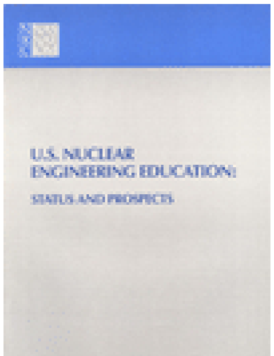

U.S. Nuclear Engineering Education: Status and Prospects

Committee on Nuclear Engineering Education, National Research Council

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U.S. Nuclear Engineering Education: Status and Prospects

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National Research Council

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Preface

This study, conducted under the auspices of the Energy Engineering Board of the National Research Council, examines the status of and outlook for nuclear engineering education in the United States (see Appendix A, Statement of Task). The study resulted from a widely felt concern about the downward trends in student enrollments in nuclear engineering, in both graduate and undergraduate programs. Concerns have also been expressed about the declining number of U.S. university nuclear engineering departments and programs, the ageing of their faculties, the appropriateness of their curricula and research funding for industry and government needs, the availability of scholarships and research funding, and the increasing ratio of foreign to U.S. graduate students. A fundamental issue is whether the supply of nuclear engineering graduates will be adequate for the future. Although such issues are more general, pertaining to all areas of U.S. science and engineering education, they are especially acute for nuclear engineering education.

Impetus for the study came from various sources, including the American Nuclear Society (ANS), the Institute of Nuclear Power Operations (INPO), the Nuclear Engineering Department Heads Organization (NEDHO), and the U.S. Department of Energy (DOE). All were concerned to examine trends in nuclear engineering education and to identify possible solutions if adverse trends were identified. Major funding to conduct the study was provided by DOE, through its Division of University and Industry Programs, Office of Energy Research. INPO and ANS also provided funding.

The Committee on Nuclear Engineering Education was established to include those familiar with science and engineering education, and industrial employment in the nuclear field. Biographical sketches of the committee members are contained in Appendix B.

The committee's charge was to review nuclear engineering education in the United States and to recommend any appropriate responses. Specifically, the committee was asked to perform the following tasks:

- Characterize the current status of nuclear engineering education in the United States, taking into account present faculty and student numbers, existing curricula, availability of research and scholarship/fellowship funds, and other factors as appropriate
- Estimate the supply and demand for undergraduate and graduate nuclear engineers in the United States over the near-to mid-term (5 to 20 years), for scenarios with various assumed trends in the nuclear power industry, the federal laboratories, the Navy, and the universities
- Address the spectrum of material that the nuclear engineering curriculum should cover and how it should relate to allied disciplines
- Recommend appropriate actions to ensure that the nation's needs for competent nuclear engineers, as represented at both graduate and undergraduate levels, are satisfied over the near and mid-term, with consideration of career opportunities, potential student base, research funding, and ensuring an excellent background in individual students. The field of health physics was not encompassed by the study, even though it is covered by many nuclear engineering programs. The committee also did not address the supply, demand, or curricula of two-year nuclear technology programs.

In accordance with this charter, the committee was organized into three subcommittees, on the current status of U.S. nuclear engineering education, the curriculum and research activities, and the supply of and demand for nuclear engineers. These subcommittees were chaired respectively by Robert Seale, Warren Miller, Jr., and Wallace Behnke. The panels obtained appropriate current data through questionnaires, briefings, and other diverse resources. Appendix C lists committee meetings and invited presentations on those occasions. Individuals and organizations who provided information in response to committee requests are acknowledged in Appendix D.

Arrangements to conduct the study were facilitated by Dennis F. Miller, Director of the Energy Engineering Board until November 1987, and by Archie Wood, who succeeded him in December 1987. Robert Cohen served as study director only until January 1990 when he was seriously injured in an accident; James Zucchetto continued as study director through the completion of the study, helping the committee to form and edit this report. John Crawford resigned from the committee in October 1989, with his presidential appointment to the Defense Nuclear Facilities Safety Board.

GREGORY R. CHOPPIN, CHAIRMAN
COMMITTEE ON NUCLEAR ENGINEERING EDUCATION

Contents

List of Tables

List of Figures

Executive Summary

BACKGROUND

Nuclear engineering may be broadly defined as the discipline concerned with the utilization of nuclear processes and nuclear forces in engineering. The first formal U.S. academic programs in nuclear engineering were established in the mid-1950s. These early programs were at the graduate level, primarily emphasizing nuclear physics, reactor physics, and neutron transport analysis. With the emergence of the commercial nuclear power industry, undergraduate programs were established in the early 1960s.

The initial growth of these programs was rapid: 80 nuclear engineering departments and programs had been established by 1975, along with 63 programs in health physics. This rapid growth created faculties composed of those who themselves had been educated—in the absence of nuclear engineering departments—in disciplines such as nuclear physics, radiochemistry, and electrical engineering.

Nuclear science and engineering were glamour fields in the 1950s and 1960s, attracting students who were, on average, well above the norm for science and engineering students. This trend was promoted by the strong growth in the nuclear power industry, a relatively large number of fellowships provided by the U.S. Atomic Energy Commission (AEC), and the ample support of university research programs and nuclear reactors for research and education. The AEC awarded 129 graduate fellowships in nuclear engineering in 1963, and 76 university research reactors were in operation by 1970. Such numbers reflected a national commitment to the development of civilian nuclear power as expressed in the "Atoms for Peace" policy of the Eisenhower administration.

During the last two decades, the national commitment to nuclear applications has weakened considerably. By 1987 only 27 university reactors were operating, and by 1989 the number of nuclear engineering degree programs declined to 39, and nuclear engineering concentrations to 18. Of these, 20 programs had less than 20 students each; 50 percent of the students are in 14 programs. This decline has inhibited the addition of young faculty, who are needed for the long-term quality and vigor of any academic discipline. Over one third of the nuclear engineering faculty are 55 years of age or older, while only 16 percent are 40 or younger. This is approximately 10 years greater than the national average for engineering faculty. In the last decade, there has also been a 30-to 35-percent decrease in the number of undergraduate and graduate students majoring in nuclear engineering. Federal fellowships declined to as few as 8 in 1981, but there has been a modest increase over the past two years, with DOE funding 49 nuclear engineering fellowships (including in health physics and fusion).

This pattern of decline in U.S. nuclear engineering education raises issues that may be vital to implementing U.S. energy policies and practices in the next 20 years. Will the decline in the number of programs continue? Has a "steady-state" condition been attained between the numbers of nuclear engineers being educated and the number that will be required? How will government and industry personnel needs change, if at all, in the next few decades? If demand increases, can programs expand readily to supply the needed personnel? Can any shortfall in supply be met by other physicists, radiochemists, or other engineering specialists? Are better students still being attracted to nuclear engineering? At the graduate level, will faculty research interests and activities be adequate to train the nuclear engineers likely to be in demand in the next few decades? Are current educational programs appropriate for future industry and government needs? What skills and education may be required for the next generation of nuclear engineers? These and similar questions motivated this study.

To better understand the history, status, and future of U.S. nuclear engineering education, the committee interviewed and surveyed experts from academia, industry, and government. It sought a variety of documents, presentations and data to further its work.

Three subcommittees or panels focused on major parts of the study's charge: the status of U.S. undergraduate and graduate education in nuclear engineering, with attention to such aspects as faculty age and research interests, and trends in student populations, curricula, instructional and research facilities, and funding: the educational needs of the next generation of nuclear engineers, with attention to curriculum changes that might be required and the adequacy of current university research programs; and projected personnel supply and demand for periods of 5, 10, 15, and 20 years in the future, for both military and nonmilitary segments of the federal government, industry, and academia. The results of these three panels were integrated to produce this report and its findings, conclusions, and recommendations.

These could serve to make available engineers who, with retraining, could meet some of the needs reflected in this report. However, at this point, the nature and the resultant effects are impossible to evaluate and the committee could not take this possibility into account.

FINDINGS AND CONCLUSIONS

The committee addressed a variety of issues to answer its charge. The following sections summarize the committee's findings and conclusions on nuclear engineering as a separate discipline, the status of nuclear engineering education, supply and demand issues, and future needs for nuclear engineering education.

Nuclear Engineering as a Separate Discipline

CONCLUSION: NUCLEAR ENGINEERING IS A BROAD, DIVERSE FIELD THAT IS VITAL AS A SEPARATE ENGINEERING DISCIPLINE TO U.S. NUCLEAR ENERGY PROGRAMS.

Committee findings that support this conclusion include the following:

- Nuclear engineering has unique academic requirements, including courses in reactor physics, reactor engineering, nuclear materials, reactor operations, and radiation protection.
- Nuclear engineering requires knowledge of an unusually broad combination of mathematics, physics, and engineering processes relative to other engineering areas.
- The complexities of reactor core physics, reactivity control, and radiation effects and protection tend to be handled best by nuclear engineers.
- Nuclear engineering research extends from applied nuclear science through the development of near-term nuclear technologies. The reach is analogous to the electrical engineer's study of broad applications of electromagnetic phenomena or the mechanical engineer's study of fluid mechanics.

Status of Nuclear Engineering Education

CONCLUSION: SINCE 1979, NUCLEAR ENGINEERING ACADEMIC PROGRAMS AT BOTH UNDERGRADUATE AND GRADUATE LEVELS HAVE DECLINED IN TERMS OF (1) THE NUMBER OF STUDENTS ENROLLING IN SUCH PROGRAMS, (2) THE NUMBER OF SCHOOLS OFFERING NUCLEAR ENGINEERING CURRICULA, AND (3) THE NUMBER OF RESEARCH REACTORS ON UNIVERSITY CAMPUSES.

Committee findings that support this conclusion include the following:

- Undergraduate senior enrollments in nuclear engineering programs decreased from 1,150 in 1978 to about 650 by 1988. Enrollments in masters programs also peaked in the late 1970s, at about 1,050 students, and steadily declined to about 650 students in 1988. Since 1982, however, student enrollments in doctoral programs has remained relatively steady at about 600.

- The number of U.S. undergraduate nuclear engineering programs declined from 80 in 1975 to 57 in 1989.
- Two decades ago, 76 U.S. university research reactors were operating. By 1987, only 27 university research reactors were in operation at universities offering nuclear engineering degrees or options in nuclear engineering.

CONCLUSION: TRENDS IN NUCLEAR ENGINEERING PROGRAMS THAT ARE OF CONCERN INCLUDE: (1) A SHIFT IN THE RESEARCH FUNDING AWAY FROM AREAS RELATED TO POWER REACTOR TECHNOLOGY, (2) PROBLEMS IN MAINTAINING LABORATORIES AND EQUIPMENT IN SUPPORT OF NUCLEAR ENGINEERING EDUCATION, (3) THE AGEING OF EXISTING NUCLEAR ENGINEERING FACULTIES AND (4) THE DECLINE IN NUMBERS OF NEW JUNIOR FACULTY MEMBERS.

Committee findings that support this conclusion include the following:

- Currently less than 20 percent of funded research in nuclear engineering programs concerns power reactors, although the greatest demand for bachelor's of science and, to some extent, master's of science comes from the nuclear power industry.
- Because of the shift in research funding, graduate nuclear engineering education no longer focuses primarily on civilian nuclear power, but has broadened to include the utilization of nuclear processes and forces in diverse engineering applications, such as medicine, fusion, materials, and space applications.
- The lack of adequate funding for teaching laboratories and equipment has required curriculum changes, diversion of funds from research, and other actions, to maintain the facilities needed for nuclear engineering programs.
- The average age of U.S. nuclear engineering faculty is about 10 years greater than that of all engineering faculty, and only 18 percent of faculty qualified to teach nuclear engineering have less than 5 years of teaching experience. Failure to introduce young faculty will necessarily limit research development in many institutions and promises serious interruptions in future program continuity.

CONCLUSION: THE CONTENT OF NUCLEAR ENGINEERING CURRICULA IS BASICALLY SATISFACTORY, THOUGH A-FEW MODIFICATIONS ARE SUGGESTED.

Committee findings that support this conclusion include the following:

- Nuclear engineering curricula cover more basic and other engineering sciences than other engineering programs. Formal course work in nuclear science is rarely required for students in other engineering disciplines, yet nuclear engineering curricula generally include more than five credit hours in each of chemistry, mechanics, electromagnetism and electronics, and thermal sciences, enhanced courses in physics, and uniquely, additional required credits in nuclear science.

- The content of nuclear engineering programs is generally appropriate for the needs of employers of nuclear engineering graduates at all levels.
- A survey of organizations that hire undergraduate nuclear engineers indicates a desire for increased oral and written communication skills, better knowledge of the nuclear reactor as an integrated system, and greater understanding of the biological effects of radiation.

Supply and Demand

CONCLUSION: THERE IS NOW A BALANCE IN SUPPLY AND DEMAND FOR NUCLEAR ENGINEERS. HOWEVER, EVEN IF THERE IS NO DEMAND GROWTH IN THE FUTURE, SUPPLY WILL NOT SATISFY EXPECTED DEMAND IF PRESENT TRENDS IN NUCLEAR ENGINEERING EDUCATION CONTINUE.

Committee findings that support this conclusion include the following:

- Current U.S. replacement needs for those with bachelor's, master's, and doctorate degrees in nuclear engineering are about 400 new labor market entrants annually. This demand roughly balances the current output of the educational system.
- During the last decade, while the number of degrees awarded in quantitative fields increased at all degree levels, the number of B.S. and M.S. degrees awarded annually in nuclear engineering decreased. If current demand trends continue, a shortfall in supply will occur and grow with time.
- The potential for increased demand is greater than the potential for increased supply, owing primarily to decreasing student populations. Significant shortages in nuclear engineers may be observed as early as the mid-1990s.

CONCLUSION: THE GROWTH IN DEMAND FOR NUCLEAR ENGINEERS OVER THE NEXT 5 TO 10 YEARS WILL BE DRIVEN BY EXPANDED FEDERAL PROGRAMS. THE PROJECTED INCREASE IN ANNUAL DEMAND OVER THIS PERIOD EXCEEDS THE CURRENT OUTPUT OF NUCLEAR ENGINEERING PROGRAMS. THE PROBLEM IS EXACERBATED IN MANY CASES BY THE REQUIREMENT OF U.S. CITIZENSHIP AND SECURITY CLEARANCES FOR EMPLOYMENT IN GOVERNMENT PROGRAMS.

Committee findings that support this conclusion include the following:

- The expansion of federal programs in areas such as nuclear waste management and environmental remediation and restoration is expected to increase the annual demand for nuclear engineers by about 50 percent and 25 percent, respectively, in 1995 and 2000.
- Although enrollment of foreign nationals in undergraduate nuclear engineering programs has dropped in the last decade from about 7 to about 2 percent, the non-citizen share of graduate student populations has been high in recent years. Currently the non-citizen share of master's and doctoral

candidates represent about 30 and 50 percent of total candidates, respectively.

