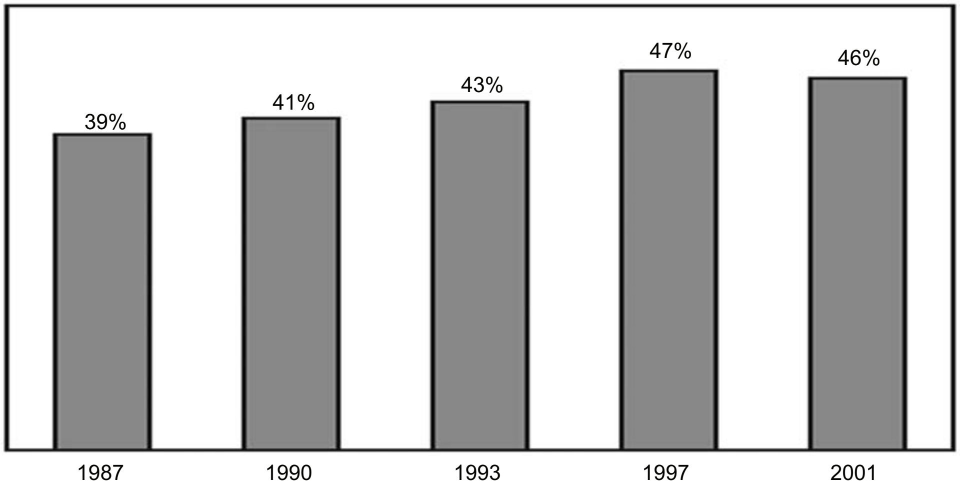
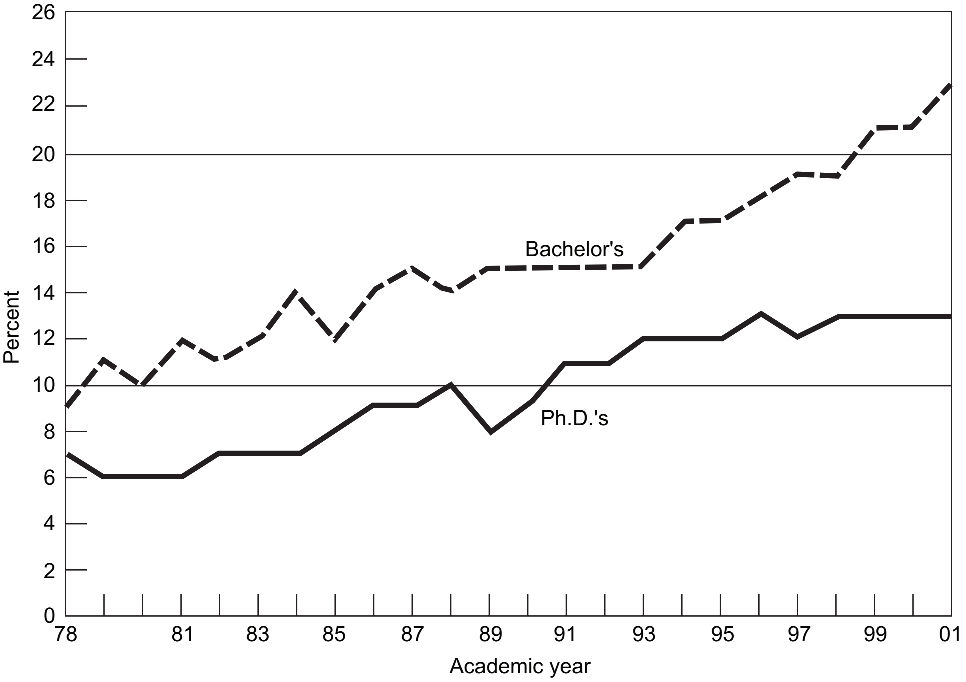


Figure 7-3. Percentage of female students enrolled in high school physics, 1987–2001.



the percentage of physics bachelor's degrees awarded to women is still much lower than that, as shown in Figure 7-4 [Mulvey and Nicholson]. The percentage of degrees awarded to women has steadily increased since the late 1970s, but the near-parity that we see in high school physics has disappeared at the undergraduate level. In Figure 7-4, we see yet another twofold drop in the percentage of degrees awarded to women in physics, relative to men, when we look at Ph.D.'s. This increasing disparity clearly indicates something about the environment in our universities that is not conducive to women in physics.

Figure 7-4. Percentage of bachelor's and Ph.D. degrees in physics awarded to women, 1978–2001. A form change occurred in 1994 resulting in a more accurate representation of women among physics bachelor's. Some of the increase in 1994 may be a result of that change.



From 1991 to 2002, 12.5% of the nuclear physics Ph.D.'s awarded went to women, while 16.8% of the nuclear chemistry Ph.D.'s went to women [SED 2000, 2002]. It is also interesting to note in Figure 7-5 the marked rise for women in the past two years (19.2% of all nuclear science Ph.D.'s), compared to the first ten years (13.1%) [data from SED 2000, 2002].

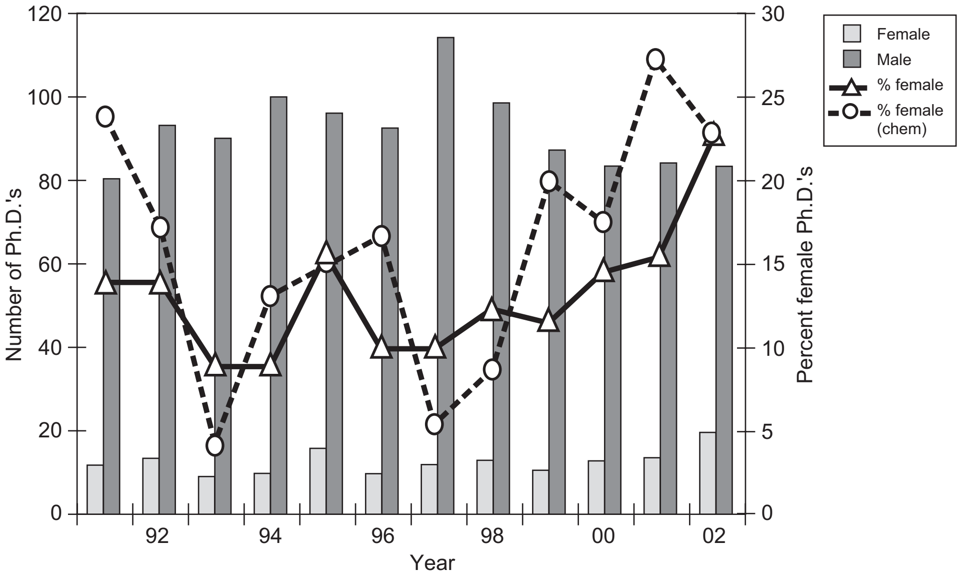


Figure 7-5. Number (bars) and percentage of Ph.D.'s awarded to women. The percentage of nuclear chemistry Ph.D.'s is calculated as a three-year moving average.

Unfortunately, as bleak as the numbers are for women, the situation for ethnic minorities is dramatically worse. As shown in Table 7-3, over 87% of all Ph.D.'s and bachelor's awarded to U.S. citizens are given to white students [Mulvey and Nicholson].

Table 7-3. Number and percentage of physics degrees granted to U.S. citizens of several ethnic groups in 2001.

	Bachelor's		Exiting Master's		Ph.D.'s	
	Number	Percent	Number	Percent	Number	Percent
African American	140	4	34	8	18	3
Hispanic	137	4	24	6	10	2
White	3344	87	344	82	527	88
Asian	148	4	18	4	37	6
Other	85	1	2		7	1
Total U.S. citizens	3854	100	422	100	599	100

The percentage of recent nuclear science Ph.D.'s in several minority groups who are either U.S. citizens or permanent residents is shown in Table 7-4, along with the corresponding numbers for all of physics and astronomy. Both physics as a whole and the subfield of nuclear science are doing poorly.

Table 7-4. Percentage of nuclear science Ph.D.'s by ethnicity, compared with the percentage for physics and astronomy as a whole.

	Percentage			
	Native American	Asian	African American	Hispanic
Nuclear Science (91–02)	0.3		1.3	1.3
Nuclear Science (00–02)		3.3		
Physics & Astronomy (00–02)	0.2	9.9	2.1	3.2

In summary, women take high school physics and upper-level mathematics courses at a rate rivaling that of men, yet they obtain only one-third as many bachelor's degrees in physics. Furthermore, women with bachelor's degrees in physics obtain Ph.D. degrees at a rate about 35% lower than men (see Figure 7-4; we assume a six-year lag between the bachelor's and the Ph.D.). With regard to minority ethnic groups, increases in the number of Ph.D. degrees in physics are slow in coming. However, there are some encouraging signs. For example, the percentage of minority students taking physics in high school has doubled in the last decade, and the number taking advanced math courses in high school is slowly increasing [NCES 00]. Still, only about 8% of minority students who receive bachelor's degrees in physics go on to obtain Ph.D.'s, as compared with about 16% for all physics students who are U.S. citizens [CPST 01]. Improving this situation will require sustained effort at all points in the pipeline. In particular, we see a clear need to significantly increase activities that encourage both women and ethnic minorities at the undergraduate level to pursue careers in physics.

In the physical sciences, the pathway to the professoriate typically includes not only a Ph.D., but also postdoctoral training [AIP 2000]. Therefore, if we are going to increase the 1.8% of physics faculty who are African American, we must also consider what happens during this crucial post-Ph.D. stage of their careers. The postdoctoral position is important not only for those who are going into academia, but also for those pursuing other careers. In fact, 56% of new physics Ph.D.'s take postdoctoral positions—often referred to as an "invisible" part of the scientific workforce [AIP IER].

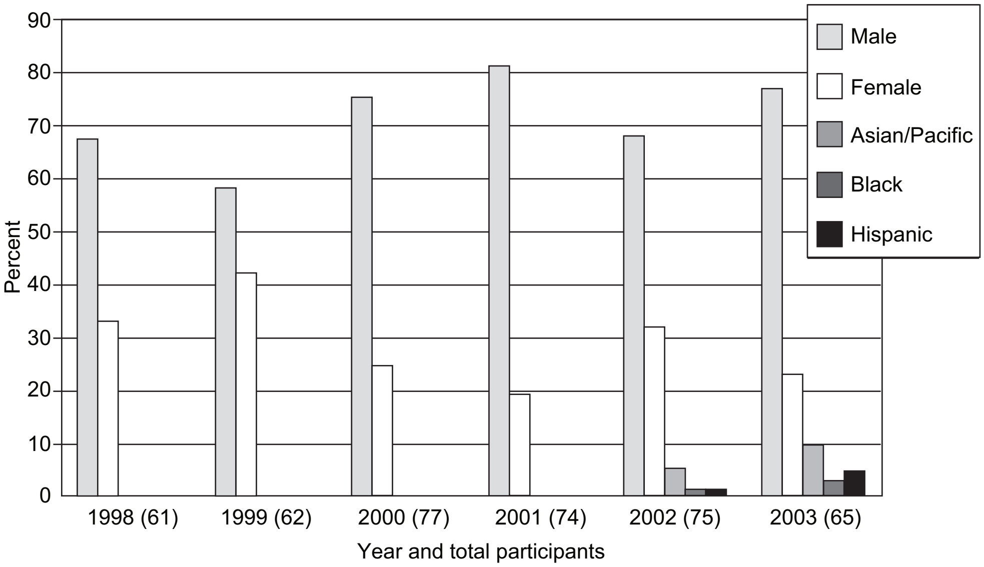
A More Detailed Picture

A more detailed diversity picture for nuclear science emerges, in part, from the surveys summarized in the earlier chapters of this report, in particular, the survey of participants in the Research Experience for Undergraduates (REU) program, the graduate student survey, the postdoc survey, and the survey of Ph.D.'s five to ten years after their degrees. One goal was a more comprehensive picture of the barriers to the inclusion of members of underrepresented groups in the field of nuclear science. However, the numbers of Hispanic, African American, and Native American respondents to our surveys were very small, so the data that can be reliably extracted are minimal. Therefore, in an attempt to understand the situation with respect to these populations, we augmented the survey data with previously published data from a broader cohort of individuals.

Survey demographics

The representation of women in our surveys mirrors the recent increase in the number of women getting Ph.D.'s. In the graduate student survey, the cohort was 20% female. (Twenty percent of the women who were U.S. citizens were chemists.) This value drops to 14% in the postdoctoral survey, and 12% for the Ph.D.'s five to ten years after their degrees. A bright spot in the data is that respondents to the REU student survey were 48% female. However, since this survey was administered by REU-site principal investigators and the number of respondents was a small fraction of the number of students in the program, this percentage may be biased by who responded to the survey. A more accurate view of the participation of underrepresented groups in undergraduate research—particularly in nuclear science—is provided by the Conference Experience for Undergraduates (CEU) program. Participation by women in the CEU program has recently averaged approximately 25%, but was as high as 40% in 1999. Figure 7-6 shows a breakdown by gender and ethnicity. Since, based on the graduate student survey, participation in undergraduate research is almost a prerequisite for graduate school, the high rate of female participants in the REU and CEU programs may translate into an increase in the numbers of female graduate students if they are presented with a welcoming and supportive climate.

Figure 7-6. Participation in the CEU program by gender and ethnicity.



One striking feature of Figure 7-6 is reinforced by the responses to our surveys: There are essentially no ethnic minorities among nuclear science graduate students and Ph.D. recipients who are U.S. citizens. In the graduate student survey, 95% of the U.S. citizens described themselves as white; the corresponding numbers for postdocs and Ph.D.'s five to ten years following their degrees were 93% and 90%, respectively. A more detailed breakdown is shown in Table 7-5.

Table 7-5. Ethnicity of survey respondents who were U.S. citizens.

	Graduate students		Postdocs		5-10 yr (Native Born**)	
	N	%	N	%	N	%
American Indian or Alaskan Native	0	0.0	2	3.0	1	0.6
Asian or Pacific Islander	7	3.3	3	4.5	2	1.2
Black	1	0.5	0	0.0	2	1.2
Chicano or Latino	0	0.0	0	0.0	1	0.6
White	205	95.3	62	92.5	145	90.1
Mixed race/ethnicity	2	0.9	0	0.0	10	6.2

**23 more individuals were naturalized citizens or held a green card at the time of their Ph.D.'s. Additionally, 24 more individuals had been naturalized or obtained a green card since their Ph.D.'s.

Interestingly, the average age of U.S. female nuclear science graduate students (about 26) is lower than either their U.S. male counterparts (27.5) or the average population (28). This is correlated with the fact that the percentage of U.S. females peaks at 31% in the third year of graduate school and drops to about 8% in the sixth and subsequent years.[1] This can be interpreted as showing either that more women are joining the program now (in which case we should see an increase in the number of female Ph.D.'s in the coming few years) or that more women are dropping out of the program after their third year. The distribution of year in graduate school for the whole cohort of respondents was roughly constant over years two through six.

For those graduate students who go on to be postdocs, the men are, on average, 0.4 years older than the women at the start of this stage of their careers. Thus, the age difference in the graduate student survey represented the year-in-school distribution more than any difference in time to degree. Indeed, the average time to degree for women, as reported for nuclear science in the Survey of Earned Doctorates for

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[1] These figures reflect the results for a relatively small sample, and the situation is markedly different for non-U.S. women. See Chapter 3.

1991–2001, was 6.82 years, and for men, 6.97 years [SED 2002]. The women who are succeeding in graduate school are actually spending about two months less time in graduate school than the men.

A graduate school parity index

Recent work by Valerie Kuck tried to determine if there was some subtle discrimination present in graduate school [Kuck]. She studied this by developing what she called a parity index, a relative measure of the likelihood of a woman successfully completing graduate school, as compared with a man at the same institution. (Values greater than 1.0 indicate a greater likelihood of success; values less than 1.0, a lesser likelihood.) She looked at the top 25 institutions in physics and chemistry, as determined by the 1995 National Research Council rankings. The overall percentages for obtaining a Ph.D. and the parity indices are shown in Table 7-6. It is clear that things are not equal. In an attempt to isolate the schools that had large nuclear science programs, we looked at the schools that were in Kuck's top 25 that had produced at least ten nuclear science Ph.D.'s in either of the time intervals 1991–95 or 1996–2001. Of the top 21 nuclear science Ph.D. producers, nine were in Kuck's data set. These nine represented 265 Ph.D.'s over the ten-year period. Among these schools, the parity index ranges from a low of 0.696 at MIT to a high of 1.265 at the University of Illinois. The overall parity index for nuclear science—weighted for the number of Ph.D.'s granted at each school—is 0.96. Nuclear science is thus doing better than physics as a whole, though not achieving full parity.

In the postdoc survey discussed in Chapter 4, the average age for men at the time of the survey was 1.2 years greater than for women, representing an additional year in the postdoctoral rank for men relative to women. This means either that men

Table 7-6. Parity indices for highly ranked U.S. universities. Women lag behind men in receiving doctorates.

	Physics	Chemistry
At Universities Ranked 1–10:		
Female Ph.D. Yield	79.2 %	68.7 %
Male Ph.D. Yield	88.0 %	78.1 %
Parity Index	0.90	0.88
At Universities Ranked 11–25:		
Female Ph.D. Yield	60.9 %	54.9 %
Male Ph.D. Yield	64.1 %	67.8 %
Parity Index	0.95	0.81

persist longer in hopes of a permanent job (while women are leaving the field) or that women are getting permanent jobs at a younger age than men. Of the respondents in the Ph.D.'s 5–10 Years Later survey who got tenure-track jobs, the women were approximately 1.3 years younger than the men. For respondents who got permanent jobs at national laboratories, the women were approximately a half year younger than the men.

Salary and financial matters

Within the postdoctoral population, respondents who identified themselves as minorities (predominantly non-U.S. citizens) received approximately $2,700 less in annual compensation relative to nonminorities. Furthermore, whereas the likelihood that minorities incurred debts while working on their Ph.D.'s was similar to that of nonminorities, the amount of such debt was twice as large. A significantly higher percentage (41.7%) of those responding as minorities had a spouse or partner who was underemployed, compared to the white population (26.3%), though some of this difference may be due to the fact that spouses of non-U.S. citizens have difficulty getting permission to work.

The compensation for women was similar to that for men (0.5% lower), and responses to the survey indicated that more women (46.7%) than men (29.4%) were satisfied with their salaries. This is not unexpected, since research shows that women tend to be satisfied with less compensation [Babcock]. In addition, based on answers to the open-ended questions, even those who were concerned about salary did not feel strongly enough about it that they would change their career directions because of it.

We found essentially no difference in the salaries of male and female graduate students. Likewise, while acquiring their Ph.D.'s, men and women were about equally likely to incur debt, and when they did, they incurred about the same debt load. As compared with men, women were about 10% less likely to receive health insurance (80% versus 91%) and dental insurance (67% versus 75%).

Career Path Limitations

Debt burden

Debt burden is one of the five career limitations studied in recent surveys of doctorate recipients [SED 2000, 2002], and one that is much more significant for underrepresented groups than for whites. Debt burden incurred during the pursuit of undergraduate degrees was cited as a career limitation by only 17% of the science and engineering doctoral recipients who sought career-path jobs. The corresponding numbers were 27% and 25% for African American and Hispanic recipients, respectively. For African Americans, the percentage increases to 28% in the sciences and to 62% for the physical sciences, as compared with 14% for whites in the physical sciences [NSF 03-312].

Much of the difference can be explained by the difference between the family incomes of underrepresented minorities and nonminorities, as reflected in Table 7-7 [Choy and Berker]. The financial situation for the families of many of these minority students probably prevents them from even entering graduate school and may also steer them to undergraduate degrees that offer more lucrative jobs immediately after the bachelor's degree. Forty-six percent of African American undergraduates and 44% of Hispanic undergraduates come from families with annual incomes below $30,000. By comparison, only 15% of the white students have family incomes below $30,000. Many of these students may feel a need to get a job to contribute to the support of their families, rather than to put off a job for the five to ten years required for graduate school and a possible postdoctoral position.

Table 7-7. Family incomes for full-time, full-year dependent undergraduates, by gender and race or ethnicity. The table entries are in percentages.

	Low: less than $30,000	Low middle: $30,000–44,999	Middle: $45,000–74,999	Upper middle: $75,000–99,999	High: $100,000 or more
Total	21.6	15.2	29.9	15.4	17.9
Sex					
Male	20.1	15.9	29.7	15.4	19.0
Female	22.9	14.6	30.1	15.4	17.0
Race/ethnicity[1]					
American Indian	28.2	12.0	33.0	9.5	17.3
Asian	38.1	14.2	23.9	8.2	15.7
Black	45.9	17.9	17.9	9.4	8.9
Hispanic	44.4	17.7	21.0	7.8	9.1
Pacific Islander	15.3	23.5	16.4	22.7	22.2
White	14.6	14.6	33.0	17.5	20.3
Other[2]	26.2	15.7	26.9	18.8	12.4
More than one race	36.8	12.6	24.9	13.4	12.3

[1] American Indian includes Alaska Native, Black includes African American, Pacific Islander includes Native Hawaiian, and Hispanic includes Latino. Race categories exclude Hispanic origin unless specified.

[2] Respondents were given the option of identifying their race as "other."

Educational attainment of parents

Among doctorate recipients, there is also a marked difference in the educational attainments of the parents of white and minority students, as shown in Table 7-8. For white students, over half of the parents (52% of the mothers and 65% of the fathers) had at least a bachelor's degree, and less than 5% of the parents did not have a high school diploma. By contrast, for Mexican Americans, 28% of the mothers and 30% of the fathers did not have a high school diploma. Only 27% of the mothers and 31% of the fathers had at least a bachelor's degree. The numbers are similar for other Hispanic, African American, and Native American groups [Woolston].

Table 7-8. Educational attainments of parents of 1999 science and engineering doctorate recipients, by gender and race or ethnicity.