- The employers of nuclear engineers that require U.S. citizenship and security clearances for employees (including the federal government, national laboratories, and weapons facilities) will be at a serious disadvantage in attracting quality graduates in the projected competitive hiring market.

CONCLUSION: BEYOND THE YEAR 2000, THE DEMAND FOR NUCLEAR ENGINEERS WILL DEPEND ON THE VIGOR AND TIMING OF ANY RESURGENCE OF COMMERCIAL NUCLEAR POWER. SUCH GROWTH COULD DOUBLE OR TRIPLE THE ANNUAL DEMAND FOR NUCLEAR ENGINEERS. THIS DEMAND WOULD GREATLY EXCEED THE OUTPUT OF CURRENT NUCLEAR ENGINEERING PROGRAMS EVEN IF THEY WERE TO EXPAND TO FULL CAPACITY.

Committee findings that support this conclusion include the following:

- If there is a resurgence of nuclear power, the committee's best-estimate projection is that the annual demand for nuclear engineers would increase at least 200 and possibly 300 percent between 2000 and 2010.
- Most nuclear engineering programs have the capacity for only modest expansion of either undergraduate or graduate populations without additional resources and faculty. To expand the undergraduate population would require diverting faculty and resources from the graduate and research programs and vice versa making major expansion at both levels together difficult. Undergraduate expansion is primarily limited by laboratory resources while graduate student expansion is primarily limited by resources for research and faculty for supervision. Continued erosion in faculty size over the next 5 to 10 years will limit institutions' ability to respond to increased demands for nuclear engineers in a timely fashion. Just using existing faculty engaged in sponsored research would require additional financial resources.

Training and Education for Future Needs

CONCLUSION: THE UNDERGRADUATE CURRICULUM FOCUSES ON POWER REACTOR SCIENCE AND TECHNOLOGY AND THIS EMPHASIS WILL CONTINUE TO BE APPROPRIATE IN THE FUTURE FOR MOST UNDERGRADUATE ENGINEERS WHO WILL ENTER THE UTILITY INDUSTRY OR THE ENGINEERING OR MANUFACTURING INDUSTRIES THAT SUPPORT THE UTILITIES. MODEST BROADENING OF THE CURRICULUM IS DESIRABLE TO ADDRESS EMERGING REQUIREMENTS IN ENVIRONMENTAL AND SAFETY AREAS. IN GRADUATE PROGRAMS, RESEARCH RELATED TO POWER REACTORS HAS DECLINED GREATLY AS AVAILABLE RESEARCH FUNDING HAS BEEN DIVERTED TO OTHER AREAS. RESEARCH RELATED TO POWER REACTORS NEEDS TO BE EXPANDED TO ENSURE THAT FACULTY RETAIN THE SKILLS AND ENTHUSIASM NECESSARY FOR THE UNDERGRADUATE CURRICULUM, WHICH IS DOMINATED BY POWER REACTOR TECHNOLOGY.

Committee findings that support this conclusion include the following:

- Bachelor of science graduates need strong skills in areas relating to nuclear power reactors because they are very likely to be employed in the nuclear power industry. This is also true, though less so, of master of science graduates.

- Nuclear engineering curricula are properly focused on the fundamentals of the discipline but need modest broadening to respond to the following trends: the growing use of integrated systems approaches to evaluate reactor safety and risks, increased interest and concern about the biological effects of radiation, greater emphasis on radioactive waste management and related environmental remediation technologies, and the widely shared opinion of employers that graduates need improved oral and written communications skills (a concern common to all engineering disciplines and especially a problem given the many foreign students).
- Currently there is a broad employment market for Ph.D.s in nuclear engineering, with the power reactor industry playing only a modest role.
- Over the past 10 to 15 years, power reactor research has substantially declined. There has been some increase in research on fusion, space power applications, medical applications, and waste management. While research support levels are inadequate for the discipline, a broader-based research program on applications of nuclear forces and processes has emerged.
- There is a significant and growing mismatch between the research interests of the faculty and the subject matter of the undergraduate curricula.
- University research reactors have substantially declined in number over the past two decades. These reactors are important assets for training, research, and testing for the nuclear engineering programs that have them, and can substantially add to the undergraduate and graduate educational experience.

RECOMMENDATIONS

The responsibility for a viable nuclear engineering education system is shared by the federal government, private industry, and the academic community. Because the likely near-term shortage (in the next 5 to 10 years) of nuclear engineers would largely owe to expanded government programs, DOE has added responsibility for near-term solutions (also see Chapter 7, Summary and Recommendations). Based on the study's findings and conclusions, the committee offers the following recommendations to decision makers in the three responsible sectors.

Responsibilities of the Federal Government

- Funding for traineeship and fellowship programs should be increased.
- Additional research funds should be made available to support work on nuclear power reactors, especially for innovative approaches. Increasing the existing DOE research program from $4 million to $11 million per year is recommended.

- Programs to attract women and minorities into nuclear engineering should be enhanced, a need sharpened by demographic trends.
- DOE should consider providing funds for nuclear engineering participation in minority-oriented science and technology initiatives, notably those being established by the National Science Foundation.
- DOE should assess supporting the access, for educational purposes, of all nuclear engineering departments to the research reactors in the United States.
- DOE should ensure that its personnel data base in nuclear engineering, based on its Survey of Occupational Employment in Nuclear-Related Activities, promptly and accurately reflects supply and demand. Several actions should help accomplish this:

  - The definitions of the discipline and job skill requirements should be revised and clarified to better match those used by the sectors being surveyed.
  - Survey methods should be revised to ensure that no temporary assignments or offices are excluded and that all sectors of nuclear-related employment and all appropriate employees more generally are included.
  - Survey questions and format should be reviewed both by professional questionnaire experts and by sector practitioners, to ensure thoroughness, consistency and clarity.
  - The present exclusion from DOE personnel data of those in the fields of fusion, education and academia, and the health-care industry, and of uniformed military personnel should be reexamined.

Responsibilities of Industry

- While the projected near-term need owes largely to government programs, any increased longer term need for nuclear engineers is likely to arise from the resurgence of nuclear power. For this reason, electric utilities and the supporting industry should increase their participation and support to help ensure the supply of properly trained people their programs will require. Such support should cover cooperative student programs, research sponsorship, scholarships and fellowships, seminar sponsorship, and establishing and supporting academic chairs.
- Industry should continue working with the American Nuclear Society in support of its strong advocacy for nuclear engineering education, and with other professional societies, such as the American Society of Mechanical Engineers and the Institute of Electrical and Electronic Engineers, that support the industry through codes and standards.

Responsibilities of Universities

- Nuclear engineering curricula should continue to be broad based. At the undergraduate level, however, programs should increase their emphasis on systems-oriented reactor engineering, study of the biological effects of radiation, and oral and written communication skills. At both undergraduate and graduate levels, more emphasis should be given to nuclear waste management and environmental remediation and restoration.

- Research programs should include more research in reactor-oriented areas.
- Nuclear engineering faculty should actively develop and seek support for research related to power reactors, nuclear waste management, and environmental remediation.
- University administrators should develop innovative procedures, such as partial or phased retirement of older faculty to retain access to their special capabilities and skills, to allow the addition of junior faculty in a timely fashion.

1

Introduction

STUDY GENESIS AND BACKGROUND

From 1960 to 1975, U.S. nuclear engineering education expanded in response to growth in the nuclear power industry. However, since the late 1970s, this educational infrastructure has contracted with the significant decrease in U.S. orders for nuclear power reactors (U.S. NRC, 1980; Campbell, 1988), a slower growth of electrical power demand than projected, and unfavorable and uncertain economics in the current regulatory environment. Enrollments in nuclear engineering programs have dropped and several nuclear engineering programs have closed (Table 1-1). From a peak of about 850 in 1980, the number of bachelor's degrees awarded has declined to less than 500 in 1988. A decline in government support has also led to reductions in scholarship, fellowship, and research funds, and prevented timely replacement and upgrading of equipment; an increasing portion of research equipment has become obsolete.

Nevertheless, a widespread perception among students that the demand for nuclear engineers is declining is not correct. Nuclear engineers are not only in demand by the civilian power industry, but are also needed in the federal government, especially in the Department of Energy (DOE). In addition to the traditional R&D needs of national laboratories, the cleanup of sites of the DOE complex, for example, will require much expertise in nuclear engineering. Additionally, nuclear engineering training is suitable for work in fields beyond reactor engineering, such as applied physics, accelerator physics and engineering, radiation physics, nuclear medicine, and fusion.

Given the nuclear engineering enrollment trends, what will happen to fields that require nuclear engineers in the future? For example, total U.S. electricity consumption has been increasing and will probably continue to increase (EIA, 1990). In addition, as existing nuclear electric power plants age, life extension or replacements will be required. Further, environmental, economic, and national security concerns could increase the need for nuclear-generated electricity as part of the U.S. energy mix. If an increased demand for such electricity leads to new power plant orders in the 1990s, will appropriately trained nuclear engineers be available for the plants' timely and economic operation? Will nuclear engineers be available to meet the national needs of DOE? Will they be available for the wide array of other technical areas?

TABLE 1-1 Programs with Nuclear Engineering Majors and Options, 1975-1989[a]

Program	1975	1980	1985	1987	1989
Schools offering a nuclear engineering major	50	44	44	41	39
Schools offering only an option in nuclear engineering	20	19	21	20	18
Total programs	70	63	65	61	57

[a] Data represent both undergraduate and graduate programs.
SOURCE: Data provided by the U.S. Department of Energy, Office of Energy Research, Division of University and Industry Programs and Oak Ridge Associated Universities.

SCOPE AND TASKS OF THE STUDY

To address these issues about the decline of nuclear engineering education and its national implications, the committee undertook several tasks (see Appendix A for the complete statement of task):

- Characterizing the status of nuclear engineering education in the United States
- Estimating the supply and demand for undergraduate and graduate nuclear engineers in the United States over the near-to mid-term (5 to 20 years)
- Addressing the spectrum of material that the nuclear engineering curriculum should cover and how it should relate to allied disciplines
- Recommending appropriate actions to ensure that the nation's needs for nuclear engineers at both graduate and undergraduate levels are satisfied over the near-and mid-term.

Part of the committee's formal charge was to "examine the curriculum used in France, Japan and other countries, as appropriate, for strengths that might be applicable in the United States." The committee made an effort early in the study to obtain data on curricula in foreign countries. It soon became obvious that this task required time and resources well beyond those of the committee. Preliminary data indicated that the educational systems are so different that the curricula could not be readily evaluated for the U.S. education system. For some background see Rydberg (1988) and IAEA (1980, 1986). The committee also recognizes that continuing education is important, as outlined in a recent report (NAE, 1988); this subject is not addressed here.

ORGANIZATION OF THE STUDY AND REPORT

Beyond reliance on its members' expertise, the committee invited a number of experts to provide briefings on pertinent issues (see Appendix C). The committee was divided into three panels: one to evaluate the status of nuclear engineering education, a second to study the educational needs of the next generation of nuclear engineers, and a third to project the supply and demand for nuclear engineers for the next 5, 10, 15, and 20 years. The three panel reports provided material for the integrated final report here.

This report consists of seven chapters. Chapter 2 provides a brief background description of the nuclear technology field, how it has evolved, and how the nuclear engineering profession has evolved with it. Chapter 3 analyzes and projects the U.S. demand for nuclear engineers. Chapter 4 gives a detailed summary of the current status of nuclear engineering education. Chapter 5 evaluates trends in the educational system and their relevance to the future supply of nuclear engineers. Chapter 6 identifies changes in nuclear engineering education to address the imbalance that appears to be emerging between supply and demand. Finally, Chapter 7 summarizes the report and provides recommendations.

The appendixes contain some background information. Appendixes A to D provide the statement of task, committee members' background, study activities, and acknowledgments. Appendix E describes the demand model used in Chapter 3. Appendix F contains more detailed tables and data on the supply trends in education discussed in Chapter 5 and information gathered from the committee's questionnaire to nuclear engineering departments; Appendix G contains the questionnaire.

The reader should note that the DOE data base on nuclear-related activities is maintained by the Oak Ridge Associated Universities (ORAU). In the text, references to either the ORAU data or the DOE data are synonymous.

2

The Evolution of Nuclear Technology and the Nuclear Engineering Profession

Nuclear technology has undergone extensive development since the end of World War II. The nuclear engineering profession, originally concerned mainly with the design of nuclear power plants, has been applied increasingly to solve other problems, as in radioactive waste management, health and medical applications, space applications, and accelerator physics and engineering. In response to the field's broadening scope, nuclear engineering education has also evolved, if not in the same direction, in both undergraduate and graduate programs.

A BRIEF HISTORY OF NUCLEAR TECHNOLOGY

Following the development of nuclear weapons during World War II, the U.S. government devoted substantial resources to developing nuclear energy for peaceful purposes. In 1946 President Truman signed into law the Atomic Energy Act, which gave rise to the Atomic Energy Commission (AEC) and the Joint Congressional Committee on Atomic Energy. Although the bill stressed civilian applications of nuclear power, the AEC was at first preoccupied with building a stockpile of nuclear weapons and with other defense applications. In 1954, the first nuclear-powered submarine, the *U.S.S. Nautilus*, was launched.

Under President Eisenhower, the Atoms for Peace initiative and the Atomic Energy Act of 1954 set the stage for the development of civilian nuclear power in the private sector. The AEC announced its Power Reactor Demonstration Program in 1955, providing R&D funding with utility companies building and operating prototype nuclear power plants. Through this program the Westinghouse Electric Corporation built the first nuclear power plant connected to a commercial grid in Shippingport, Pennsylvania. This 60-megawatt plant began operations in 1957 (Adato et al., 1987). By the late 1950s, and through the 1960s, there was a strong national commitment to civilian nuclear power. In the late 1960s there was rapid commercialization and expansion of nuclear power, and through much of the 1970s many new plants were planned in anticipation of the expected growth of electricity demand.

U.S. development and commercialization of nuclear power for electricity slowed considerably in the late 1970s, leading eventually to the cessation of new plant orders and the cancellation of a substantial number of previously ordered plants; in the 1980s many other plant orders were also cancelled (U.S. Nuclear Regulatory Commission, 1980; Campbell, 1988). A number of events and trends have led to the situation today, when it is highly unlikely that a utility would order a nuclear power plant under present conditions. Concerns about safety and the potential release of radioactivity have led to increasing regulation of nuclear power plants. These concerns were increased by the Three Mile Island nuclear plant accident in 1979. Energy price increases in the 1970s stimulated intense efforts in energy conservation, which unexpectedly lowered electricity demand. In 1986 a severe accident at the Chernobyl nuclear power reactor in the Soviet Union released significant amounts of radioactivity into the environment. Although this reactor used a different technology than U.S. civilian reactors, the event further increased public concern about nuclear power.