		Educational attainment of mother							**Educational attainment of father**						
		Less than high school	High school	Some college	Bachelor's degree	Master's degree	Professional degree	Doctoral degree	Less than high school	High school	Some college	Bachelor's degree	Master's degree	Professional degree	Doctoral degree
Category	**Number**	**Percent distribution**													
Total	17,038	7.7	23.2	18.9	25.2	16.7	4.3	4.0	7.2	16.6	12.9	22.4	15.8	8.7	16.4
Male	10,255	8.1	23.7	18.7	25.4	16.3	4.0	3.8	7.5	16.7	12.7	22.4	15.8	8.2	16.7
Female	6,783	7.1	22.4	19.2	25.0	17.2	4.8	4.3	6.9	16.3	13.3	22.3	15.9	9.5	15.8
White, non-Hispanic	13,351	4.4	23.8	19.8	26.0	18.0	4.1	4.0	5.1	16.4	13.0	22.4	16.9	9.0	17.1
Asian/ Pacific Islander	1,925	20.4	19.4	13.7	25.8	10.5	5.4	4.9	12.3	13.5	10.3	28.6	11.7	8.1	15.
Black, non-Hispanic	686	21.1	21.9	18.0	16.2	15.9	4.0	2.9	19.8	24.7	17.5	13.1	10.8	5.2	8.9
Mexican American	156	28.3	27.0	17.8	11.2	13.2	0.7	2.0	29.8	20.5	17.9	7.9	15.9	1.3	6.6
Puerto Rican	159	17.0	24.8	20.3	19.0	10.5	5.2	3.3	22.7	22.1	12.3	11.0	11.0	9.1	11.7
Other Hispanic	353	22.9	23.9	18.9	16.8	9.4	4.4	3.7	16.8	20.2	12.8	16.8	11.4	6.7	15.2
American Indian/ Alaskan Native	112	24.2	27.3	17.2	18.2	9.1	2.0	2.0	21.4	29.6	15.3	9.2	9.2	7.1	8.2

Marriage and family

Overall, marriage and family are the most important factors in differentiating the participation of men and women in the science and engineering labor force [Long]. Among the women who responded in the postdoc survey that they felt they were at a “large disadvantage,” 40% identified having children as the primary reason for that feeling (see Chapter 4, especially Table 4-34). Little or no accommodation is made for women who choose to have children during their postdoctoral tenures. Specifically, there are no provisions for paid maternity leave in some instances, a lack of any provisions to “stop the clock” during the period of childbirth, and a lack of any allowance for this circumstance by those in positions to determine future career advancement. The consequence is that a woman who chooses to have a child while she is a postdoc is likely choosing to give up her career.

This is consistent with the larger picture of the science and engineering workforce. As shown in Figure 7-7, significantly more women than men cite family considerations as reasons for working part-time [Long]. Likewise, the percentage of doctoral recipients in the full-time workforce depends strongly on marital status and whether a woman has children (see Figure 7-8).

Figure 7-7. Percentage of science and engineering Ph.D.’s who cited family reasons for working part-time, by gender and year of survey. Values are five-year moving averages.

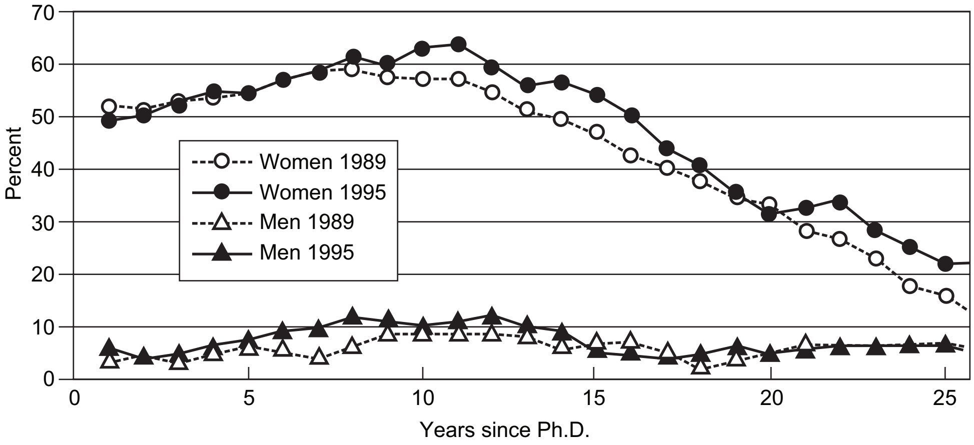
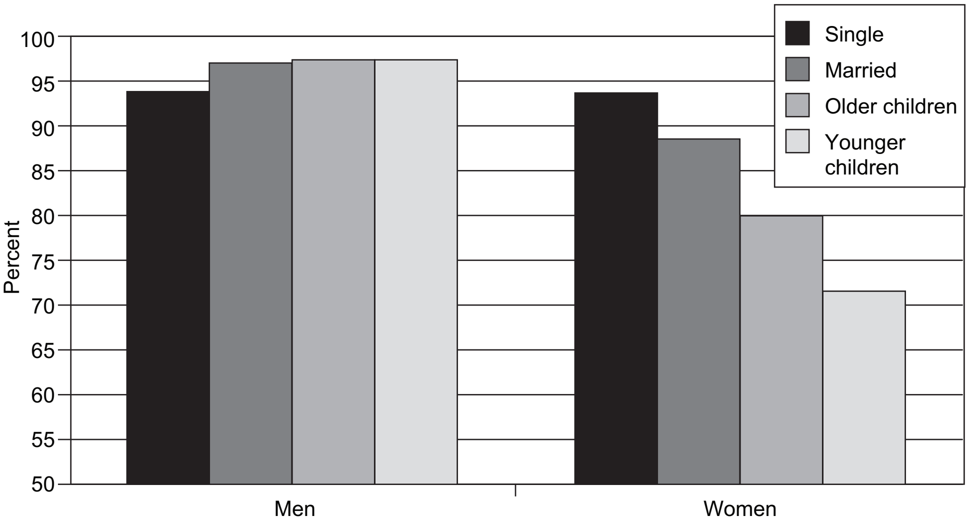


Figure 7-8. Percentage of science and engineering Ph.D.’s who were employed full-time in 1995, by gender and family status.



Approximately 70% of the population of the postdoc survey were married or in a committed relationship; approximately 10% had been in a relationship but were not at the time of the survey; and approximately 15–20% had never been married or in a committed relationship. There is a slight difference indicated for women: 65.5% had been married or in a committed relationship, with 17.2% indicating that this was no longer the case. Thus, women are somewhat more likely to have been in a broken relationship than those in other populations.

Also among the five career limitations studied in the NSF Survey of Doctorate Recipients, spouses' careers and the desire not to relocate—in addition to debt burden—were found to be significant career limiters for individuals in the physical sciences, especially for ethnic minorities. These considerations were issues more than half of the time for both African American and Hispanic populations.

By way of illustration, a female respondent to the Ph.D.'s 5–10 Years Later survey stated:

> My career choice was not very family friendly because of the large number of times I had to move and because it took so long to find a job in the same place as my spouse. Even though I am quite happy now with the way it worked out (both career and family) it took so many years I wouldn't do it again.

Another woman reflected:

> One thing I do regret is that the graduate and postdoc experience really made me put off marriage and children. The biggest reason that I might not do it all again is because it takes so long to get a position of job security, that people tend to give up things along the way. Particularly women. If you want to get more people into physics, and particularly nuclear physics, then you know you are missing a huge pool of people that are tremendously under represented.

Dual career issues

The issue of dual careers was prevalent throughout the populations we surveyed and is a major impediment to the advancement of women. In the postdoc survey, approximately 66% of the women responded that they were in a committed relationship. Of those, 78% indicated the highest degree earned by their spouse or partner was a Ph.D., M.D., or J.D.; 22% had earned a master's. This is contrasted with the response for men, indicating 30%, 38%, and 30% for Ph.D./M.D./J.D., master's degree, and bachelor's degree, respectively (see Table 7-9). Women are therefore significantly more likely to be in a committed relationship with someone who has earned a Ph.D. than are men. Furthermore, female postdocs were significantly more likely (68% versus 40%) to have spouses or partners working full-time than were men, and they were significantly less likely (5% versus 34%) to have spouses or partners who were "not employed."

Table 7-9. Highest degrees earned by spouses or partners of male and female respondents to our postdoc and Ph.D.'s 5–10 Years Later surveys.

	Postdocs		**5–10 survey**	
	Women	**Men**	**Women**	**Men**
Bachelor's	0%	30%	14%	33%
Master's	22%	38%	18%	29%
Doctorate, M.D., J.D.	78%	30%	64%	28%

In the survey of Ph.D.'s five to ten years after their degrees, the results were similar, with 64% of the spouses or partners of women having a Ph.D., M.D., or J.D., in contrast to 28% for spouses or partners of men. Additionally, all of the spouses or partners of the women were employed full-time, while only 62% of the spouses or partners of men had full-time jobs.

Approximately 60% of the female postdocs (compared with 10% of the men) indicated that their spouses or partners were also nuclear scientists. Women therefore appear to be entering committed relationships primarily with others who have Ph.D.'s in nuclear science, in contrast with men, whose partners are much less likely to have Ph.D.'s, and whose areas of specialty span a much broader spectrum of disciplines. Furthermore, 48% of the women reported that their spouses or partners were employed in higher education, with another 19% indicating national laboratories; the corresponding numbers for men were 27% and 10%. Academia and the national laboratories need to develop a framework for capitalizing on these "two-body" opportunities. Additionally, 45% of the female postdocs said they did not live in the same geographical area as their partners, in contrast with only 21% of the men. However, in the Ph.D.'s 5-10 Years Later survey, only 1 woman among 22 respondents (and 3 men among 181) was not living in the same geographical area as her spouse or partner. This suggests that women may be more likely than men to suffer serious career stress due to the increased difficulty of finding two high-level professional positions in the same location. Overall, our findings suggest that women may be much more likely than men to experience conflicts between career and family relationships.

Mentoring and self-esteem

In the graduate student survey, 85% of the students indicated that they worked for male advisers. This may point to a lack of female role models in the nuclear science community. In the postdoc survey, a very high percentage of ethnic minority respondents reported that their graduate advisers were Asian (43% of ethnic minorities versus 4% of whites reported Asian advisers).[2] Furthermore, a very high percentage of these postdocs are currently employed by Asian supervisors. Thus,

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[2] The vast majority of these individuals were not native-born U.S. citizens.

cultural background seems to be a very strong factor in keeping the pipeline open to graduate education and employment for ethnic minorities. If we are to make progress in the area of ethnic diversity, it follows that we may need to cultivate African American and Hispanic mentors for the next generation of nuclear science students.

This conclusion can be extended to women. In our Ph.D.'s 5–10 Years Later survey, one former graduate student responded as follows to the question, "What would have helped you with your first job search as you completed your Ph.D. or postdoctoral education?"