Despite these problems, the percentage of U.S. electricity supplied by nuclear power is approaching 20 percent (many plants ordered in the 1970s are just now coming into service), and a number of trends could lead to new nuclear power plant orders with a significant impact on the need for nuclear engineers. These trends are discussed below (see Chapter 3).

THE EVOLUTION OF THE NUCLEAR ENGINEERING PROFESSION

The nuclear engineering profession and associated education have evolved in response to the development of nuclear energy. Nuclear engineering education began soon after World War II. The Manhattan Project was dominated initially by physicists, to design the active core, and later by chemists and chemical engineers, to develop processes for production of weapons materials. The college faculties who signed the first nuclear engineering curricula soon after World War II came from this orientation. These early programs were heavily weighted toward physics, especially nuclear physics, and toward materials of special interest to nuclear weapons. Later, with the introduction of military and commercial nuclear reactors, nuclear engineering graduates were employed in the design and engineering of reactors and in reactor R&D in national laboratories. The curricula evolved to cover more reactor engineering areas, such as heat transfer, reactor control, structural materials, radiation effects, and radiation shielding. Of continuing interest were power generation and extraction of energy from the reactor core.

With no new nuclear power plants ordered since 1978, the employment of nuclear engineers (especially those with graduate degrees) has recently developed in many directions other than nuclear reactor design. Additionally, as the nuclear power reactor industry has matured, it has come to need a larger set of nuclear engineering skills.

Thus, a number of influences are broadening nuclear engineering education. More specifically, some of these trends are the following:

- Utilities have increasingly needed nuclear engineers with bachelor's, rather than graduate, degrees, for the operations, training, and maintenance related to the more than 100 U.S. licensed nuclear reactor plants. There have also been increasing requirements in systems engineering, biological effects, and professional communication. These needs will likely continue to increase. The Nuclear Regulatory Commission, the Institute for Nuclear Power Operations and others have all recognized the value of increased education and training for control room supervisors. Other utility engineers are also expected to be trained in reactor physics and shielding, the mainstays of nuclear engineering education, in addition to their principal field of engineering.
- Even in the more classical reactor engineering areas, there is now strong emphasis on the formal requirements of licensing and reactor safety technologies from the initial stages of reactor design, as well as reactor core design and energy extraction. As plants age and as they are retired, properly trained nuclear engineers to ensure continued safe operation of older plants and of safe shutdown and disassembly of retired plants will be required.
- With the lack of orders for commercial power reactors, research programs in traditional reactor physics and engineering areas have decreased dramatically. Research funding for universities in these fields has decreased as Dou's Office of Nuclear Energy has focused its funding on the national laboratories and industry. Funded research in reactor physics, thermal hydraulics, nuclear materials, and areas related to energy production and energy extraction from the reactor core has sharply declined at universities. Research related to commercial power reactors represents only about 15 percent of total research (see Chapter 4).
- Recent concern over environmental issues for nuclear weapons production facilities indicates a need for engineers with training to contribute to the cleanup and eventual disposal of radioactive and mixed-waste contamination at these facilities. Nuclear engineers educated in nuclear systems, radioactive processes, and the effects of radiation on materials and biological systems are needed for these emerging programs. Programs for both high-and low-level radioactive waste disposal will increasingly require nuclear engineers. The funding available for work

associated with nuclear processes may be dominated by this field over the next few decades.

- Although with appropriate training, scientists and engineers in other disciplines can substitute for nuclear engineers, to the extent they are available, this is not the most efficient way to ensure a pool of trained personnel with the requisite skills. Moreover, substantial personnel shortages in all types of science and engineering are predicted by the year 2010, so that the feasibility of retraining engineers in nuclear technology will diminish (Atkinson, 1990).
- With growing public concern over radiation, there is an increasing need for engineers knowledgeable in health physics and in the biological effects of ionizing radiation. Traditionally, these have been adjunct areas in nuclear engineering programs and are often included in nuclear engineering programs.
- Medical applications of nuclear processes have expanded greatly in the last decade, generating a market for graduates who can work both in the design of medical equipment using nuclear effects and in the diagnostic and therapeutic uses of this equipment.
- Funding for nuclear fusion R&D has declined markedly in the past few years but the field still has considerable financial support. Although the ratio of students with an interest in fusion to those with an interest in fission in nuclear engineering programs is small, it is the committee's impression that it has increased since the 1970s.
- Many aspects of the U.S. Department of Defense's Strategic Defense Initiative (SDI) and the National Aeronautics and Space Administration's space applications need the talents of persons with nuclear engineering education. These are both reactor-and nonreactor-oriented needs. Significant funding for research projects has been available in recent years. In the absence of R&D funding in the nuclear reactor field, nuclear engineering faculty have switched their research (and that of their graduate students) to these fields.
- Research in general and nonreactor applications of nuclear processes has experienced new vigor. Applications include gamma-ray lasers used in basic research and instrumentation for nuclear weapons treaty verification. Many such emerging research opportunities use nuclear engineering faculty and graduate students.

THE ROLE OF TECHNICAL SOCIETIES

The American Nuclear Society (ANS) has a major role in the institutional development of nuclear engineering. Specific ANS activities include the following:

- Participation in the engineering accreditation activities of the Accreditation Board for Engineering and Technology (ABET), including advocacy of nuclear engineering as a discipline

- Development of ANS General and Technical Division scholarships in nuclear engineering
- Support of minority and women student recruitment and scholarships through the ANS Nuclear Engineering Education for the Disadvantaged (NEED) program
- Coordination of its activities to support the profession with those of local sections and student organizations.

Others, such as the American Society of Mechanical Engineers and the Institute of Electrical and Electronic Engineers also support the nuclear industry, especially in the area of codes and standards (as does ANS). Both have nuclear application divisions with education-related activities.

SUMMARY

Nuclear engineering has changed considerably since the 1950s and 1960s, when curricula were first established. Today, nuclear engineers with bachelor's degrees often require the kind of systems knowledge to manage the operations, maintenance, and licensing for the safe and economic operation of commercial nuclear plants. The research directions of nuclear engineering faculties have broadened, moving away from traditional areas of importance to nuclear power. They have also shaped educational curricula.

3

The Nuclear Engineering Job Market

INTRODUCTION

This chapter summarizes U.S. demand for nuclear engineers with bachelor of science (B.S.) or higher degrees over the next 20 years. The committee considered three scenarios (high, best-estimate, and low) for projecting demand. The best-estimate scenario indicates that demand for nuclear engineers will increase substantially. In addition to nuclear engineers, there is a large population of degreed personnel in technical fields who have taken some academic courses in nuclear science and technology. The demand for these individuals is expected to grow proportionally. Such growth will clearly have an impact on academic nuclear engineering departments.

For the purpose of this demand analysis, nuclear engineers are defined as individuals who, according to their employers, serve in jobs requiring the knowledge and skills of a B.S. or higher level degree in nuclear engineering. For historical reasons, many of these employees hold degrees in the physical sciences and other engineering fields, supplemented by some coursework in nuclear engineering. With increasing emphasis on highly trained engineers, it is expected that employers seeking replacements for these individuals will endeavor to hire degreed nuclear engineers.

The committee recognizes the existence of and need for two-year nuclear technology programs and the fact that, under some circumstances, graduates of these programs do, in fact, relieve the workload on B.S. graduates in nuclear engineering. However, an analysis of the two-year programs was not undertaken as part of this study.

The committee also recognizes that, to some extent, a shortage in the supply of nuclear engineers could be met through employment of other engineers and scientists, although they would need supplemental training. However, at present, the need is for a higher order of engineering excellence and more extensive application of engineering skills than in the past, and technical expertise is increasingly being recognized as an important qualification for high-level leadership positions in nuclear-related activities. Thus, data based on historic standards and practices are likely to be misleading in evaluating the extent to which recruitment from other fields can help solve a shortage in nuclear engineering.[1]

The committee has been unsuccessful in obtaining assessments of the future number of nuclear engineers expected to be employed by Department of Energy (DOE) subcontractors (as opposed to prime contractors such as the national laboratories) for work related to new DOE initiatives in environmental remediation and waste management and also for defense programs. However, most of these subcontractors have been covered elsewhere in our census of nuclear engineers and the committee believes that the number omitted from its analysis is sufficiently small so as not to affect the findings and conclusions. Also not included in this study are the relatively small number of nuclear engineers employed by organizations doing work unrelated to nuclear energy, for example, computer manufacturers. Nor are the small number of nuclear engineers employed by state agencies included. These omissions may encourage underestimating the demand projections.

EMPLOYMENT HISTORY

In 1987, the most recent year for which data were available, 11,640 civilian nuclear engineers were employed in the industry and government segments as shown in Table 3-1. Of this total, 1,970 were associated with the Department of Defense (DOD), 1,640 with the DOE complex, and the remaining 8,030 with the civilian nuclear power industry (electric utilities accounting for 2,040), distributed across the other segments indicated in Table 3-1. There were also about 450 nuclear engineers serving in the military services. Further, the committee estimates that about 270,000 persons work in the nuclear industry, about one-third with degrees in the physical sciences or other engineering fields and with some nuclear coursework. These individuals could be replaced with individuals having similar qualifications rather than with degreed nuclear engineers.

[1] The data on civilian nuclear engineering employment used in this study are based on employment surveys conducted for the U.S. Department of Energy by the Labor and Policy Studies Program of the Science/Engineering Education Division, Oak Ridge Associated Universities and the Department of Defense Manpower Data Center. This information was validated by data provided for this study by the Department of Energy and the industrial employers of nuclear engineers listed in Appendix D. Data on the number of nuclear engineers employed by or serving in the armed forces were provided by the military services.

TABLE 3-1 Employment of Civilian Nuclear Engineers of All Degree Levels by Primary Government and Industry Segments, 1981-1987

Segment	1981	1983	1985	1987	Change, 1981 to 1987
Fuel cycle and waste management	200	340	210	520	320
Reactor and facilities design, engineering, and manufacturing	1,400	1,460	1,700	1,860	460
Reactor operations and maintenance					
Utility employees	1,	200	1,740	2,030	2,040
Nonutility employees	100	310	630	1,660	1,560
Nuclear-related education and research					
Education & fission research	1,500	1,410	1,460	1,640	140
Fusion research	650	600	500	400	-250
Weapons development and production	200	220	310	320	120
Federal government employees					
Department of Energy	180	327	265	262	82
Nuclear Regulatory Commission	820	586	595	658	-162
Department of Defense	1,180	1,547	1,680	1,970	790
Other	650	1,380	950	310	-340
Total employment	8,080	9,920	10,330	11,640	3,560

SOURCES: Biennial surveys by Oak Ridge Associated Universities (ORAU) for the U.S. Department of Energy, data provided by employers to the National Research Council Committee on Nuclear Engineering Education, and data developed by ORAU from the surveys of scientists and engineers sponsored by the National Science Foundation. The DOE/ORAU survey data have been validated using additional information and corrections obtained by the Committee on Nuclear Engineering Education. Department of Defense data were supplied by the Defense Manpower Data Center.

Table 3-1 shows the distribution of civilian nuclear engineering employment by segment from 1981 through 1987. Civilian employment in this context encompasses the federal governmental agencies and their contractors, and industry and utility jobs associated with civilian nuclear power. The civilian data exclude individuals serving in uniform with the military services. Reactor operations and maintenance account for the largest concentration of employment, 32 percent of the total in 1987; federal government employees, the second largest category, accounted for 25 percent. Other employment categories include reactor manufacturers, architect-engineers, consulting, and faculty associated with the university-based engineering programs, in 1987, 41 offering degrees in nuclear engineering and 20 offering nuclear engineering options in other engineering degree programs.

Civilian nuclear engineering employment increased by 44 percent between 1981 and 1987. Utility employment of nuclear engineers grew by 70 percent over the period, primarily as a result of an increase in the number of nuclear power plants licensed to operate (from 72 to 106) and activities stemming from the Three Mile Island nuclear power plant accident in 1979. The growth of federal nuclear engineering employment largely reflected an increasing emphasis on military preparedness between 1981 and 1987. With all but a few of the nuclear power plants that were begun in the 1970s now in service, and with no unfilled orders for additional plants, industry nuclear engineering employment is expected to remain at about current levels for at least the next five years.

EMPLOYMENT FORECAST

A forecast of U.S. nuclear engineering employment has been made by the committee for 5, 10, 15, and 20 years into the future based on what are regarded as reasonable assumptions about the principal factors that will determine those employment levels (see Appendix E). For purposes of this analysis, civilian nuclear engineering employment is divided into three categories: (1) DOE and its prime contractors, (2) other federal and state government agencies and their prime contractors, and (3) the civilian nuclear power industry. Although included in our forecast, Ph.D. holders are discussed separately because the market for their skills is so different. Our forecast is based on three scenarios: low growth, high growth, and the committee's best estimate. The high-growth and low-growth cases are regarded as unlikely but provide some bounding values.

The best-estimate scenario consists of three components: (1) DOE and its contractors data (see Table 3-2 and Table E-4 for more detail); (2) other governmental agencies and contractors data, assumed to remain constant over the study period for all three scenarios (except for the Strategic Defense Initiative Organization); and (3) civilian nuclear power industry data based on the Electric Power Research Institute's (EPRI's) estimates of potential contributions of nuclear power to the nation's electrical needs with a conservative five-year delay in implementation included. The committee's assumption of a five-year delay was derived from discussions with senior electric utility executives who indicated that the most likely date for a resumption of nuclear plant orders would be around the year 2000.

The Department of Energy and Its Contractors

The federal demand for nuclear engineers over the next five years will result primarily from replacement needs and the requirements of DOE's initiatives in such areas as environmental remediation, nuclear waste disposal, new production reactors, defense-related and nuclear energy R&D programs, and augmentation of the agency's nuclear engineering staff. Much will depend on the funding requested by the administration and appropriated by Congress. Proceeding with these initiatives according to current schedules could soon significantly increase the number of nuclear engineers required by DOE for both reactor and nonreactor-related activities.

DOE provided the committee with its projections of nuclear engineering employment for the agency itself and for its contractor system, based on both high-growth and best-estimate scenarios. The assumptions for its growth scenarios are listed in Appendix E (Table E-2). These data have been summarized by Oak Ridge Associated Universities (ORAU) and are shown in Table 3-2. The data received from DOE and its contractors reported only the nuclear engineering needs. While other types of engineers or scientists might be able to substitute for nuclear engineers in some situations, for most such types (such as environmental, mechanical, or chemical engineering) high demand and labor shortages are just as likely as for nuclear engineers.