> It would have helped to talk to other women who had been through the same process. At the time I did not know how to respond to remarks from the faculty that were interviewing me such as "What's a pretty girl like you going to do for fun in a place like this?" or "How many children do you plan to have? You look like you'd probably have about three." If I'd realized that this was going to happen I would have been much better prepared.

When asked to compare themselves to other physics or chemistry majors in their undergraduate classes, most subpopulations (men, women, and U.S. and non-U.S. citizens) responded similarly, except that female U.S. citizens ranked themselves somewhat lower on average.

In the postdoc survey, 33% of women agreed or strongly agreed with the statement, "As a woman in the field I feel I am at a large disadvantage"—a not-unfounded perception, judging from comments by some male respondents. The most frequent reason given was the failure by men in the field to treat them as peers, including a bias among coworkers that they had obtained their positions and successes because they were women. Such perceptions produce stress in the workplace and, in some cases, raise self-esteem issues.

Among female postdocs, 83% ("definitely") and 17% ("probably") responded that it was worth the effort to get their Ph.D.'s, compared with 63% and 33% for men. A somewhat stronger difference was observed between U.S. citizens (57% and 40%) and non-U.S. citizens (70% and 27%). Overall, it appears that women are more satisfied with the value of their nuclear science Ph.D.'s than are men.

The Working Environment for Women and Minorities

In the graduate student survey, 60% of the respondents thought that the working environment for women was positive. Interestingly, 80% of female U.S. citizens and more than 90% of female non-U.S. citizens rated their working environments as positive. (This latter difference may indicate a difference in the level of comfort and the ability to bring issues forward.) These numbers, however, also mean that 10% of female non-U.S. citizens and 20% of female U.S. citizens did not consider their working environments as positive. Unfortunately, we did not ask the parallel question about the working environment for men. In the postdoctoral survey, some responses to the statement, "As an ethnic minority in the U.S., I feel I am at a large disadvantage in the field," indicated a strong feeling that there was significant racism in the field.[3]

Graduate students were also asked about discouragement. Overall, the greatest source of discouragement for all subpopulations was coursework. However, the largest gender difference concerned interactions with advisers: Female U.S. citizens noted this as a major source of discouragement almost three times as often as did male U.S. citizens. For non-U.S. citizens, the gender difference was twofold, with the women again more affected.

Many of the issues regarding the working environment in the nuclear science community are similar to those in high-energy physics. In her book *Beamtimes and Lifetimes*, Sharon Treweek offers an in-depth look at the culture of the high-energy physics community [Treweek].

Summary and Recommendations

Minorities and women are poorly represented in the nuclear science community, and some of those currently in the field feel that they are at a disadvantage. Thirty-three percent of the women in the postdoc survey felt that they were at a large disadvantage in pursuing a career in nuclear science. Possible impediments to inclusion are pedigree (in particular, their educational background), children, the social "climate," gender schemas (men are overrated, women are underrated), accumulated disadvantage [Valian], social structure and values, and a failure to capitalize on "two-body" opportunities.

We need a two-pronged approach to make progress. We must transform our institutions to lower the barriers to inclusion and success, and we must give individuals the tools to survive (in fact, to thrive) in the not-yet-transformed system. Based on Carnegie Mellon University's efforts to restructure its computer science program, we know that recruitment and retention problems are typically worse for those in the minority. When Carnegie Mellon reformed its program, retention increased for all students, but the effect was greater for women [Margolis and Fisher]. Carnegie Mellon also learned that evaluating the potential of applicants, rather than previous accomplishments, led to significant increases in the number of women admitted to the computer science program. Perhaps we can similarly reevaluate our assumptions about predictors of success.

The creation of multiple pathways has also helped increase student retention in computer science at Carnegie Mellon. (Pathways previously tended to merge within two years.) Perhaps we too can be more flexible—even encouraging—of minority nuclear scientists who want to spend some time at a predominantly minority undergraduate institution and then transfer to a major research institution. (Anecdotal evidence suggests that some minority scientists desire to teach at minority institutions to inspire young minority students, at the expense of prospects for a faculty

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[3] Again, the great majority of these individuals were not native-born U.S. citizens.

position at an institution with more resources and perhaps more Ph.D. students who might go on to be faculty members.) Flexibility in the traditional pathway might also enable more women to participate fully after career interruption for family reasons, and might enhance the prospects for students who need a little more time to feel accepted and confident that they "belong." We might also consider concerted efforts to recruit out of master's programs.

Our field as a whole is not family friendly and not accustomed to accommodating two-career situations. This is a reality that must be addressed if nuclear science is to make real progress toward the equitable inclusion of women.

Mentoring is important if we wish to improve the system for all our students, but particularly for members of underrepresented groups. While there exist examples of successful mentoring programs where participants are at a single location [for example, see Montelone et al.], one of the challenges in nuclear science is that the few senior women and minorities in the field are geographically dispersed. Therefore, we need to develop a dispersed networking program. Such a program could include face-to-face meetings, in conjunction with the American Physical Society's Division of Nuclear Physics (DNP) meetings, as well as long-distance mentoring that could be enhanced by the use of technology.

As Virginia Valian has said, "Mountains are molehills piled one on top of another" [Valian]. If nuclear science wishes to take advantage of the intellectual capabilities of the entire population, it is imperative that we begin to find ways to rectify both overt discrimination and the more subtle slights that individuals often overlook. We need to be proactive about improving the way we interact with and evaluate all members—and potential members—of our community. We need to be cognizant of the cultural norms of all groups of individuals and learn to appreciate one another's differences, and we need to strive to develop policies and procedures that embrace a work-life balance. Many of these issues are shared with other areas of science, but some are exacerbated by the large international collaborations and national laboratory–based experiments that are common in nuclear science.

We recommend two specific actions aimed at enhancing participation by members of underrepresented groups and at establishing mentoring and professional development programs. We also recommend that criterion 2 for the NSF be used as a mechanism to encourage positive change in our field.

Encouraging full participation

Educational and research environments are enhanced by an increase in the diversity of the members of the community. It is essential that the nuclear science community actively work to identify promising members of underrepresented groups and to increase the opportunities for their full participation in the community. It is also essential not only that we enable individuals to thrive within our current institutions, but also that we reexamine our basic assumptions and reevaluate our institutions to see how they might accommodate a broader group of individuals. Accordingly,

We recommend that there be a concerted commitment by the nuclear science community to enhance the participation, in nuclear science, of women and people from traditionally underrepresented backgrounds, and that the agencies help provide the support to facilitate this enhanced participation.

The following steps might be taken as part of this concerted commitment:

- *Enhance connections with the faculty and students of institutions and consortia that serve traditionally underrepresented groups*, including, but not limited to, minority-serving institutions, the McNair scholars program, the National Physical Science Consortium, the NSF Alliance for Graduate Education and the Professoriate, and the Graduate Education for Minorities program. As part of this effort, we might establish exchange programs with faculty to facilitate their participation in research at universities and national laboratories. To enhance the participation of students, we should increase efforts to recruit undergraduates into, for example, the CEU and REU programs, and to work with individual investigators. In concert, we should enhance the recruitment of students from underrepresented groups for graduate study by developing and disseminating a database of students who have participated in such undergraduate programs, and by extending recruitment efforts to master's degree institutions and to students receiving master's degrees from minority-serving institutions.
- *Establish programs that help facilitate the transition of early-career scientists into forefront research activities and educational opportunities.* A general goal would be to provide greater support of prematriculation graduate student research. This might be either a research position the summer before entry into a Ph.D. program or a more extensive bridge program. The agencies might, for example, establish and fund master's-to-Ph.D. bridge programs for graduate students who may have significant potential but not yet be fully prepared for doctoral-track graduate studies. In such a program, a student admitted to a terminal master's program would take advanced undergraduate and core graduate courses while being supported to do research, for up to three years of study. Upon satisfactory completion of graduate courses and the passing of Ph.D. candidacy exams, the student would then be admitted to a Ph.D. program. The student could be enrolled at the Ph.D.-granting institution for his or her master's degree studies (internal bridge program) or be enrolled at a master's-degree institution geographically close to a research university or national laboratory, followed by doctoral matriculation and research at a Ph.D.-granting institution (external bridge program). Other bridge programs might be aimed at facilitating the transition from postdoctoral positions to tenure-track faculty or research scientist positions, or to enable individuals who have taken time away from basic research to reenter tenure-track faculty or research scientist pathways.
- *Adopt policies that recognize the personal and family responsibilities of nuclear scientists.* Realistic family-leave policies are a key example. Whereas family-leave policies are often in place at host institutions, some individuals with

their own funding (for example, postdocs) may not be covered by such policies. Principal investigators should be encouraged to make reasonable accommodations for students and postdocs dealing with family and personal responsibilities, and the funding agencies might, in addition, establish clear guidelines for institutions that host scholars supported by those agencies. Policies should also facilitate “partner hires.” Institutions should be encouraged to adopt appropriately flexible hiring practices that accommodate the hiring of partners in the same or related fields. An up-to-date bulletin board might also be maintained that lists available postdoctoral positions in nuclear science, including the university or national facility at which the postdoc is likely to be in residence, as well as the hiring institution.

- *Emphasize the value of recruiting and mentoring members of underrepresented groups.* As part of any proposal, principal investigators might be asked to describe mentoring activities (both past and proposed) for students and postdocs, with particular attention to mentoring members of underrepresented groups.
- *Enhance the visibility of underrepresented minorities in the nuclear science community.* For example, we urge that a database be created (similar to the speakers list maintained by the Committee on Status of Women in Physics) that would include members of underrepresented groups in the U.S. nuclear science community, and that this database be made available to funding agencies and professional societies. The nuclear science community would then be encouraged to invite individuals in this database for seminars and colloquia at their home institutions and laboratories. In addition, the community should track data on the gender and ethnicity of individuals recognized for their accomplishments, including invited speakers at professional meetings, award and professional fellowship nominees, and committee and panel participants.
- *Develop effective models for enhancing the participation of individuals from traditionally underrepresented backgrounds and disseminate them via best-practice sessions.* For example, mechanisms might be developed for transforming our model of linear professional advancement into a model that allows for various pathways to advancement, and tools might be pursued that help the nuclear science community identify and select individuals according to potential, rather than prior accomplishments.

Mentoring and professional development

Effective mentoring is critical to preparing nuclear scientists for the future. This is particularly true for members of underrepresented groups, who face significant barriers to success in nuclear science research and education. Therefore, it is essential that the nuclear science community work actively to provide mentoring and professional development opportunities for all aspiring scientists in the field, and especially for members of underrepresented groups. If this is done well, we can increase the satisfaction of our students and postdocs, enhancing retention in the field. By being more supportive and welcoming, our field should also become more attractive to promising people early in their careers.

We recommend that there be a concerted commitment by the nuclear science community to establish mentoring and professional development programs, and that the agencies support such efforts through the funding of competitive proposals.

Steps that might be taken in support of this commitment include the following:

- *Develop programs at professional meetings, such as the annual DNP meeting, and at the national laboratories that provide career guidance and professional development opportunities.* The recommendation most frequently mentioned by Ph.D.'s five to ten years after their degrees (Chapter 5) was "to provide career planning and guidance, especially for careers in business, government, or nonprofit organizations." Such programs might include short courses to enhance communication skills (including grant writing, resume preparation, and interviewing), workshops on preparing to teach outside of the university environment, and panels of nuclear scientists with careers outside basic nuclear science and university research and education.
- *Enhance mentoring and advising of undergraduate and graduate students and postdoctoral scholars, especially those from underrepresented groups.* We might, for example, provide training and best-practice sessions for mentors at professional meetings, develop a mentoring program that couples face-to-face mentoring at professional meetings with technology-assisted long-distance mentoring, and maintain a database of senior nuclear scientists who are willing to serve as mentors, especially of members of underrepresented groups. The community should also develop a dynamic Web document that highlights best practices in nuclear science career advising, professional development, and mentoring, using the resources of the national laboratories, together with the professional societies. We should also develop, maintain, and circulate a database that tracks the careers of U.S. nuclear science Ph.D.'s. This will allow us to ensure that, when the agencies are picking people for NSAC or when the DNP is selecting invited speakers, nuclear scientists from underrepresented groups can be appropriately identified and encouraged to contribute their expertise.

References

AIP 2000: Physics Academic Workforce Report, American Institute of Physics, 2000 (*http://www.aip.org/statistics/trends/reports/awf01.pdf*).

AIP 2002: Physics Academic Workforce Report, American Institute of Physics, 2002 (*http://www.aip.org/statistics/trends/reports/awf02.pdf*).

AIP IER: Initial Employment Report: Physics and Astronomy Degrees Received 2000, 2001, AIP Statistical Research Center (*http://www.aip.org/statistics/trends/reports/emp0001.pdf*).

Babcock: L. Babcock and S. Laschever, *Women Don't Ask: Negotiation and the Gender Divide*, (Princeton University Press, Princeton, NJ, 2003).

Choy and Berker: Susan P. Choy and Ali M. Berker, "How Families of Low and Middle-Income Undergraduates Pay for College: Full-Time Dependent Students in 1999–2000," U.S. Department of Education, Institute of Education Sciences, NCES 2003–162, 2003.

CPST 01: Committee on Professionals in Science and Technology, data derived from the American Institute of Physics, Survey of Enrollments and Degrees, 1995–2001, *http://www.aip.org/statistics/trends/highlite/ed/table8.htm*.

Kuck: V. Kuck, "Women Physicists and Chemists Make Slow Progress in Academe," CSWP Gazette, Fall 2001 (*http://www.aps.org/educ/cswp/gazette/fall01.pdf*).

Long: J. Scott Long, Ed., "From Scarcity to Visibility: Gender Differences in the Careers of Doctoral Scientists and Engineers," Panel for the Study of Gender Differences in Career Outcomes of Science and Engineering Ph.D.'s, Committee on Women in Science and Engineering, National Research Council (National Academy Press, Washington, DC, 2001).

Margolis and Fisher: Jane Margolis and Allan Fisher, *Unlocking the Clubhouse: Women in Computing*, (MIT Press, Cambridge, MA, 2002).

Montelone et al.: Beth A. Montelone, Ruth A. Dyer, and Dolores J. Takemoto, "A Mentoring Program for Women and Minority Faculty Members in the Sciences and Engineering: Effectiveness and Status after Nine Years," *J. Women Minorities Sci. Engin.* **9**, 259–71, 2003.

Mulvey and Nicholson: P.J. Mulvey and S. Nicholson, "Enrollment and Degrees Report," AIP Pub. R-151.39, Aug. 2003 (*http://www.aip.org/statistics/trends/reports/ed.pdf*).

NCES 00: U.S. Department of Education, National Center for Education Statistics, National Assessment of Educational Progress, "High School and Beyond: First Followup Survey," 2000 (see *http://nces.ed.gov/programs/digest/d02/tables/dt141.asp*).

NSF 03-312: National Science Foundation, Division of Science Resources Statistics, "Women, Minorities, and Persons With Disabilities in Science and Engineering: 2002," NSF 03-312, 2003 (*http://www.nsf.gov/sbe/srs/nsf03312/toc.htm*).

Neuschatz and McFarling: Michael Neuschatz and Mark McFarling, "Broadening the Base: High School Physics Education at the Turn of a New Century" (American Institute of Physics, 2003); see *http://www.aip.org/statistics/trends/reports/hsreport2003.pdf*.

SED 2000: T. B. Hoffer et al., “Doctorate Recipients from United States Universities, Summary Report 2000: Survey of Earned Doctorates” (National Opinion Research Center, Chicago, 2000).

SED 2002: T. B. Hoffer et al., “Doctorate Recipients from United States Universities, Summary Report 2002: Survey of Earned Doctorates” (National Opinion Research Center, Chicago, 2002).

Thom: Mary Thom, “Balancing the Equation: Where Are Women and Girls in Science, Engineering and Technology?” (National Council for Research on Women, 2001); see *http://www.ncrw.org/research/iqsci.htm*.

Treweek: Sharon Traweek, *Beamtimes and Lifetimes*, (Harvard University Press, Cambridge, MA, 1988).

Valian: V. Valian, *Why So Slow? The Advancement of Women* (MIT Press, Cambridge, MA, 1999).

Woolston: Chris Woolston, “The Gender Gap in Science,” *Chron. Higher Ed.*, **22** October 2001 (*http://chronicle.com/jobs/2001/10/2001102201c.htm*).

8. Outreach: Educating the Public

Introduction

Nuclear science is an active and exciting field. Research in nuclear physics, chemistry, medicine, and engineering has a powerful and beneficial effect on the economy, technology, and security of our society and will profoundly affect our future. Important examples of the benefits made possible by nuclear science abound and include diagnosing physical ailments without the need for exploratory surgery, alerting families to the threat of fire, helping to ensure adequate supplies of electrical power, guarding against biological agents carried through the mail, guarding our country's borders against the transport of dangerous materials, and ensuring the nation's ability to defend itself. From detailing the structure of matter and understanding the source of energy in our sun to exploring the state of matter that existed at the beginning of the universe, nuclear science is alive with an array of important scientific pursuits and technological developments that profoundly impact our society.

Yet, we are concerned to find that the public and even some scientists in other fields are often uninformed or misinformed about nuclear science and its benefits. As documented in a book-length study, in public discussions surrounding any topic involving the word "nuclear," unreasoned reaction to the word itself often drowns out the important technical and societal issues that should be of primary interest to informed citizens [Weart]. For example, the medical technique now known as magnetic resonance imaging was initially called nuclear magnetic resonance. The present title, while descriptive, is notable for the absence of the word "nuclear," which was removed when it was said to have raised serious concern among potential patients. In the political realm, the discussion of radioactive waste disposal has become a confused political issue, while there has been little serious discussion of the positive aspects of nuclear power generation.

To quote an article in a recent issue of *Nuclear Physics News*[1] [Oberhummer]: "In the last few decades, public awareness of science has become of the utmost importance for the prevalence and sometimes even the survival of scientific disciplines. The general public has become more and more critical about the necessity of research." We agree with this statement, and we conclude that as nuclear scientists we can ignore public perceptions of our field only at great cost to us and to society.

Whereas Weart discusses the public reaction to the word "nuclear," Oberhummer points out that a wide range of fascinating aspects of our field are often underreported or ignored [Oberhummer]. Such topics include the rapidly increasing application of nuclear physics to both diagnosis and treatment in medicine, and the fundamental importance of nuclear science in studies of the smallest objects we know, as well as the development of the universe itself. The fact that the field remains a source of both intellectual excitement and practical innovation with universal benefit is almost entirely obscured. More than ever before, the survival of the field depends critically on the ability of scientists and researchers to articulate the importance and value of nuclear science research and innovation to our society.

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[1] *Nuclear Physics News* is a publication of the Nuclear Physics European Collaboration Committee (NuPECC), an expert committee of the European Science Foundation.

Misinformation about nuclear science can easily lead the general public to incorrect decisions concerning new medical procedures, energy availability, food processing, and a host of other matters in our society where nuclear science currently plays a safe and useful role.

In addition, the lack of understanding and appreciation of nuclear science by the general public permeates our society so completely that curricula that promote a basic understanding of the fundamental properties of matter are in large part missing or disappearing from K–12 educational programs. This is damaging enough to the prospects of sustaining a technologically advanced workforce. But it is even more damaging to efforts to engage women and members of underrepresented minorities in nuclear science, or in math and science more broadly. Such individuals make critical decisions about their future during this formative period, perhaps without ever having been exposed to a course that discusses the basic structure of matter.

We thus conclude that a broad, basic knowledge of nuclear science is critical for an educated population that can deal effectively with a wide range of important scientific topics, including medicine, energy policy, homeland security, and defense. It is equally critical for the future of nuclear science in the U.S.

Existing Educational Resources

It cannot be said that opportunities to learn about nuclear science are absent from everyday experience. A typical Web search engine returns a list of more than four million sites when the phrase "nuclear science" is entered. Searching with the words "nuclear science universities" returns a half-million sites. In addition, "nuclear science K–12" lists more than fifty thousand sites. There is ample evidence that considerable effort has already been made to disseminate information about this topic. Also, countless books, pamphlets, and similar sources already exist to distribute information about nuclear science.

Furthermore, a number of effective and valuable public outreach efforts directed toward topics in science exist at national laboratories and universities. A few examples are listed below. We applaud those programs and feel that they should be supported and, where possible, strengthened. We note, however, that in many cases such programs are not directed specifically toward nuclear science topics and that they are often effective in only local geographical areas. Therefore, we recommend the creation of a Center for Nuclear Science Outreach. We believe that the achievements and potential of nuclear science and technology and the value of enhanced support for research in these areas deserve a central, coordinating resource. Such a resource, focused on developing communication and outreach on nuclear issues, would best be served by the presence of dedicated professionals skilled in communicating with students of all ages, with K–12 teachers, and with the general public. Strong leadership from within the nuclear science community would be an important facet of this resource.

Professional organizations such as the American Nuclear Society (*www.ans.org*), the World Nuclear Organization (*www.world-nuclear.org*), the International Atomic Energy Agency (*www.iaea.org*), and the Society for Nuclear Medicine (*www.snm.org*) have extensive resources on radioactivity and the applications of nuclear science. These groups work actively to improve the public perception of "nuclear"-related activities. However, these groups may not be viewed as unbiased or have the same credibility as the nuclear science research community. The nuclear science community is in a unique position to use the public's interest in basic science and nature to help inform them. Our specific contribution can be to inform the public and students about exciting scientific efforts and results, at the same time demystifying some of the issues related to the application of nuclear techniques. For example, the answer to the question, "Where were the atoms in my body made?" can be used to introduce radioactivity, nuclear power generation, and the use of radiotracers.

Examples of effective outreach efforts

As our goals are to expand and enhance outreach efforts throughout our society, we mention here a few existing efforts and comment on their applicability to these goals.

Contemporary Physics Education Project (CPEP) (*http://www.cpepweb.org*)—This nonprofit organization of teachers and educators provides posters, charts, and Web-based materials on the fundamental nature of matter and energy. We admire the posters offered by CPEP and feel that they are certainly of value to high school and undergraduate physics teachers.