TABLE 3-2 Actual and Projected Employment of Nuclear Engineers for DOE Headquarters, Field, and Contractors, 1987-2010

	Employment Scenario		
Year	High Growth	Best Estimate	Low Growth
1987	1,640	1,640	1,640
1995	4,010	2,940	1,740
2000	4,950	3,140	1,840
2005	5,720	3,230	1,840
2010	7,620	3,310	1,840

SOURCE: U.S. DOE (1989)

Other Government Agencies and Contractors

Economic, political, and strategic factors could alter the federal government's needs for nuclear engineers. However, in the absence of related information, the committee assumed that nuclear engineering employment in non-DOE government agencies (not including the Nuclear Regulatory Commission), the military services, and associated contractor services will remain relatively constant at 1,970 personnel over the study period for all three scenarios.

Another exception to this assumption concerns the Strategic Defense Initiative (SDI) Organization (SDIO). SDIO requirements for employment of nuclear engineers are expected to increase if nuclear power is selected as the primary source of power for a significant number of SDI satellites (see Appendix E, Table E-5). The highest projected SDIO employment requirements were calculated in the high-growth scenario. These requirements are projected for 1995 to be 300 nuclear engineers, for the year 2000 to be 600, for 2005 to be 1,500, and for 2010 to be 2,000 (Monahan, 1989). The best-estimate scenario does not include SDIO requirements, because present international developments may result in a decreased SDIO program.

Civilian Nuclear Power Industry

The civilian nuclear power industry is the principal nongovernmental market for nuclear engineers holding bachelor's and master's of science degrees. Replacement needs alone will create a significant demand. The committee believes that environmental concerns, such as about global warming, and possible rising costs of electricity generated from fossil fuels may result in a resurgence of nuclear power plant orders in the United States. These factors could have a significant impact on nuclear engineering employment, depending upon their timing and vigor. In interviews with utility chief executive officers (CEOs), the committee was told that the most likely date for a resumption of nuclear power plant orders would be around the turn of the century. These CEOs pointed out that this resumption would have to be preceded by further revisions of the nuclear licensing process to reduce the financial risks and exposure to excessive delays associated with existing law. It would also require a satisfactory resolution of the problems encountered in the federal nuclear waste management program.

The committee believes that a primary determinant of nuclear engineering employment in the civilian nuclear power industry is the number of nuclear power plants on order, under construction and in service. The committee's forecast relies on a mathematical model developed by Dr. William F. Naughton, consultant to the committee, in which the independent variables are time and the number of committed nuclear power units (see Appendix E). The model assumes that any reductions in demand for nuclear engineers arising from the use of advanced technologies, such as computer-aided design, would be smaller than other uncertainties. This impact was not quantified and could reduce the projected demand estimate slightly.

For purposes of this study, it is assumed that few, if any, of the 111 nuclear power units currently licensed to operate or nearing service will be retired before the year 2010. Even if some are retired, the nuclear engineering employment needs associated with decommissioning are likely to offset the reduction in employment of engineers for plant operations and maintenance. The committee further assumes that utility staffing for the nuclear plants under active construction and nearing service is essentially complete. Because of the uncertain outlook for the inactive projects still on the books, they have been omitted from this analysis.

The Electric Power Research Institute (EPRI) was designated by the electric utility industry to provide the committee with a forecast of the earliest realistic date at which the U.S. electric utilities could be expected to begin ordering new nuclear power plants for public utility systems and an estimate of the rate at which such new orders could be expected in the years covered by this study. EPRI supplied a comprehensive analysis of the outlook for electricity demand and potential generating resources based on a range of average annual peak load growth rates from 1 to 3 percent, and various assumptions about contributions from load management, plant life extension, imports, and nonutility generation. EPRI's best-estimate case assumes a 2.6-percent annual growth in electricity demand through the year 2000, followed by a decade of 1.5-percent annual growth, with a 10-percent chance these growth rates will be exceeded.

EPRI's median estimate translates into 170 gigawatts (electric) (GWe) of new generating capacity by the year 2000 and over 300 GWe by 2010, some fraction of which will be met by nuclear power. EPRI observed that a resumption of nuclear power plant orders appears more likely than at any time in the past decade, given such recent events and trends as the Nuclear Regulatory Commission's new combined license rulemaking (10 CFR 52), increased congressional interest in one-step nuclear licensing legislation, growing awareness and concern about the environmental damage being created by combustion of fossil fuels, and changes in public attitudes about the supply of electric power stemming from shortages that occurred in some areas of the country last year. EPRI concluded that as much as 10 percent of the new base load electric generating capacity required by the year 2000 could be provided by nuclear plants with new orders placed as early as 1993. This figure could increase to 15 percent of new capacity from 2000 to 2005 and to 30 percent from 2005 to 2010.

The EPRI estimate was used in forecasting nuclear engineering employment for the high-growth case. The low-growth case assumes no new orders are placed before the year 2010. The best-estimate case assumes a resurgence of orders beginning, as predicted by the utility CEOs, in the year 2000, with nuclear power accounting for 10 percent of new capacity through the year 2005 and for 20 percent of new capacity through the year 2010. Table 3-3 shows the amount of additional nuclear capacity assumed in making the employment forecasts. The committee also assumed that two-thirds of the newly committed reactors will be 1,200 megawatts (electric) (MWe), advanced light water reactors and one-third will be 600 MWe class advanced designs with passive engineered safety features.

TABLE 3-3 Projected Cumulative Additional Nuclear Power Plant Capacity Ordered by U.S. Utilities, for Three Different Scenarios (in GWe)

	Scenario		
Year	High Growth	Best Estimate	Low Growth
1990	0	0	0
1995	0	0	0
2000	18	0	0
2005	59	18	0
2010	108	59	0

Based on the assumptions for the different civilian nuclear power growth scenarios of Appendix E (Table E-1), the committee's projections of employment of nuclear engineers for the civilian nuclear power sector are shown in Table 3-4.

TABLE 3-4 Actual and Projected Employment of Nuclear Engineers in the Civilian Nuclear Power Sector, 1987-2010

	Scenario		
Year	High Growth	Best Estimate	Low Growth
1987	8,030	8,030	8,030
1995	8,030	8,030	8,030
2000	9,450	8,030	8,030
2005	12,670	9,450	8,030
2010	16,450	12,670	8,030

Consolidated Employment Forecast

Based on the above discussion and the 1987 civilian employment levels for the nuclear power industry (8,030) and the federal government (3,610), as shown in Table 3-1, the committee's employment forecast, using the forecasting model and growth scenarios of Appendix E, is illustrated in Figure 3-1.

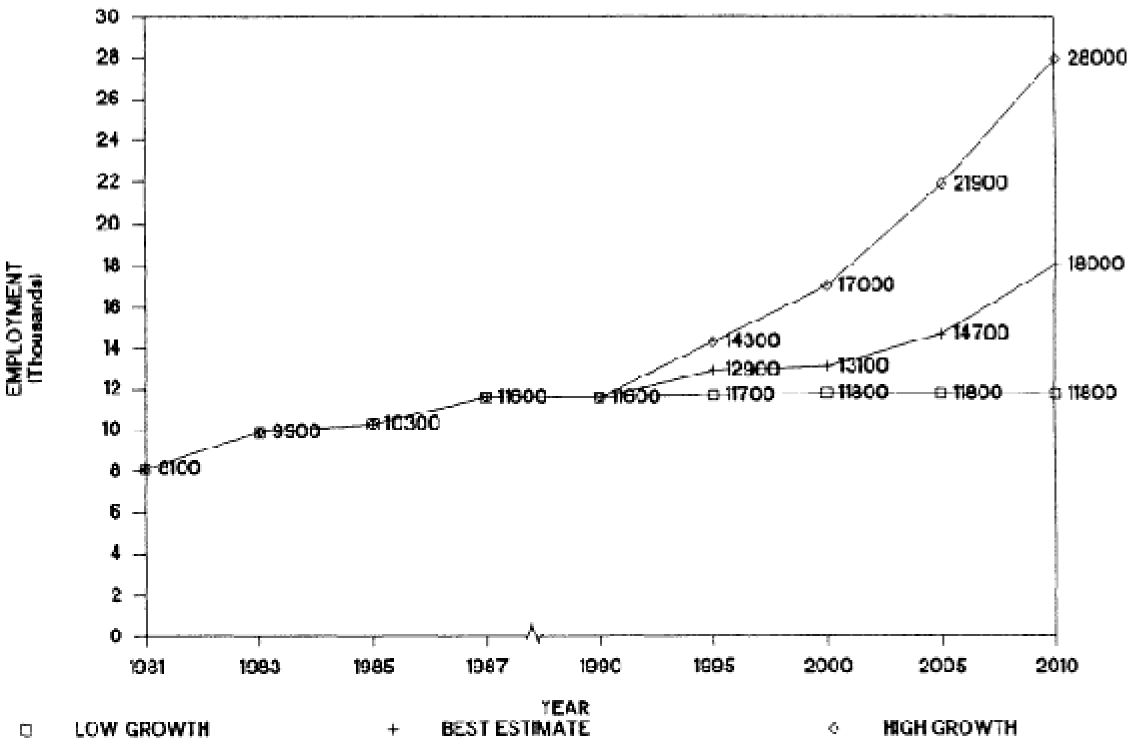


Figure 3-1
Projected total civilian employment of nuclear engineers, 1990-2010, for three scenarios (estimated to the nearest hundred).

Ph.D. Employment

In 1987, approximately 13 percent of nuclear engineers in the civilian labor force (or about 1,500 persons) held Ph.D. degrees. The distribution of employment for nuclear engineering Ph.D.s in 1987 is as follows: 38 percent were employed in DOE laboratories, 37 percent in business, industries, and utilities, 13 percent in educational institutions, and 12 percent in government, nonprofit, and other organizations (OSEP, 1987). Currently, there is a stable market for nuclear engineering doctorates, with the power reactor sector playing a modest role.

Throughout the 1980s, about 12 percent of the graduates in nuclear engineering obtained doctoral degrees (Engineering Manpower Commission, 1980-1988). Employment of nuclear engineers holding Ph.D. degrees is expected to follow total nuclear engineering employment, that is, to remain at current levels under the low-growth scenario and increase proportionally under the high-growth and best-estimate scenarios. Most jobs for nuclear engineers with federal agencies and their contractors require U.S. citizenship or security clearances, or both. Since only about one-half of today's graduating Ph.D.s in nuclear engineering are U.S. citizens, these requirements could be cause for concern, especially under the high-growth scenario.

PROJECTED DEMAND FOR NUCLEAR ENGINEERS

In this study demand is defined as the annual new hiring requirement as determined by projected increases in the level of employment plus expected losses due to attrition (retirement, deaths, etc.) and transfers to management and to jobs for which nuclear engineering skills are not required. In its demand forecast, the committee assumed a replacement rate of 3.5 percent of current employment rate. This estimate has been derived from assessments conducted by ORAU's Labor and Policy Study Program using historical data and age profiles from the Department of Labor's Bureau of Labor Statistics, and the National Science Foundation's surveys of scientists and engineers (see Appendix E).

The current demand distribution for nuclear engineers from the employment data for 1988 graduates is shown in Table 3-5.

The Department of Energy and Its Contractors

ORAU has estimated the number of annual job openings for nuclear engineers within DOE and its contractors for both the high-growth and best-estimate scenarios (see Table 3-6). The committee prepared an additional low-growth estimate, which assumes a 3.5-percent replacement rate and no change in the level of employment.

Other Government Agencies and Contractors

Since the committee assumed that nuclear engineering employment in non-DOE federal agencies other than DOE, the military services, and related contractor services would all remain relatively constant over the period the study covered for all three scenarios (except for the SDIO), the demand for this sector is also projected to remain constant at 70 nuclear engineers per year (with a 3.5-percent replacement rate for the 1,970 personnel).

TABLE 3-5 Placement of 1988 Graduates with Degrees or Equivalent Options in Nuclear Engineering (in percent)[a]

	Degree		
Placement	B.S.	M.S.	Ph.D.
Nuclear utility	13	14	6
Other industrial	15	9	12
DOE contractors	2	3	14
U.S. academic	2	2	18
Federal government	5	3	12
Continued study	24	36	7
U.S. military	16	10	3
Unknown	18	10	4
Foreign employment		8	19
All other	4	5	5

[a] Totals may not equal 100 because of rounding.
SOURCE: U.S. Department of Energy (1989).

TABLE 3-6 Actual and Projected Job Openings Annually for New Nuclear Engineering Graduates at DOE and DOE Contractors, 1987-2010

Year	High-Growth Estimate	Best Estimate	Low-Growth Estimate
1987	60	60	60
1995	440	270	60
2000	360	150	60
2005	350	130	60
2010	650	130	60

SOURCE: ORAU.

As in the employment forecast, the SDIO demand for nuclear engineers is considered only in the high-growth scenario. In this scenario, SDIO employment forecast data are used with the demand equation (eq.4) in Appendix E, yielding the following projected annual SDIO demand: 10 nuclear engineers in the year 1995, 80 in the year 2000, 230 in the year 2005, and 170 in the year 2010.

The best data the committee could obtain on the annual demand for uniformed military personnel with nuclear engineering degrees did not allow an exact count but it is estimated to be relatively small compared to nuclear engineering enrollments. For purposes of this study, it is assumed that this demand will remain constant over the study period. The Navy's Nuclear Propulsion Program trains approximately 650 college-educated officers each year for service in the nuclear fleet. Some come from Naval Reserve Officer Training Corps (NROTC) programs at various universities. Others are graduates of the military academies or receive equivalent training at the Navy's in-house training facilities.

Civilian Nuclear Power Industry

The final component of the demand projection results from assumptions about the resurgence of civilian nuclear power. Applying the demand model of Appendix E to the civilian nuclear power forecast of Table 3-3 yields the estimated demand for this sector shown in Table 3-7.

TABLE 3-7 Actual and Projected Annual Demand for Nuclear Engineers in the Civilian Nuclear Power Sector, 1987-2010

	Scenario		
Year	High Growth	Best Estimate	Low Growth
1987	280	280	280
1995	280	280	280
2000	620	280	280
2005	1,090	620	280
2010	1,330	1,090	280

Consolidated Demand Forecast

Applying the demand model of Appendix E to the forecast for industry and government nuclear engineering employment results in the forecasts of tota demand shown in Figure 3-2 (see Tables E-6 and E-7). Both low-growth and high-growth scenarios are considered less likely than the bestestimate, but suggest some limits. Because the best-estimate projection leaves out some components of demand, the committee believes the best estimate is somewhat conservative and that actual demand could be higher. Even so, the best-estimate projection forecasts a growing demand that increases beyond the year 2000. Shortages should be anticipated and adequate remedial programs initiated in time to educate recruits (five to six years for B.S. graduates, seven to eight years for M.S.s and nine to ten years for the Ph.D.s).