Guide to the Nuclear Wall Chart—This valuable resource, created by Lawrence Berkeley National Laboratory (LBNL) and posted on the Web at *http://www.lbl.gov/abc/wallchart/outline.html*, has the motto, "You don't need to be a nuclear physicist to understand nuclear science." It includes a wide range of well-presented topics from introductory and basic nuclear physics to industrial applications of nuclear science. Indeed, this resource is so versatile and well presented that its title seems somewhat limiting and unlikely to transmit the rich educational potential of the site.

Quarknet—This valuable educational tool (at *http://quarknet.fnal.gov*), organized at Fermilab by the high-energy physics community, encourages participation by school teachers and students in the online analysis and discussion of particle physics data. It thus serves as a resource for more advanced and involved students and schools. This site has considerable potential to attract the more curious and intelligent students to experimental particle physics. We feel that a resource directed specifically toward nuclear science, similar to this one, would be of considerable value.

The CHICOS Project (*http://www.chicos.caltech.edu/overview*)—This project allows students and teachers in the Los Angeles area to participate in the construction and operation of cosmic-ray detectors deployed in a wide-area array to detect showers from high-energy cosmic-ray interactions. Similar projects exist in Seattle (WALTA) and at CERN. This application of experimental nuclear physics to studies of importance to cosmology is exciting and attractive. The needed equipment is, in many cases, available from previously used experiments. The effort has wide educational potential and can be useful to students of modest scientific background, as well as those with a more advanced understanding of physics, electronics, and computer techniques. It has the important virtue of fostering continuing interactions among experimental scientists, students, and their teachers.

Other university and national laboratory resources—Excellent resources exist at several nuclear science research centers. To name only a few, we note the sites at Michigan State University (*http://nucoutreach.msu.edu*), where students or teachers can search for educational resources in their state or local area; at LBNL (*http://www.lbl.gov/abc*), where "The ABC's of Nuclear Science" leads a visitor through a wide range of attractive and well-presented topics; at Thomas Jefferson National Accelerator Facility (JLab) (*http://education.jlab.org*), where teacher and student resources include projects and online computer games to attract a range of interested students; and at Brookhaven National Laboratory (BNL) (*http://www.bnl.gov/scied/*), where a long list of resources is made available, including a special page for parents who home-school their children. Finally, the outreach Web site at the Department of Physics at Florida State University (*http://www/physics.fsu.edu/outreach/default.htm*) exhibits an impressive array of outreach possibilities, most of which could be imitated by other physics departments around the country.

European resources—At its Web site (*http://www.nupex.org*), the European Nuclear Physics Society has recently begun a site intended for education both within the schools and for the general public. In addition, the European Union has funded an exhibition, *Radioactivity: A Facet of Nature*, which has traveled to several European cities after initially being presented during European Science and Technology Week in 2000.

Information about nuclear science is thus widely available to teachers, students, parents, and the general public, even apart from the many books and magazines that treat the subject. The deeper need thus appears to be guidelines or selection criteria that will assist interested persons to find the information of greatest utility to them. At present, the great number of nuclear science–related Web sites can ironically tend to work against the effective dissemination of information to the interested student or teacher. Separating the useful and informative sites from unhelpful, inaccurate, or specious ones can easily require the assistance of an expert. We have found no single site that does a complete job of providing such assistance on topics relating specifically to nuclear science. Yet, the value of such guidance is unquestionable. We will address this issue below in outlining some of the characteristics of an effective outreach center.

Additional educational approaches

The use of Web-based outreach techniques is valuable but should not exclude approaches that can reach a wider or a different potential audience. For example, we note the limited amount of positive news or informational offerings on nuclear topics in newspapers, on television, and in the various other outlets for news. By contrast, advances in biological science, astronomy and cosmology, nanotechnology, information science, and other scientific fields appear to receive far more coverage—and more positive coverage—in the popular media. We feel that an effort should be made to create educational videos (CDs or DVDs) on nuclear topics and to disseminate them to public schools and libraries. It would be of additional value to produce a video of sufficient quality to justify its broadcast on a national television program such as "Nova" or "Discovery." We recognize that such an effort would require the cooperation of skilled experts, and we address that point below.

A Clearinghouse for Public Outreach

Many nuclear scientists have commented upon the need for broadened and enhanced outreach by the nuclear science community. Indeed, we believe that enhanced involvement by all scientists in K–12 education and in public outreach should be seen as a pressing need. Misconceptions about science, challenges to modern science by misguided people, and unreasonable reactions to issues such as the irradiation of food and the storage and shipment of nuclear waste are among the many matters that scientists can ignore only at great disadvantage to all. To cite a particularly nettlesome example, the presence of widespread natural sources of radiation and comparisons between doses one may receive from natural and man-made radiation sources are widely misunderstood by the public. Nuclear scientists should feel both a sense of public responsibility and a definite self-interest in helping the public to resolve controversial issues that can prevent intelligent decision-making, both by ordinary individuals and by political leaders, on issues related to nuclear science.

We strongly urge each nuclear scientist to consider educational outreach to be an important part of his or her professional responsibility. We view such a community effort as essential and feel that with a Center for Nuclear Science Outreach to coordinate and leverage individual efforts, the impact on the field can be enormous. The successful stimulation of public interest in several topics related to nuclear science—cosmology, astrophysics, and aspects of homeland security—provides evidence that a well-organized outreach effort can be very successful. We particularly recommend educational outreach among underrepresented groups, and especially ethnic minorities. The increasing number of minority students taking physics in high school is encouraging, and we urge an increased effort to introduce students from minority groups to basic concepts of nuclear science during their precollege education. Such an effort is essential to enhancing diversity in our profession.

We believe, for example, that many science faculty and researchers would be willing to give short lectures in local schools and yet lack the necessary experience or encouragement to do so. It should be relatively simple to create a Web-based guide that describes successful school lecture formats, including a list of demonstrations and possibly examples of PowerPoint presentations found to be effective by others. A nuclear science clearinghouse could easily serve as an initial repository for such information, with the goal of including a broad range of basic scientific concepts. We believe that a contribution by each individual at the 10% level is more valuable if it can be coordinated and directed by a central organization. An example can be found in high-energy physics, where faculty contribute at the 10% level to adding content to the QuarkNet Project. This represents an effort that is highly leveraged, as others promote and disseminate this content.

We believe that the activities described above can contribute to the advance of scientific education in our country. We further believe that active public involvement by the nuclear science community in these fields is of both intrinsic social value and disciplinary self-interest. As pointed out above, despite the wide range of available information, no central resource is available to interested parties searching for current, reliable, and unbiased information or advice on topics related to nuclear science. We have thus concluded that a need exists for such a central resource and that it should be funded by the federal granting agencies. Thus our recommendation below that the highest priority for new investment in education be the creation by the DOE and the NSF of a Center for Nuclear Science Outreach.

Formation and composition of an outreach center

We recognize that laudable efforts are being made by both universities and national laboratories to explain nuclear science to the public, and we encourage those organizations to continue their efforts. We feel strongly, however, that no single existing organization currently addresses all of the important concerns we have raised. We believe that a central organization to assist in coordination of existing outreach efforts, such as those at BNL, JLab, LBNL, Michigan State, and other institutions could multiply these programs' effectiveness.

We have considered the suggestion of forming a representative committee drawn from the outreach sites already in existence. However, we are concerned that such a committee, meeting occasionally at one of their respective sites or more frequently by phone or teleconference, would not be as successful as the dedicated Center we propose. Members of such a committee would inevitably have their home institutions' parochial interests as a major focus. By contrast, the Center we propose would have a national focus, as well as professionally trained staff, skilled in education and outreach. For the staff of the Center, excellence in nuclear science outreach for the entire nuclear science community would be its sole responsibility and its highest priority. At the same time, however, we recognize that cooperation between the new Center and existing educational efforts will be essential to the effective and efficient development of a coordinated educational effort to represent nuclear science.

Goals of the Center

We recommend specifically that a substantial group of professional personnel skilled in education and nuclear science be established at a dedicated center as the Center for Nuclear Science Outreach. The Center should be staffed appropriately, and have sufficient resources, to carry out an effective national program of nuclear science outreach, with the goal of achieving the same level of societal recognition as currently enjoyed by space-based research programs. The mission of the Center would be to understand the barriers within our society to a widespread understanding and appreciation of the excitement and importance of nuclear science; to develop strategies to effectively communicate the value of what we do to the general public and to scientists in other disciplines; and to coordinate efforts by members of the nuclear science community to do so. The Center staff would establish ties with the American Physical Society's Division of Nuclear Physics (DNP) and its Committee on Education, as well as the Division of Nuclear Chemistry and Technology of the American Chemical Society (ACS). That cooperation would provide valuable support for this effort, including possible assistance in the selection of projects undertaken by the Center and possibilities for evaluation and feedback on the results achieved.

The efforts of the Center should be nationwide. It would work to provide resources to teachers at all levels so that recent results in our field can be communicated to students and the general public. Increasing nuclear science in the K–12 curriculum would be one of its major goals. It would serve as a central clearinghouse where efforts can be coordinated and resources made available for people in our field. It would be a professional effort where new outreach methods are initiated. There are a number of concrete examples of efforts that could be used to achieve these goals. Examples of initial efforts include:

- Creation of an effective nuclear science Web site directed toward K–12 teachers and students. Such a site could be an extension of an existing laboratory site or might be formed specifically for this project. The Web site would contain information created by the Center's professionals, as well as links to sites examined and recommended by those experts.
- Plans for the production of one or more educational CDs or DVDs suitable for distribution to interested schools nationwide. In addition, a version might also be produced for the general public, to be distributed to libraries or senior centers.
- Interaction with the media (including *Physics News*, etc.) to regularly publish articles on advances in nuclear science.
- Initiation and coordination of a nationally directed public lecture series with outstanding speakers on nuclear science.
- Explicit development of materials focused on motivating students, at all educational levels, to pursue careers in nuclear science. Particular attention should be paid to stimulating interest in nuclear science among young students from groups underrepresented in the sciences.
- Development of funding for outreach fellows, with the goal of encouraging new and innovative ideas. This would allow one or two people each year to work where they wish, to develop national outreach materials and/or to perform research related to improving outreach in nuclear science. It would attract people with special talent for such work to these positions. These fellowships would not necessarily be limited to younger people but could also be senior scientists on leave or sabbatical. It would be valuable to recruit fellows from traditionally underrepresented groups, including women and

ethnic minorities, to serve as role models for students just beginning to select possible career paths.

- Funding for workshops aimed at graduate students and postdocs, as well as more established scientists, to demonstrate presentation techniques intended for broader public and K–12 audiences.
- Collaboration with one or more universities having nuclear science faculty to develop NSF GK-12 proposals—proposals for graduate teaching fellows who serve as resources for K–12 schools.
- Assistance in coordinating and disseminating information concerning selected community educational programs, such as current programs at Yale and LBNL for first responders to emergencies.
- Liaison with and support for science museums and centers across the country. A catalog of effective science displays would assist not only the science museums, but also a number of universities and organizations seeking to set up hallway science demonstrations. Ideally, this catalog would include sources of relevant equipment or plans for construction of those items not generally available.