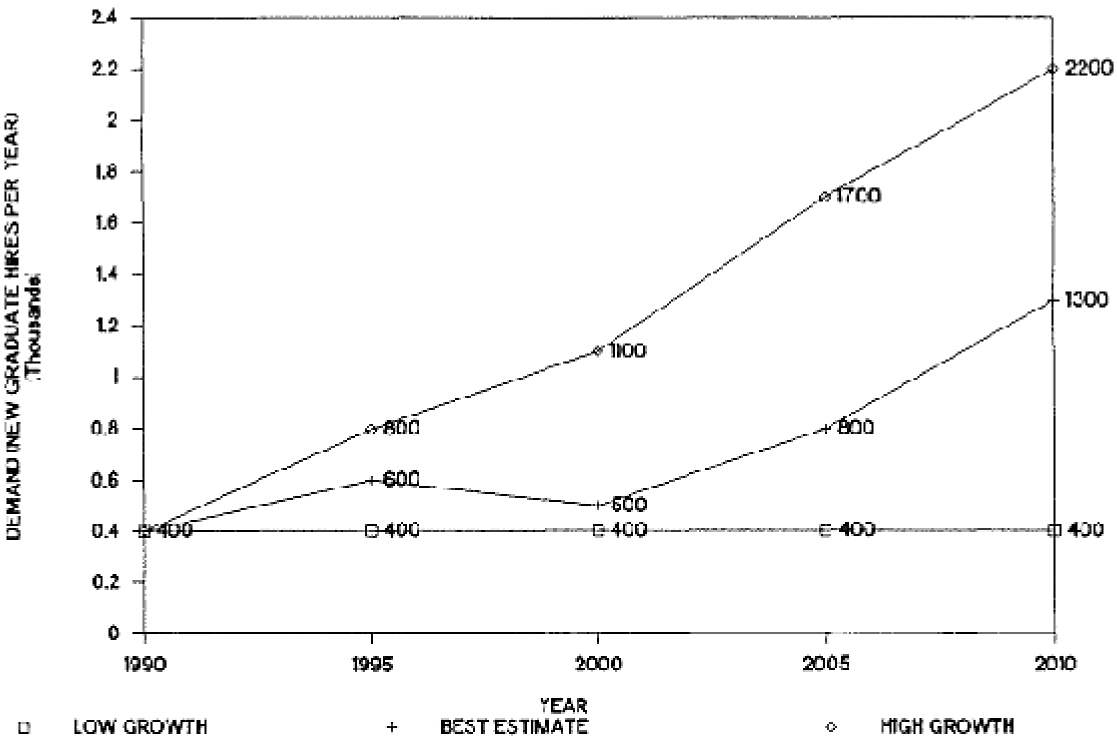


Figure 3-2
Projected annual demand for civilian nuclear engineers in government and industry, 1990-2010, for three scenarios (estimated to the nearest hundred).

FINDINGS

In summary the committee reached the following findings:

- From 1990 to 1995 the demand for nuclear engineers in the United States will be largely driven by DOE program initiatives. Beyond the turn of the century, the principal driver of demand is expected to be the number of nuclear power plants in service, under construction, and undergoing life extensions.
- The committee's best-estimate projection indicates an increase by 1995 by as much as 50 percent above the annual demand for nuclear engineers but about 25 percent greater demand in 2000 (based on current figures). The best-estimate projection envisions a doubling or trebling of current demand between 2000 and 2010.

4

The Status of U.S. Nuclear Engineering Education

This chapter focuses on some features of U.S. nuclear engineering education as gleaned from a committee survey (see Appendix G for the questionnaire and Appendix F for results). These features include faculty age structure and research interests, undergraduate and graduate programs, levels of financial support, student-faculty ratios, and status of university reactors.

NUCLEAR ENGINEERING FACULTY

Age Distribution and Experience

Faculties of the academic departments in which nuclear engineering is taught are generally weighted heavily toward the senior ranks. Such departments developed between 1955 and 1970, with faculty appropriate to relatively high enrollments and the expectation of further growth.

The accident at Three Mile Island and subsequent adverse publicity apparently led many prospective students to choose other career options. A decrease in enrollments largely halted the addition of junior faculty to many departments and resulted in the present distribution of nuclear engineering faculty by rank: (1) full professors account for 67 percent; associate professors for 21 percent; and assistant professors for 12 percent.

Furthermore, 23 percent of these faculty are over 60 years of age and approaching retirement. These experienced faculty are responsible for teaching related to nuclear reactors and their replacement requires recruiting similarly qualified individuals. Because such engineers are also very attractive to industry and government, there will be stiff competition for their services. The slow pace of recruiting junior faculty in recent years is reflected in the fact that only 17 percent of present faculty are 40 years of age or less (Figure 4-1).

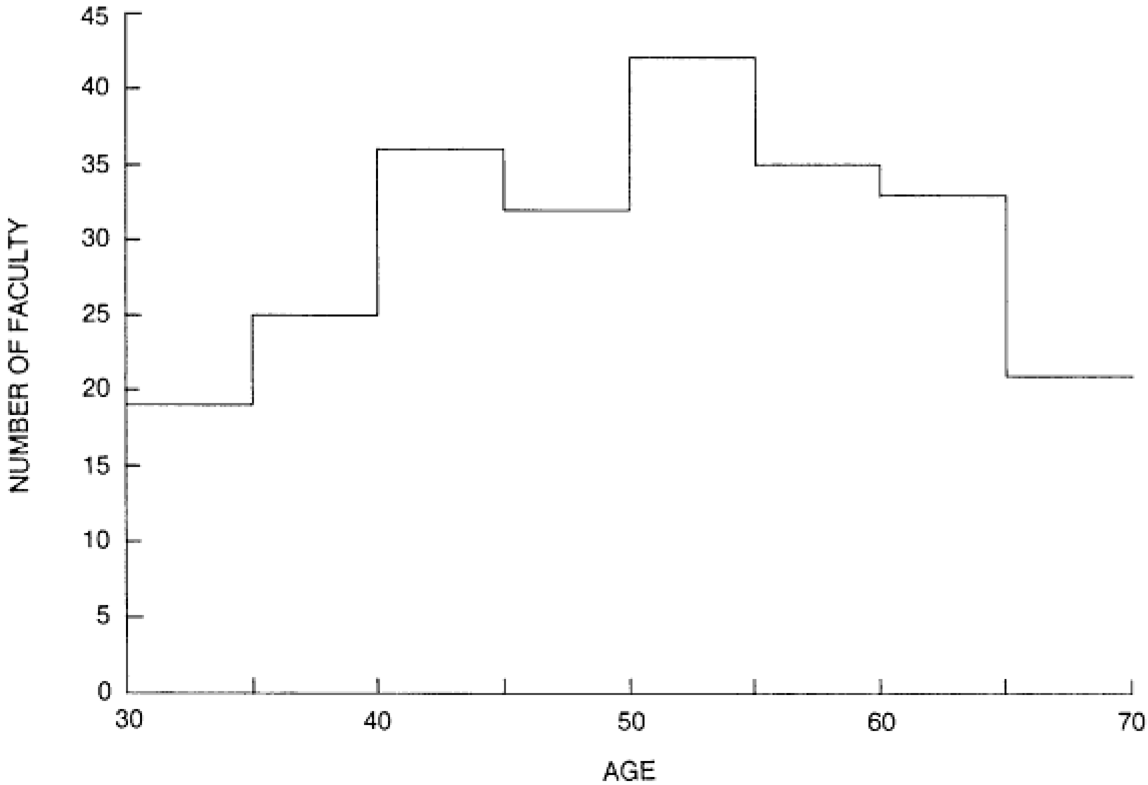


Figure 4-1
Distribution of nuclear engineering faculty by age.
Source: Committee survey (see Appendixes G and F).

The age of the faculty raises concerns about the degree of innovation and the reference to contemporary issues in present coursework. Although no specific problems were identified by the committee, such concern may be warranted any time the influx of new individuals and ideas into a faculty group is restricted over an extended period of time (Figure 4-2). Of course, faculty members' interest in recent issues varies and, in some cases, older faculty do involve themselves with new areas of research.

The concern for the relatively older average age of the nuclear engineering faculty becomes particularly serious when one considers the difficulty of their replacement. First, it should be apparent from the information presented elsewhere in this report regarding the capacity of the nuclear engineering programs, and the need for nuclear engineering graduates at the various degree levels, that the present number of nuclear engineering faculty will have to be at least maintained and more likely increased to meet future needs. However, the time required to bring an aspiring entry level student through the bachelor's, master's, and Ph.D. levels, and be qualified as a nuclear engineering faculty member is at least 8, and perhaps 10, years. Twenty-three percent of the present faculty in graduate nuclear engineering departments will, if they are replaced upon retirement, be drawn from students who have been or are currently in nuclear engineering programs. Replacements for another 30 percent of the faculty will be drawn from that group of students entering in the next five years. The reductions in the number of nuclear engineering departments and the sizes of their faculties that have occurred over the last 10 years have not only reduced the capacity to meet the

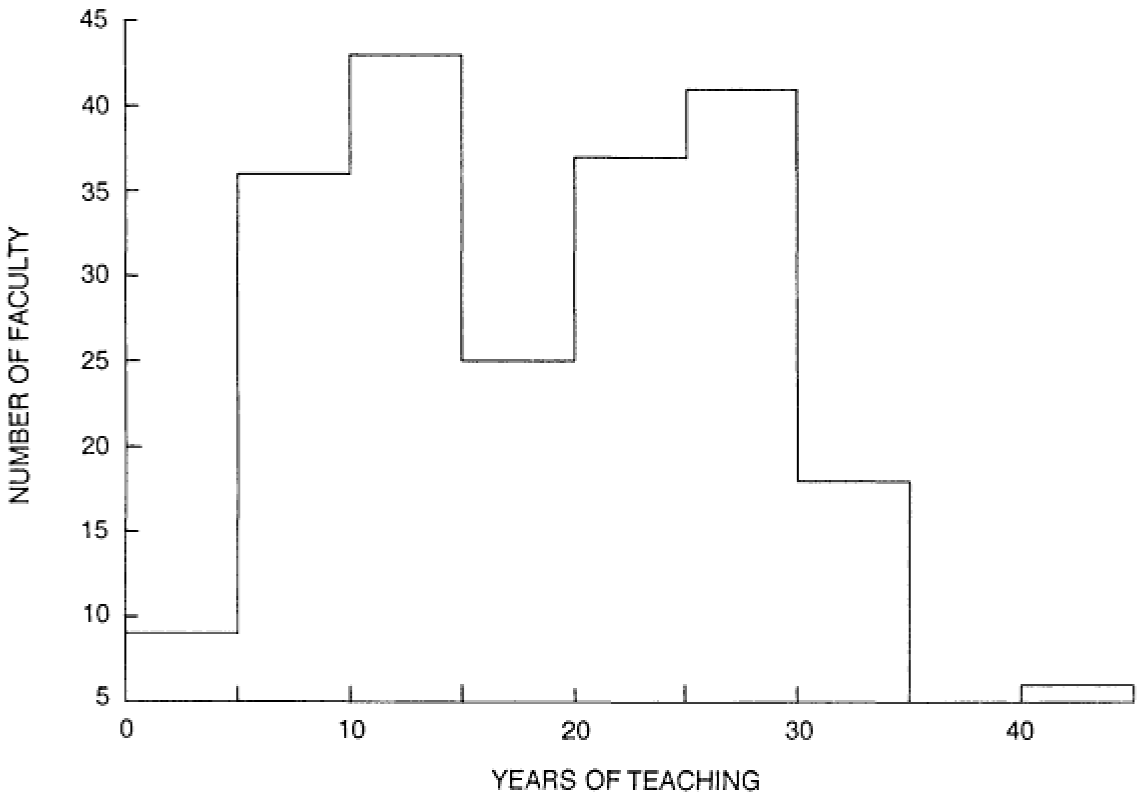


Figure 4-2
Experience of nuclear engineering teaching faculties.
Source: Committee survey.

industrial and governmental demand for nuclear engineers in the future, but have also failed to take into account that about 15 percent of Ph.D. graduate production will be required to replace retiring faculty over the next 10 years.

Comparison With Other Disciplines

The distribution of ages of faculty in other disciplines are available from 1987 survey data by the Oak Ridge Associated Universities (ORAU, 1987). At that time, the average age of nuclear engineering faculty was 8 to 10 years greater than that of faculty in mechanical, electrical, chemical, and, in fact, all other engineering disciplines. For example, the median and mean ages for all engineering were 46.0 and 46.8, respectively, while for nuclear engineering the median and mean ages were 58.0 and 55.0, respectively.

Faculty Research Interests

Reported research interests of nuclear engineering faculty in different age groups were examined, to identify the emergence of new research foci or the decay of former strengths. Some older faculty members are involved in newer areas of research interest, reflecting their willingness to grow with the evolution of the discipline. This tendency makes the identification of trends difficult. Analysis is further complicated by the tendency of new specializations to develop special nomenclatures as they evolve to address new technologies and as they seek the "buzzwords" that seem to be required to reassure sponsors of the timeliness of research.

Thus, it has been necessary to group the numerous research topics identified by individual departments into a more compact set. A total of ten categories of research were selected to cover the field:

- Reactor physics and shielding
- Computational methods and artificial intelligence
- Reactor systems analysis and design
- Thermal hydraulics
- Reactor safety
- Reactor operations
- Radiation effects
- Materials and nuclear fuels
- Biological effects, waste management, and the environment
- Fusion and plasma physics.

The first eight categories are referred to as "reactor-related disciplines" in this report. For each heading, the ages of those faculty claiming research activities in those areas were noted. The comments that follow are based on the resulting profiles of each research area.

1. Younger faculty tended to identify themselves with a larger number of research areas. Thus, the research population distribution in general did not reflect the age distribution of the total faculty population. This might suggest that younger faculty are being asked to cover more topics; it could also reflect greater research activity.
2. For most research areas, there is a continuing level of interest, suggesting little tendency to abandon some traditional areas. The specific areas where this tendency is noted include reactor physics and shielding, reactor systems analysis and design, fusion, materials and nuclear fuels, and waste management. Interest also exists in computational methods and artificial intelligence. Among the topics of materials, nuclear fuels, and waste management, there is some indication that the emphasis of younger researchers is on waste management, with fuels and materials more commonly the declared interest of older faculty.
3. Reactor safety interests the older faculty, thermal hydraulics, the younger faculty. Recognizing trends in recent years, this difference could be a semantic one.
4. In some areas, emerging trends raise some concerns. Young faculty who identify reactor operations as their research interest are few. Only 15 percent of those with this interest are less than 40 years of age; 33 percent are over 55 years old.
5. Radiation effects research is receiving less attention from nuclear engineers. Currently, most of the effort in this area is in electronics, where electrical engineers dominate.

NUCLEAR ENGINEERING ENROLLMENT AND DEGREE TRENDS

Undergraduate Programs

Undergraduate Enrollments

Based on DOE data maintained by ORAU, total enrollment in junior and senior classes in nuclear engineering has steadily declined since 1970 (Figure 4-3 shows the trends since 1978). Spring 1980 B.S. graduates are identified by many as the "Chernobyl Class," reflecting the impact of that accident on the number of declared majors. The interest of entering students in nuclear engineering has increased in the last two years by as much as 50 percent, according to some institutions. It is too early to assess the success rate of these students, who are not yet reflected in these data (which covers only graduates in nuclear engineering).

At the undergraduate level, about 98 percent of the nuclear engineering students are full-time students. The enrollment of women in undergraduate nuclear engineering has remained constant at about 8 percent of the total over the last five years. Over the last decade, the enrollment of foreign nationals has dropped from about 7 percent of the total to the present level of about 2 percent.

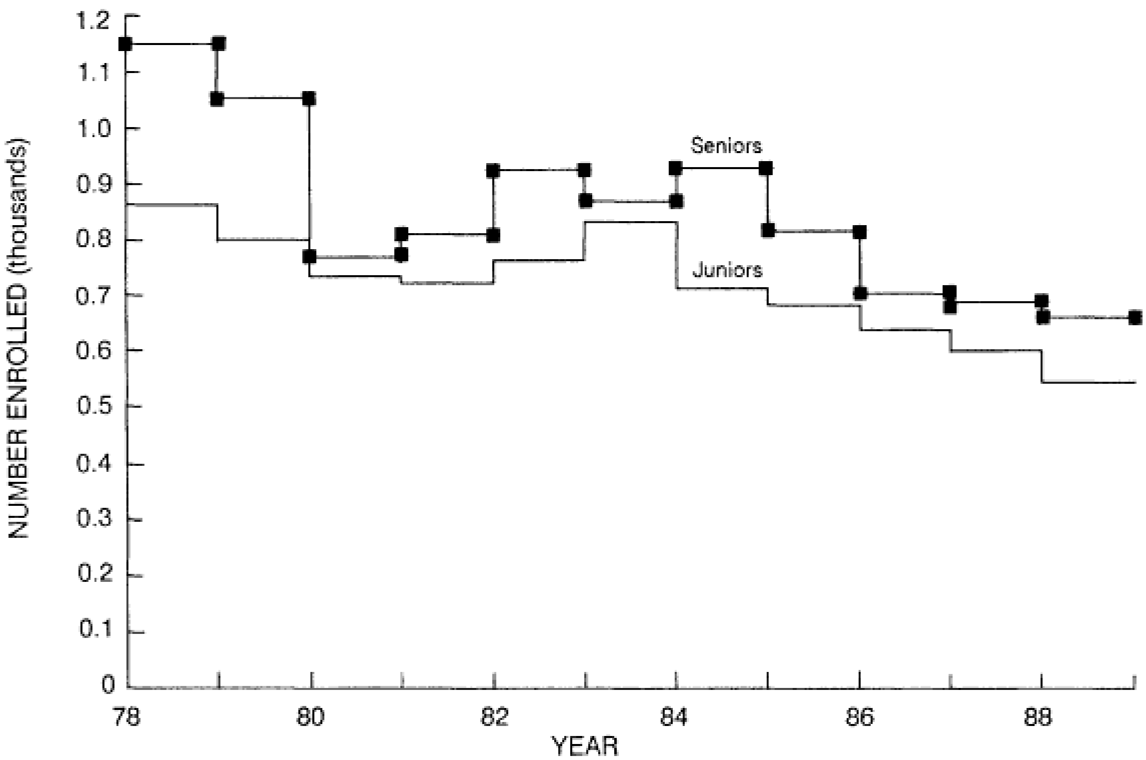


Figure 4-3
Total enrollment in nuclear engineering junior and senior classes.
Source: DOE Data, (U.S. DOE, 1984).

Undergraduate Degree Awards

The award of B.S. degrees in nuclear engineering and in other engineering fields with nuclear engineering options has shown a steady decrease over the last decade. ORAU data are graphed in Figure 4-4. Even fewer graduates are expected for 1988 and 1989, about 400 graduates for each of these years.

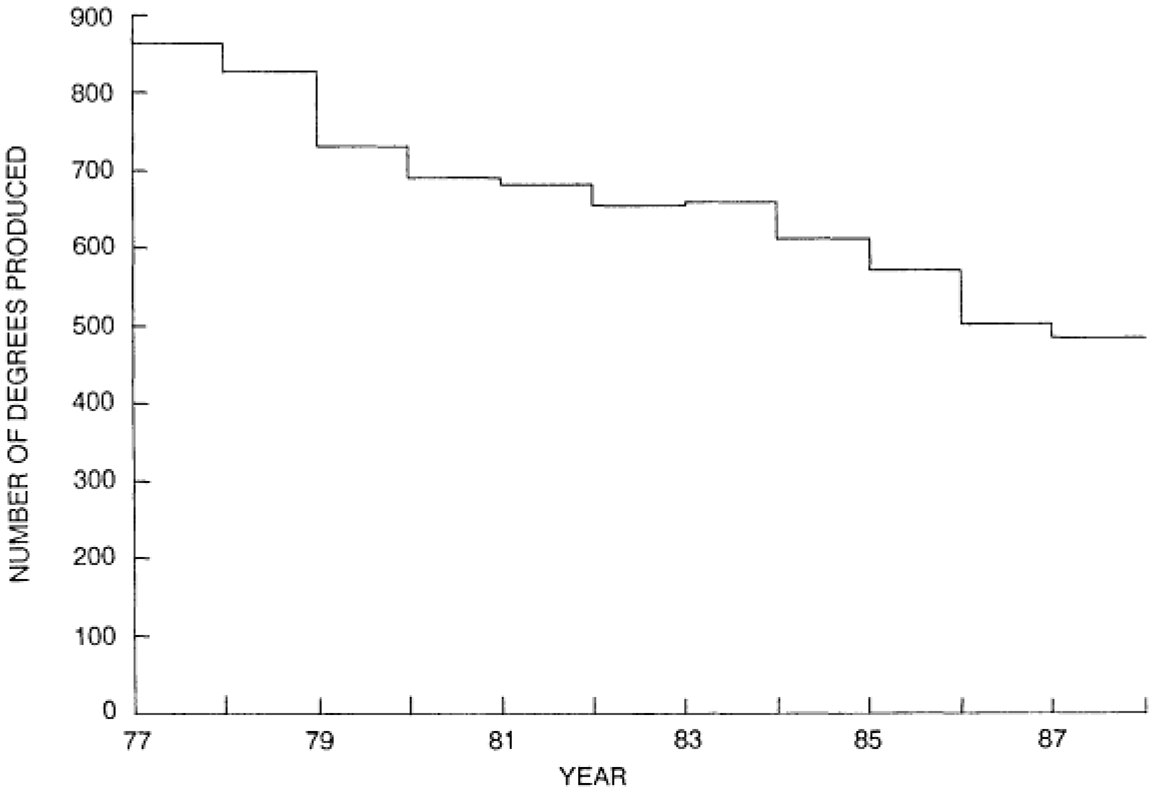


Figure 4-4
Total undergraduate degree awards in nuclear engineering, 1977-1987.
Source: DOE Data (U.S. DOE, 1984).

Employment of B.S. Graduates in Nuclear Engineering

Figure 4-5 shows the first-job employment distribution for B.S. graduates in nuclear engineering between 1983 and 1988. Nearly one-third enter graduate studies, 20 percent are employed by utilities, and significant numbers by reactor vendors, the military, national laboratories, and others. The employment base is relatively diverse.

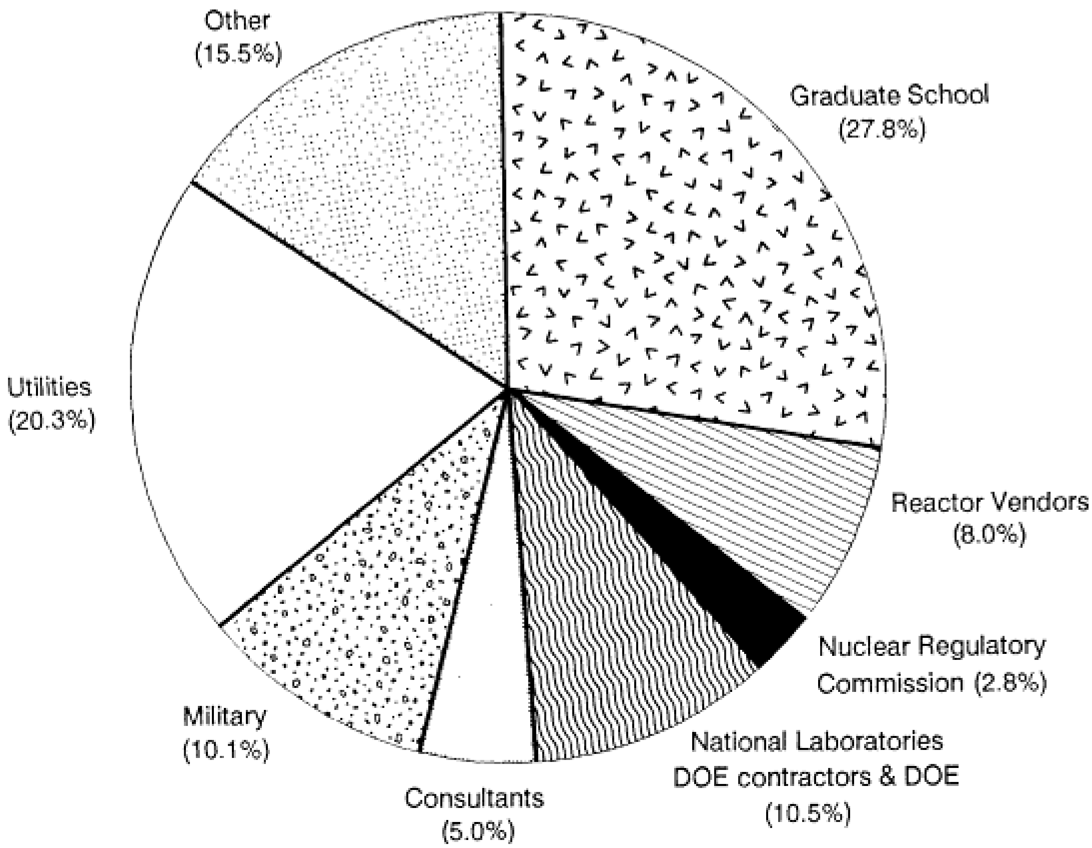


Figure 4-5.
First-job employment distribution for B.S. graduates in nuclear engineering for the past five years.
Source: Committee survey.

Capacity of Undergraduate Programs

The estimated maximum capacity of existing undergraduate programs is based on the assumption of no change in the number of faculty, but with additional support through proportional increases in operational resources for laboratories and classes. Thus, the addition of class sections and the teaching of additional classes both semesters is not considered in the estimate, since either of these alternatives would require the addition of faculty. The estimate of capacity is based on responding institutions answers to the committee's questionnaire and by raising estimated class sizes to 20. Based on these assumptions, the entry class capacity of present undergraduate nuclear engineering programs is 800 students per year. This figure corresponds to all entry class enrollments reported by ORAU for as recently as 1985. As nuclear engineering programs contract, and in some cases are eliminated, their ability to expand readily will be diminished.

Graduate Programs

Graduate Enrollments

Enrollments in graduate nuclear engineering programs reported by ORAU are shown in Figure 4-6. In the past 10 years, the number of M.S. Degree

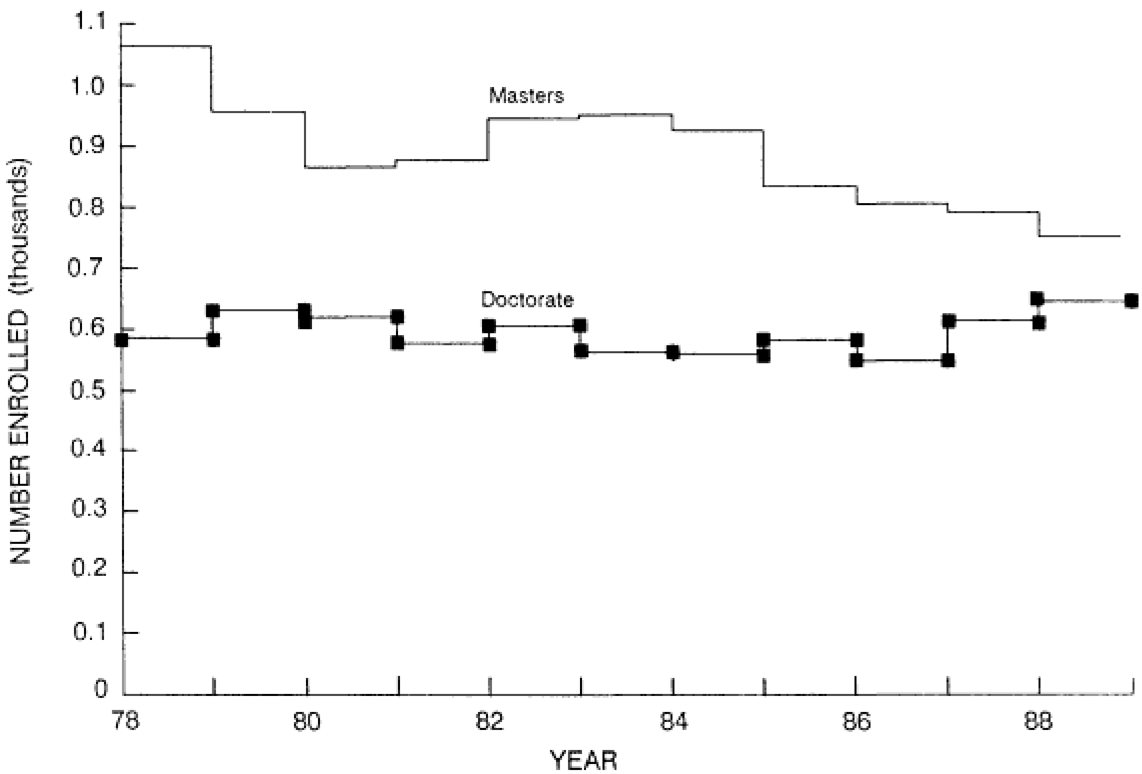


Figure 4-6
Graduate student enrollments in nuclear engineering programs, 1978-1989.
Source: DOE Data (U.S. DOE, 1984).

candidates has decreased by about 255. The impact of the Three Mile Island accident is perhaps recognizable in the plot. There has been a slight increase in the fraction of women students in the master's programs, from eight percent in 1982 to nearly 10 percent in 1987. Enrollments of foreign nationals in M.S. programs have remained steady, at 30 percent.