Comments by Members of the Nuclear Science Community

In the survey described in Chapter 5 (Ph.D.'s 5–10 Years Later), recent doctoral graduates were asked to suggest how interest in nuclear science might be stimulated. Some of the responses are worth quoting in the context of the proposed outreach center:

> [We need to] market all the related fields and applications [within nuclear science]. Physicists are the worst at marketing their own.
>
> Show off the interesting questions we are trying to answer and the exciting methods we are undertaking to answer them. Make it clear that there are excellent employment opportunities outside the academic sector.
>
> More [positive] exposure [is needed] in the popular press. For too many people, even the word nuclear evokes a very negative response. Unless people think of nuclear science as something other than working to create weapons of mass destruction we will be fighting an uphill battle.
>
> One student [a communications major] said [to a survey respondent], "You guys have a major PR problem." I do agree. It seems to me we need to do a better job (somehow) of getting the word out. NASA has always done a lot of outreach, and I think we need to do something along these lines. You need the general public to get more interested in science in general, but you also need to organize outreach

> programs at the middle school and high school level. And the national labs could do a much better job.

NuPECC stated, in the issue of *Nuclear Physics News* cited earlier [Oberhummer], that they perceive at least three profound reasons to promote understanding of science within our society. With slight modification, we paraphrase here the reasons they give:

- *Cultural reasons*—Nuclear science is an important part of our cultural heritage; it contributes to answering fundamental questions about the structure of matter, the birth and fate of our universe, and the origin of life in the cosmos. It is relevant to our understanding of the environment and the place humankind occupies in nature.
- *Economic reasons*—Technology and innovation are created through science, and that includes nuclear science. Such progress plays an important role in creating wealth and provides one of the driving forces in our society.
- *Sociopolitical reasons*—Scientific literacy among the public is essential as a foundation for rational choices in the intelligent uses of technology. Understanding and communicating the benefits as well as the risks of our modern technologies is a vital component of an advanced society.

Summary and Recommendation

We believe that despite the existence of a number of valuable Web-based resources and meaningful outreach efforts, the dynamism and the future possibilities of nuclear science have been seriously underestimated by many in our society, including some fellow scientists. We firmly believe that this lack of understanding will persist unless resources are provided for a dedicated attack on the problem. We believe this demands the creation of an outreach center staffed by specialists in communications and education who would spearhead a focused effort to articulate the value and importance of nuclear science to society, to research the factors that influence diversity and to develop effective strategies to enhance diversity in nuclear science, to assess and to heighten the visibility of nuclear science in K–12 curricula, and to coordinate outreach efforts by members of the nuclear science community. Accordingly,

We recommend that the highest priority for new investment in education be the creation by the DOE and the NSF of a Center for Nuclear Science Outreach.

The mission of the Center would be to understand the barriers within our society to a widespread understanding and appreciation of the excitement and importance of nuclear science, to develop strategies to effectively communicate the value of what we do to the general public and to scientists in other disciplines, and to coordinate efforts by members of the nuclear science community to do so. The Center should be staffed appropriately, and have sufficient resources, to carry out an effective national program of nuclear science outreach, with the goal of approaching the same level of societal recognition as currently enjoyed in space-based research programs. We would expect this program to lead to an enhanced awareness on the part of legislators and academic leaders of the vital nature of nuclear science in the U.S., and to a greater visibility for the field in the public and professional press.

The structure of the Center, its mode of operation (for example, the extent to which it is networked), and how it might be most effective in cooperating and coordinating with other existing or planned outreach efforts are questions to be answered in future discussions between the proponents and potential stakeholders. There are many valuable ongoing efforts which must be continued. Our intent in making this recommendation is that those efforts be highly leveraged by the plan that is developed. It is our firm conviction, however, regardless of implementation, that the Center for Nuclear Science Outreach must comprise a dedicated resource with a national focus and with dedicated support and specialized expertise in order to be successful. In addition to cooperating with existing efforts, the Center would establish ties with the DNP, the DNP Committee on Education, and the Division of Nuclear Chemistry and Technology of the ACS, for possible assistance in the selection of projects undertaken by the Center and for opportunities for evaluation and feedback on results achieved. We agree with Oberhummer that "if nuclear science and its application are to have a long-time future the community has to make every effort to change public opinion in its favor."

We note in passing that NASA is dedicated to incorporating a substantial education and outreach component into every research program and every space flight mission (see, for example, *http://spacescience.nasa.gov/education/resources/strategy/index.htm*). Currently, it is the policy at NASA that every response to an "Announcement of Opportunity" include an education and outreach component that is 1–2% of the mission cost (*http://ssibroker.colorado.edu/Broker/*). This proposed Center for Nuclear Science Outreach is likely to represent a considerably smaller fraction of the total annual nuclear science budget.

References

Oberhummer: H. Oberhummer, "Public Awareness of Nuclear Science: Why and How," *Nucl. Phys. News* **14**(2), 38–40 (2004).

Weart: S. Weart, *Nuclear Fear: A History of Images* (Harvard University Press, Cambridge, MA, 1988).

Appendices

Appendix A: Charge Letters

The following pages reproduce, first, a letter from the National Science Foundation and the Department of Energy to Richard Casten, the chair of the Nuclear Science Advisory Committee, outlining the charge regarding education in nuclear science; and second, a letter from Professor Casten to Joseph Cerny, the chair of the Education Subcommittee, assigning responsibility for responding to this charge. Portions of the charge letter dealing with other requested studies have been deleted from the copy reproduced here.

U.S. Department of Energy
and the
National Science Foundation

March 4, 2003

Professor Richard F. Casten
Chairman
DOE/NSF Nuclear Science Advisory Committee
Wright Nuclear Structure Laboratory

Yale University
New Haven, CT 06520

Dear Professor Casten:

With this letter the National Science Foundation (NSF) and Department of Energy (DOE) request that the Nuclear Science Advisory Committee (NSAC) provide guidance beyond its recommendations in the most recent Long Range Plan with respect to three specific issues of interest to the agencies.

(1) NSAC is asked to do an assessment of how the present NSF and DOE educational investments relevant to nuclear science are being made and to identify key strategies for preparing future generations of nuclear physicists and chemists.

Education of young scientists is integral to any vision of the future of the scientific field and the nation's nuclear-related activities. It is an important responsibility for both agencies. A substantial fraction of the agencies' research funds is used for support of students at the undergraduate and graduate levels and junior scientists at the postdoctoral level. It is important that these investments be made in an optimal way. Your assessment should take into account such factors as: the necessary qualifications and skills of nuclear scientists and their roles in the public and private sectors; the annual number of Ph.D. degrees presently awarded; the number projected as needed in the future to maintain a world-leadership role in fundamental research and also to meet the nation's needs in applied areas such as nuclear medicine and national security; and the present and projected demographics of nuclear scientists, including the participation of women and under-represented minorities.

Your report should document the status and effectiveness of the present educational activities, articulate the projected need for trained nuclear scientists, identify strategies for meeting these needs, and recommend possible improvements or changes in NSF and DOE practices. Your report should also identify ways in which the nuclear science community can leverage its capabilities to address areas of national need regarding K-12 education and public outreach. We request that an interim report be submitted by September 2003 and a written report responsive to this charge be provided by November 2003.

(2) NSAC is asked to review and evaluate current NSF and DOE supported efforts in nuclear theory and identify strategic plans to ensure a strong U.S. nuclear theory program under various funding scenarios.

. . . .

(3) NSAC is requested to review and evaluate the current and proposed scientific capabilities for fundamental nuclear physics with neutrons and make recommendations of priorities consistent with projected resources.

. . . .

Thank you very much in advance for your efforts on these important issues.

Sincerely,

John B. Hunt Acting Assistant Director Directorate for Mathematical and Physical Sciences National Science Foundation	Raymond L. Orbach Director Office of Science Department of Energy

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OFFICE OF THE DIRECTOR

Dr. Joseph Cerny
Lawrence Berkeley National Laboratory
1 Cyclotron Road, Mail Stop 88R0192
Berkeley, CA 94720-0192

Dear Joe,

On March 4, 2003, the NSF and DOE charged NSAC with a broad-ranging task to assess the educational investments being made by these agencies related to nuclear science. The charge asked NSAC to identify key strategies in order to prepare future generations of nuclear scientists and to maintain a world leadership position in both fundamental and applied areas of nuclear science.

Answering this charge will entail an understanding of current demographics in nuclear science, and of projected needs, as well as an assessment of the status and prospects for the participation of women and minorities in this field. An important issue is the attractiveness of nuclear science-based careers. This will involve an analysis of educational efforts from K-12 through college, graduate school and post-doctoral positions. Public awareness of nuclear science is vitally important as well in order to have an informed electorate in this ever more technological world. This is particularly critical for nuclear science with its myriad applications for national security, energy, medicine, and industry.

With this email, I would like to formally ask you to Chair an NSAC sub-committee to respond to this charge. You have already seen the full charge and can appreciate the extensive work that will be involved. I can only say that this service to the community and the nation is highly important and is being requested at a critical juncture in our nation's scientific and technological journey.

As we have already discussed, the extensiveness of the charge and the obvious benefits of a thorough analysis have led the Agencies to informally extend the deadline indicated in the charge to the Fall of 2004.

I would ask you to present an interim Report on your methodology, results, and key recommendations to an NSAC meeting in the Summer of 2004, and a final Report to NSAC later in the same year.

I thank you and all those who will serve on this sub-committee for the work that lies ahead in responding to this charge and for the ultimate Report which is likely to influence nuclear-science-based educational policies and activities from kindergarten through post-doctoral mentoring for decades to come.

I stand ready to help in any way possible.