The number of Ph.D. students has remained very nearly constant, at about 600, with perhaps a slight increase recently. The fraction of the enrollment by women Ph.D. students has grown steadily from 5 percent in 1982 to 9 percent in 1987. Ph.D. enrollments of foreign nationals have constituted between 45 and 50 percent of all Ph.D.s over the past decade.

Figure 4-7 shows the distribution of undergraduate majors of students entering nuclear engineering graduate programs over the last five years, for

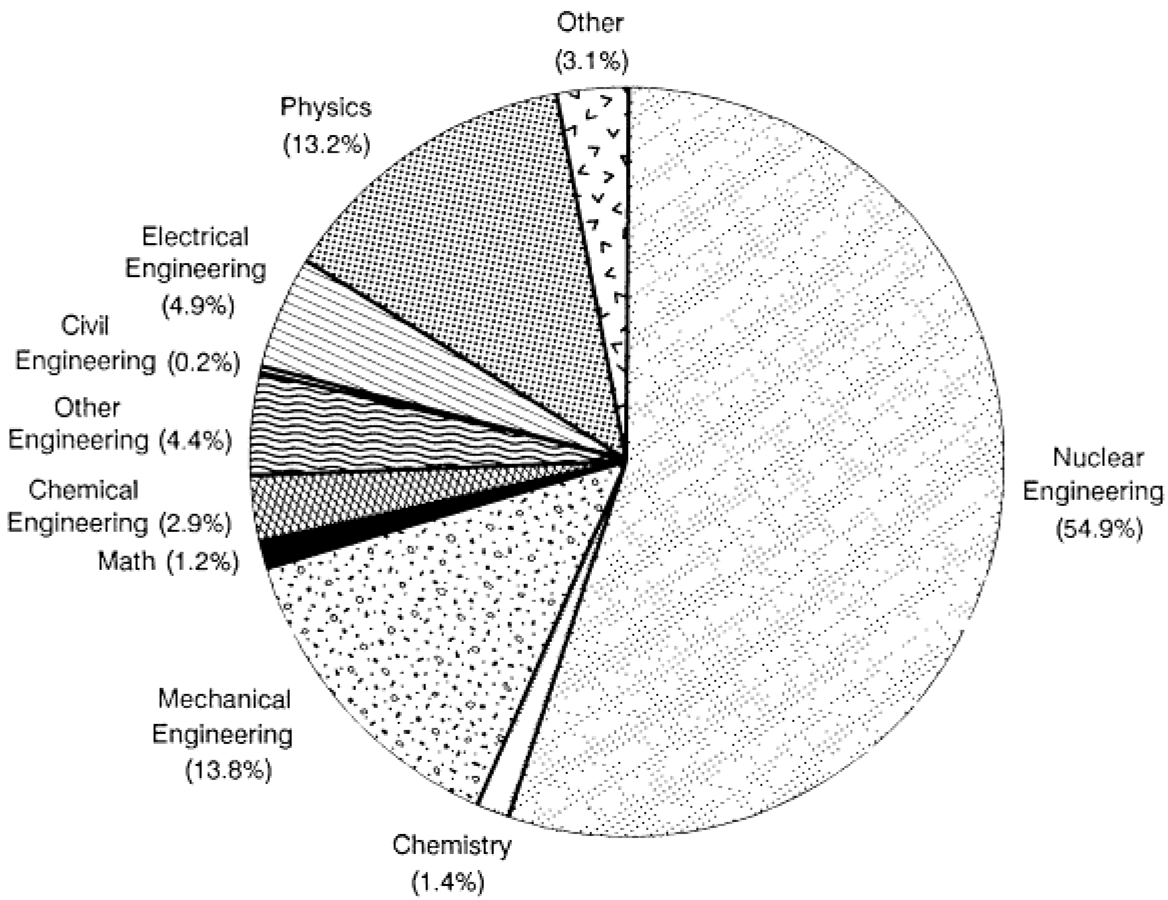


Figure 4-7
Weighted distribution of undergraduate majors for students entering nuclear engineering graduate programs.
Source: Committee survey.

all schools responding to the questionnaire. While 45 percent of the graduate students in nuclear engineering were undergraduate majors in other fields, obtaining an undergraduate degree in nuclear engineering is still a strong preference. The most noticeable shift in recent years is the increased number of mechanical engineering undergraduates that go on to graduate studies in nuclear engineering. Undergraduate physics majors have traditionally been a source of graduate students in nuclear engineering.

Graduate Degree Awards

DOE data on the number of M.S. and Ph.D. graduates in nuclear engineering are shown on Figure 4-8. There has been a steady decrease in M.S. degrees awarded in recent years following the drop by approximately one-third in 1979-1980. Ph.D. awards have remained steady, at about 100 per year throughout the decade.

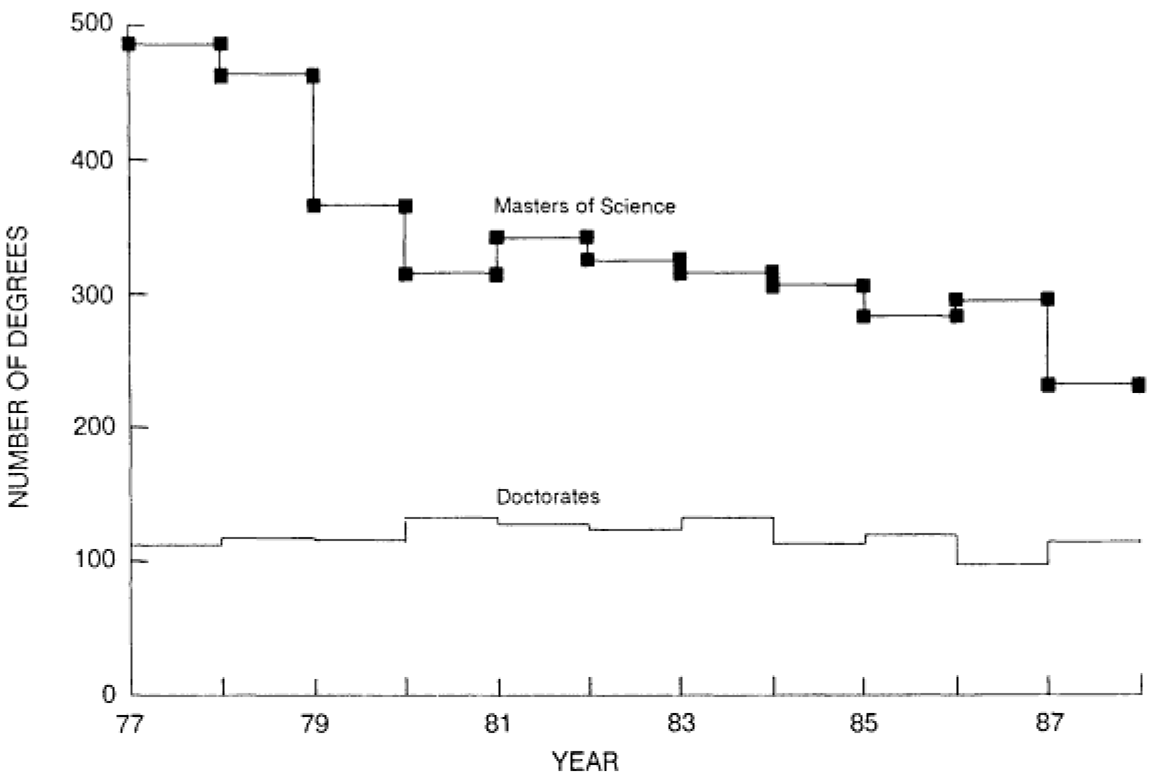


Figure 4-8
M.S. and Ph.D. graduates in nuclear engineering.
Source: DOE Data (U.S. DOE, 1984).

Employment of M.S. and Ph.D. Nuclear Engineers

Figure 4-9 shows the first-job employment distribution for M.S. and Ph.D. degree recipients over the last five years. The large sector marked "other" in part reflects the large nonresident enrollment in graduate programs in nuclear engineering.

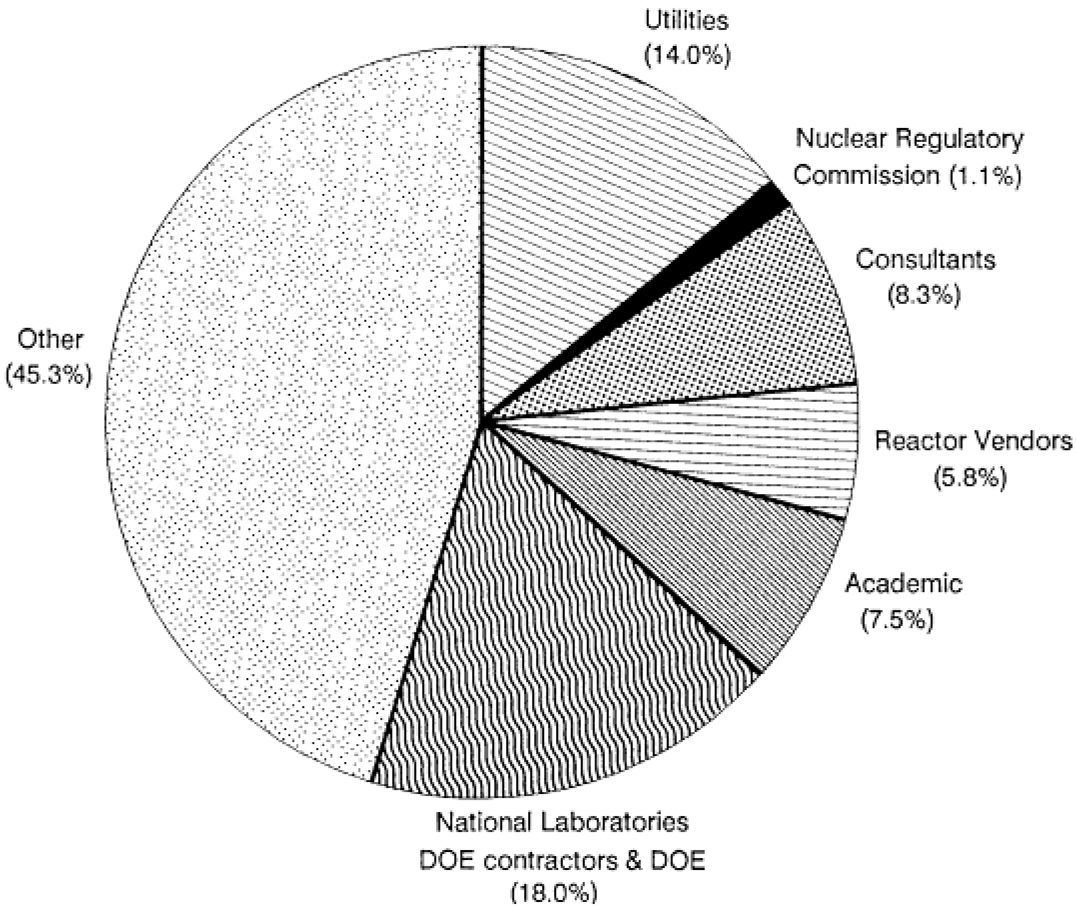


Figure 4-9
M.S. and Ph.D. nuclear engineering graduates' first-job employment distribution for the past five years.
Source: Committee survey.

Capacity of Graduate Programs

The current total graduate enrollment is about 1400—while a decade ago it was 1,648. The committee estimates the capacity of existing graduate programs to be from 1,650 to 2,000 students. The former number is based on a student-to-faculty ratio of 7:1. The latter estimate is based on scaling up enrollment to 30 students per class, which is assumed to be possible with current faculty resources. However, this last figure may be too high in that the greatest faculty load in graduate programs is directing research for theses and dissertations. On the other hand, for the first two years or so of graduate study, many students do not require research direction. For this reason, the estimate covers a broad range and an accurate assessment will require a more detailed analysis for each institution.

FINANCIAL SUPPORT

It is difficult to identify the exact funding levels for nuclear engineering research for academic departments. The fiscal year used differs from campus to campus. Further, some institutions are reluctant to identify the exact amounts of funding by government agencies and industry organizations. With these uncertainties acknowledged, total funding for the 1988-1989 calendar year is estimated at approximately $43 million, distributed as shown in Table 4-1.

TABLE 4-1 Percent of Funding and Amount of Funding (millions of dollars) from Various Sources for Departments of Nuclear Engineering

Funding Source	Percent of Funding	Amount of Funding
National Science Foundation	12 3	5 29
National laboratories	6 3	2 71
Department of Energy	43 9	18 88
NASA	18 7	8 04
Electric Power Research Institute	4 7	2 02
Nuclear Regulatory Commission	1 0	0 43
Industry	6.8	2 92
Foreign institutions	1.2	0 52
Other	5.1	2 19

SOURCE: Committee survey.

Based on this total funding, an average faculty research support level would be about $180,000. However, the distribution of funding among institutions is uneven and much research funding is in multidisciplinary programs. Some faculties receive research funds several times this average, while others receive very little. Moreover, in many of the large research projects, postdoctoral researchers and members of research staffs play major roles. Some of this funding is not allocated on the basis of a competitive process. There are research laboratories and institutes in some universities that receive industrial funding, which is then allocated to research projects. The industry category refers, for the most part, to funding for specific problems.