Best regards,

Richard F. Casten
Yale University Professor of Physics and Director,
A.W. Wright Nuclear Structure Laboratory
Chair, NSAC

Phone (203) 432-3090 Fax (203) 432-3522 E-mail: rick@riviera.physics.yale.edu

Appendix B: Subcommittee Meeting Schedule and Workshop Agenda

First meeting: August 21–22, 2003, at the National Science Foundation

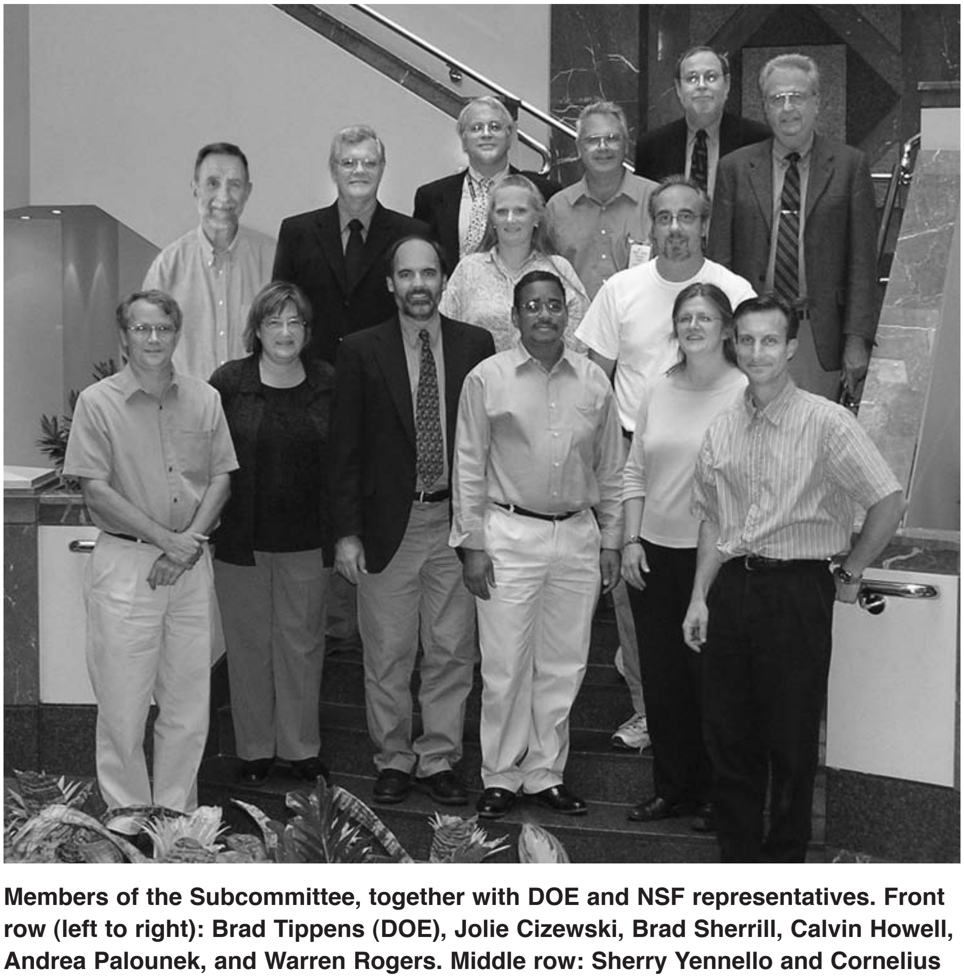
There was a lengthy interval between the first and the second meetings of the Subcommittee. The second meeting was not held until at least preliminary results were available from the surveys of graduate students, postdoctoral fellows, and nuclear science Ph.D.'s five to ten years following their degrees.

Second meeting: February 13–14, 2004, at the University of California, Berkeley

A workshop for the Subcommittee and a few invited guests was held on February 12; the workshop agenda appears on the next page.

Third meeting: April 15–16, 2004, at the National Science Foundation

Fourth meeting: June 21–22, 2004, at the National Science Foundation



Members of the Subcommittee, together with DOE and NSF representatives. Front row (left to right): Brad Tippens (DOE), Jolie Cizewski, Brad Sherrill, Calvin Howell, Andrea Palounek, and Warren Rogers. Middle row: Sherry Yennello and Cornelius Beausang. At rear (left to right): Robert Welsh, Timothy Hallman, Brad Keister (NSF), Richard Casten (chair, NSAC), Dennis Kovar (DOE), and Joseph Cerny (chair).

AGENDA

Workshop for the NSAC Subcommittee on Education
February 12, 2004
Women's Faculty Club Lounge, UC Berkeley

Morning Session: Graduate and Postdoctoral Education

Educating Scientific Leaders in the Physical Sciences and Mathematics.

George Walker, Senior Scholar, The Carnegie Foundation for the Advancement of Teaching, and Professor of Physics, Indiana University

Preparing Future Faculty and the Professional Science Masters.

Gerard Crawley, Dean of the College of Science and Mathematics, and Professor of Physics,
University of South Carolina

Postdocs are Concerned about their Pay, Status, Standards and Roles:
What is Happening at Berkeley, within the UC System and (a bit of) Nationally.

Joseph Cerny, Professor of Chemistry, University of California, Berkeley

Afternoon Session: Workforce Diversity

Do Babies Matter: The Effect of Family Formation on the Lifelong Careers of Academic Men and Women.

Mary Ann Mason, Dean of the Graduate Division and Professor of Social Welfare, University of California, Berkeley

The GradPortal Program.
Gerard Crawley

Initiatives for Increasing Graduate Student Diversity at UCSF and within the University of California System.

Cliff Attkisson, Dean of Graduate Studies, Associate Vice Chancellor of Academic Affairs, and
Professor of Psychology, University of California, San Francisco

Balancing a Culture of Conformity and Divergence: Science Education that Enhances Diversity.

Karan Watson, Dean of Faculties, Associate Provost, and Professor of Electrical Engineering, Texas A & M University

Appendix C: The Three General Surveys

To "document the status and effectiveness of the present educational activities" in nuclear science, the Subcommittee decided, at its first meeting in August 2003, to conduct comprehensive Web-based surveys of (i) the graduate student population, (ii) the postdoctoral population, and (iii) those individuals who had received Ph.D.'s in nuclear science between July 1, 1992, and June 30, 1998. We also agreed to conduct two online surveys of undergraduates involved in REU and CEU programs. The following discussion pertains only to the former surveys, since they did not involve current or recent participants in any specifically directed program in nuclear science. As a consequence, these three surveys fell into the category of social science research studies involving "general populations" and thus required prior approval by Institutional Review Boards for the protection of human subjects. These surveys were therefore approved by the following Institutional Review Boards: Texas A&M University (graduate student survey, disseminated from Yale University), Brookhaven National Laboratory (postdoc survey), and the University of California, Berkeley (Ph.D.'s 5–10 Years Later survey). Complete confidentiality of the responses was assured. Secure passwords were given to each potential respondent, which also allowed them the possibility of completing the survey during multiple sessions.

We obtained names and e-mail addresses for current graduate students and current postdoctoral fellows funded by the Department of Energy or the National Science Foundation by contacting principal investigators in nuclear physics and nuclear chemistry at universities and division heads at national laboratories. Names of their graduates who met the criteria for the Ph.D.'s 5–10 Years Later survey were requested from arbitrarily chosen "head principal investigators" at each relevant university, who were also asked to supply e-mail addresses for these recent graduates. As many of these e-mail addresses were not available, or found to be inaccurate, we subsequently searched for current e-mail addresses by making internet database inquiries of the rosters of appropriate professional societies and by doing general internet searches for individuals (that is, "Google searches"). We also asked recent Ph.D.'s who had been located, if they knew the e-mail addresses (or work locations) of "missing" colleagues from their graduating classes.

Although all three surveys were lengthy, taking 30 to 45 minutes to complete, the response rates were excellent. This was due, no doubt, to the "appeal" materials sent out with the surveys to all the potential respondents, asking them as fellow nuclear scientists to assist their discipline and their colleagues in this study of nuclear science education. Three hundred and fifty-three of the 627 graduate students for whom we had been given e-mail addresses completed the survey, a response rate of 56%; and 225 of the 352 postdoctoral fellows for whom we had e-mail addresses completed the postdoc survey, a response rate of 64%. In the time available, we were able to obtain only 412 accurate e-mail addresses for the 585 known Ph.D.'s in the 5–10 Years Later cohort. Of these, 251 responded, a response rate of 61%. These overall response rates can be compared, for example, with the 39% response rate recently obtained by the American Institute of Physics for their 2001 graduate student report, and to the 42.5% response rate obtained in a 2001 study by C. M. Golde and T. M. Dore of doctoral students in 11 fields at 27 universities [“At Cross Purposes: What the Experiences of Today’s Students Reveal about Doctoral Education,” a report prepared for the Pew Charitable Trusts; see *www.phd-survey.org*].

The Subcommittee would like to thank the faculty, the arbitrarily chosen “head principal investigators,” and the national laboratory division heads for their crucial assistance in providing the names and e-mail addresses of the members of the survey cohorts. We also thank the survey respondents for their invaluable personal assessments of their current (and past) education in nuclear physics and nuclear chemistry. Much has been learned from this unique set of surveys, which will surely contribute to future improvements to education in nuclear science.

Appendix D: Acknowledgments

We thank Winston Roberts at Old Dominion University for valuable advice on outreach and diversity issues and Sally Fisk and Jan Tyler at JLab for educational outreach discussions. We also gratefully acknowledge the extremely helpful and informative conversations with Roman Czujko from the American Institute of Physics. We would like to thank the Physics (or Nuclear Science) Division Directors at ANL, BNL, JLab, LANL, LBNL, LLNL, and ORNL for their valuable help in assessing the present state and the future of the nuclear science workforce at the U.S. national laboratories. The data on the nuclear science workforce at U.S. colleges and universities were compiled by Thomas Kazmiercsak; we greatly appreciate his dedication in completing this many-month task.

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Appendix E: Acronyms

AAAS	American Association for the Advancement of Science
AAPT	American Association of Physics Teachers
AAU	Association of American Universities
ACS	American Chemical Society
AGEP	Alliance for Graduate Education and the Professoriate
AIP	American Institute of Physics
AIP GP	American Institute of Physics Graduate Programs
AIP IER	American Institute of Physics Initial Employment Report
ANL	Argonne National Laboratory
APS	American Physical Society
BGN	business (or industry), government, or nonprofit organizations
BNL	Brookhaven National Laboratory
CEBAF	Continuous Electron Beam Accelerator Facility
CERN	European Organization for Nuclear Research
CEU	Conference Experience for Undergraduates
CHICOS	California High School Cosmic Ray Observatory
COSEPUP	Committee on Science, Engineering, and Public Policy
CPEP	Contemporary Physics Education Project
CPST	Commission on Professionals in Science and Technology
DNP	Division of Nuclear Physics (American Physical Society)
DOE	Department of Energy
GEM	National Consortium for Graduate Degrees for Minorities in Engineering and Science, Inc.
IGERT	Integrative Graduate Education and Research Traineeship
JLab	Thomas Jefferson National Accelerator Facility
LANL	Los Alamos National Laboratory
LBNL	Lawrence Berkeley National Laboratory
LLNL	Lawrence Livermore National Laboratory
MORE	Minority Opportunities in Research
NASA	National Aeronautics and Space Administration
NIH	National Institutes of Health
NPSC	National Physical Science Consortium
NRC	Nuclear Regulatory Commission

NSB	National Science Board
NSF	National Science Foundation
NSF CAREER	National Science Foundation Faculty Early Career Development
NuPECC	Nuclear Physics European Collaboration Committee
NSAC	Nuclear Science Advisory Committee
ORNL	Oak Ridge National Laboratory
REU	Research Experience for Undergraduates
RHIC	Relativistic Heavy Ion Collider
RIA	Rare Isotope Accelerator
RUI	Research at Undergraduate Institutions
S&E	science and engineering
SEAB	Secretary of Energy Advisory Board
SED	Survey of Earned Doctorates (National Science Foundation)
SULI	Science Undergraduate Laboratory Internships
UC	University of California
UMI	University Microfilms
WALTA	Washington Large Area Time Coincidence Array