Areas that receive research support cover a broad span of activity (Table 4-2). Again, identifying research areas by category is complicated, both because of many disciplinary designations (such as materials, thermal hydraulics, dosimetry, radiation transport, plasma physics, and reactor physics) and because of broad project-definitions (such as fusion, waste management, environmental effects, civilian nuclear power and space power) adopted by funding agencies and thus by principal investigators. The activity in fusion and plasma physics is the largest (about $19 million), mainly because of very sizeable programs in those areas at two of the institutions in the survey. One institution has $11 million, the other $5.5 million, in fusion and plasma physics research. In these two institutions, those programs involve nonteaching professional staffs and faculty

TABLE 4-2 Percentages of Total Research Funds for Various Areas

Research Area	Percent of Funds	Amount of Funds (million dollars)
Basic nuclear sciences	11.3	4.86
Civilian nuclear power	14.6	6.28
Space nuclear power	2.0	0.86
Medical applications	3.8	1.63
Materials sciences	10.9	4.69
Energy research	0.5	0.22
Fusion and plasma physics	44.0	18.92
Environmental assessments	2.7	1.16
Other	10.2	4.38

SOURCE: Committee survey.

and students from other academic disciplines inside and outside the engineering community. Fusion and plasma physics research funding at other institutions is about $2.7 million, with one institution at $0.5 million, and at several others $0.2 to $0.3 million. Perhaps a more representative figure for total research support would be determined by considering fission systems and the related engineering research. This figure of about $24 million would reflect research on fission energy production systems, materials, and basic nuclear sciences.

The commitment of university funding to the support of nuclear engineering programs varies widely by program. Low enrollment is the norm for many of the programs, so an evaluation of average program costs, which attempts to be reflective of enrollment, has been made. This evaluation examined the degree programs and groups of one or more nuclear engineering options available in other engineering discipline programs in U.S. universities. Total enrollment in all of the programs, counting juniors and seniors and all graduate students, is 2,603. Fifty percent of the nuclear engineering students are enrolled in 14 of the 64 programs or option groups, 90 percent are in 40 programs or option groups. There are 20 programs and option groups with fewer than 20 students enrolled. In computing the averages of committed resources, these 20 smallest programs are not included.

With respect to the level of support the nuclear engineering programs receive, comparative numbers are very difficult to determine. Institutional support includes a wide variety of categories, including operations, supplies, facilities, capital equipment, staff salaries, travel, and so forth. Research support covers all categories (fission, fusion and plasma physics, materials, etc.), but in many cases includes nonteaching faculty, interdisciplinary efforts, and other such cases. Department staff are typically not separated into instructional and research categories, or by research specialties. Thus, "averages" can only be representative of resource availability and do not necessarily meet any criterion for full. consistency.

Table 4-3 shows level of support for the "high," "median," and "low" institutions. "Low" institutions are those with the lowest level of support among those 40 programs that account for 90 percent of the enrollment.

UNDERGRADUATE CURRICULUM

Results of the committee survey indicate that the educational requirements for undergraduate nuclear engineering degrees are fairly standard from institution to institution. About 130 to 135 semester hours are required for a four-year program. In addition to the usual first and second year courses in English, social sciences (including economics), and humanities, there is strong emphasis on basic sciences and mathematics. Many of the courses are determined by university policy that establishes minimum course requirements for bachelor's degrees. It is in the last two years of study that specialized courses are taken. This curriculum is increasingly driven by the Accreditation Board for Engineering and Technology (ABET) requirements and by policies of the particular college of engineering or department. It includes courses required for a general engineering education and special courses providing basic background in the performance and design of nuclear power plants and other systems.

TABLE 4-3 Levels of Institutional and Research Support (in dollars)

Type of Institution	Institutional Support	Research Support (per FTE faculty)
High	117,000	667,000
Median	87,000	214,400
Low	38,500	20,000

NOTE: "FTE" stands for "full-time equivalent." High is the highest value among institutions; low is the lowest.

In the basic engineering sciences, considerable variation exists among schools but, in general, the curriculum includes courses in mechanics, material and thermal sciences, electricity and magnetism, and computer programming. For the most part, these basic engineering requirements are taught by faculty members outside the nuclear engineering department or program. However, it is the committee's opinion that experienced nuclear engineering faculty members are essential for the most effective teaching of advanced undergraduate courses, such as applied nuclear physics, reactor theory, reactor engineering and design, the nuclear fuel cycle, radiation effects, systems design, and thermal hydraulics.

In addition, the nation's larger undergraduate programs offer elective courses in such areas as fusion technology, safety analysis, nuclear instrumentation, and in some cases, medical issues related to nuclear processes. In general, the survey indicated that curricula meet the needs of employers, although more training in reactor systems engineering and biological effects of radiation may be desirable. Tables F-21 and F-22, Appendix F, show undergraduate required courses for nuclear engineering and compare their overall content to other engineering disciplines. Note that the nuclear engineering program credit requirements are more evenly spread among the basic and engineering sciences. Also, more physics credits are taken.

THE GRADUATE CURRICULUM

U.S. master of science programs in nuclear engineering typically require 30 to 36 semester hours, including minor courses from other engineering and science programs and sometimes a thesis. They commonly take about two years. In some of the new waste management programs, minors in water resources or hydrology can be selected. The doctorate requires a dissertation based on at least one and one-half to two years of research and additional formal work beyond the master's in the major and minor disciplines. Institutional requirements are generally stated in terms of semester hours of major and minor subjects.

Advanced courses in reactor theory and design, thermal hydraulics, computational methods, radiation transport, nuclear instrumentation, and safety analysis are common in core curricula at the beginning graduate level. The more advanced graduate courses vary greatly from program to program and often bear little resemblance to the more traditional reactor-oriented nuclear engineering courses. Research activities in nuclear engineering programs are quite varied and reflect research funding rather than the classic view that nuclear engineering research focuses on civilian nuclear power. Funding of traditional reactor-oriented research represents less than 15 percent of total academic nuclear engineering research funds (see Table 4-2).

Driven by the availability of research funds, nuclear engineering as a discipline has evolved and broadened to encompass the utilization of nuclear processes and nuclear forces in diverse engineering applications, not just fission power. Research and teaching in such areas as basic nuclear science, fusion research, environmental engineering, nuclear medicine, and general materials science are common. Since research is both a training tool for graduate students and a mechanism for faculty members to further knowledge, the content of advanced courses usually reflects faculty members' active research. These trends in graduate education and research are having a profound effect on nuclear engineering education and will be addressed in more detail later in this report.

STUDENT-FACULTY RATIOS

Nationally, the total size of the undergraduate nuclear engineering student body is somewhat small relative to the total faculty of approximately 200 full-time equivalents (FTE). With about 1200 juniors and seniors in the country (U.S. Department of Energy, 1989), the student-to-faculty ratio in nuclear engineering is about 6 to 1 (see Table 4-4 for a finer breakdown). This suggests modest growth is possible in undergraduate nuclear engineering enrollments with present faculty size. Over a short period, a 40-to 50-percent increase could perhaps be achieved.

At the graduate level, the student-to-faculty ratio is comparable to other engineering disciplines. The graduate student population is approximately 1,400, resulting in a student-to-faculty ratio of 7 to 1 without faculty increase, which suggests graduate enrollments could be increased slightly. Table 4-4 also shows a breakdown of student-to-faculty ratios, and also faculty teaching loads, by type of institution.

These data are averages and fail to distinguish FTEs devoted to teaching and those associated with research. A realistic analysis of growth potential should be made for each institution with a detailed calculation of how FTEs are distributed among teaching and research. In this regard, comparing nuclear engineering enrollments per FTE faculty with those in other disciplines at the same institutions is more instructive than comparing nuclear engineering departments at different institutions. This takes into account characteristics of a given university that exist across departments. In fact, there are large differences in enrollments per FTE faculty and, hence, the capacity for increased enrollments is related to the unique characteristics of individual institutions.

TABLE 4-4 Student-to-Faculty Ratios and Faculty Teaching Loads, by Type of Institution (per full-time equivalent faculty)

Type of Institution	Undergraduate Nuclear Engineering Students	Graduate Nuclear Engineering Students	Student Credit Hours Taught
High	13.0	11.0	393
Median	4.0	5.1	192
Low	1.3	3.9	82

NOTE: High is the highest value of the institutions; low is the lowest value. Values are per academic year.

The institutions with either high or low undergraduate nuclear engineering student enrollments are not necessarily those with the same pattern at the graduate level. The three institutions with the most student credit hours taught per FTE faculty have nuclear engineering faculty that take core engineering or science teaching assignments outside the nuclear engineering program.

The technician support level varies widely by program. Where a reactor is available, some technical support staff are normally needed. Where there are large research efforts, larger technical staffs are absolutely necessary. Finally, if the nuclear engineering program is embedded in a larger academic department, the devotion of personnel to nuclear engineering support is hard to determine. These points also apply to secretarial and clerical support.

UNIVERSITY REACTORS

A nuclear reactor is a resource that can play an integral role in the formulation of courses in many nuclear engineering programs and helps students gain an important understanding of the complexities of nuclear power processes. In particular, a reactor can provide the basis for much of the experimental laboratory experience that students receive. Most reactors located in educational institutions today are simple, and their operation is basically determined by the dynamics of the nuclear fission process and the chain reaction. The effects of other phenomena, including the thermal hydraulic behavior of the system, pressurization of coolant, and so on, are either not present or only so in terms of net properties like the average temperature of the moderator.

Thus, the student in the educational reactor laboratory has the opportunity to examine and understand the dynamics of fission without the complications of many transient phenomena that pertain to power generation systems. Further, the opportunity to work with radioactive materials that show relatively low levels of activity, to develop an understanding for the principles of safe material handling and material containment, provides valuable training. Finally, the use of the nuclear reactor in support of research in a wide variety of other disciplines provides the young engineer experience with the interdisciplinary role that nuclear engineering can play in the technical community and with the challenges and satisfactions of successful interdisciplinary activity.

A detailed study of the use of university nuclear reactors was conducted by the National Research Council (NRC, 1988). Two decades ago, about 76 reactors were in operation in universities in the United States. That number has declined: in May, 1987, only 40 university research reactors were in operation. Twenty-seven of these were located at universities that offered nuclear engineering degrees or options in nuclear engineering (ANS, 1988). Currently, only 21 reactors are operating at universities with nuclear engineering degree programs or options. In addition, there are 7 reactors at institutions that do not have nuclear engineering programs. The reactors and their operators are licensed by the Nuclear Regulatory Commission; thus, some professional nonacademic staff are usually required.

Operation of these reactors can impose additional costs that may be attributed wholly or in part to maintaining the nuclear engineering program. These costs include personnel, equipment, operations, and insurance. In some institutions, the reactor budget is included directly in the nuclear engineering academic budget. In others, usually where the reactor and associated facilities are larger, the reactor is budgeted as a separate item. There are advantages and problems in both approaches. In the former, a higher cost of instruction is calculated. If it is budgeted as a separate item, it may be vulnerable to reduction since no academic programs are directly associated with it. This attitude is misleading because reactors support many disciplines in the university community (NRC, 1988).

Judging by the past attrition of reactors and the role that university reactors have played, the committee believes it desirable to integrate the reactor into the undergraduate laboratory program and to encourage the wide availability and use of the reactor by researchers from the entire campus community.

NUCLEAR ENGINEERING AS A SEPARATE DISCIPLINE

Nuclear engineering undergraduates generally receive a more balanced exposure to basic and engineering sciences (physics, including nuclear physics, materials science, thermodynamics and fluid mechanics, and electrical and electronic systems) than engineers in other disciplines. For example, many electrical engineers no longer take thermodynamics or fluid mechanics, and many civil engineers take limited physics offerings beyond mechanics and introductory electricity and magnetism. The need for breadth in the nuclear engineering curriculum becomes obvious when one examines the various roles that the nuclear engineer may play. Nuclear safety, fusion and plasma physics, nuclear waste management, and nuclear plant operations involve mechanical, thermal, fluid, electrical, and materials science, and statistics and logic for accident progression and probabilistic risk assessment methods. The committee believes that nuclear engineering programs are important to meet the needs of the discipline. They can also serve as the route for many engineering students to gain the breadth of understanding necessary to handle other engineering problems and the environmental, safety, and social impacts of engineering activities.

INSTITUTIONAL FACTORS

The assessment of the availability of resources to departments of nuclear engineering can provide insight about the level of commitment being maintained by the institutions. In making the assessment, the influence of several somewhat independent forces should become evident. Each is identified and its influence analyzed. Programs in nuclear engineering can be expected to have a higher unit cost in dollars per student credit hour taught or degree granted than other programs in engineering. Since enrollments are small, the number of student credit hours generated per faculty contact hour is low. Costs arise from faculty contact time, while resources are allocated based on student credit hours. The relatively senior average age of the nuclear engineering faculty means that salaries are higher. Thus, the average cost of a unit of faculty effort is generally higher in nuclear engineering departments.

An important influence on the resources available to a nuclear engineering department is its location. Many programs are in colleges of engineering of the first rank. At least 15 of the programs listed in the DOE data base on nuclear engineering programs are in colleges that are be included in virtually any listing of the top 25 U.S. engineering schools. The engineering programs in these schools are relatively better supported than those in most other schools.

The number of students enrolled in a program also significantly influences available resources. Funding allocation is increasingly based on enrollments, which results in small programs getting lower allocations to support faculty, equipment, operations, travel, and other expenses.

Specialization

While degree requirements are similar for the institutions surveyed, there is considerable variation in their areas of special strength (see Table 4-5). Not all of the programs are alike in terms of their research activities and there are considerable differences. Note that only one institution has an accelerator, for example. One might ask the question as to whether the instructional directions are complemented by the research activities at each institution.

TABLE 4-5 Numbers of Institutions with Given Areas of Strength

Area	Number of Institutions
Reactor engineering	10
Systems analysis and safety	10
Artificial intelligence	2
Advanced reactors	5
Radiation transport	7
Radiation effects	6
Nuclear materials	4
Radiation detection	5
Health physics	5
Criticality safety	4
Waste management	7
Fusion and plasma physics	10
Accelerators	1

SOURCE: Committee survey.

FINDINGS

In summary, the committee arrived at the following findings:

- Undergraduate senior enrollments in nuclear engineering decreased from 1,150 in 1978 to about 650 by 1988. Enrollments in master's programs peaked in the late 1970s, at about 1,050 and have steadily declined, to about 750 in 1988. Since 1982, the number of students enrolled in doctoral programs has remained relatively steady at about 600.
- Declines in nuclear engineering enrollments have limited the addition of junior faculty members, leading to high proportions of older faculty.
- The number of young faculty that identify "reactor-related" research as an area of interest is lower than among older faculty.
- The content of the nuclear engineering curriculum is basically satisfactory, with the exception that more training in reactor systems engineering, biological effects of radiation, and communications skills seems warranted.
- The current size of the nuclear engineering faculty is adequate. At the graduate level, the student-to-faculty ratio is about the same as for other engineering faculties. Faculty levels are also adequate for the present number of graduate students. However, timely replacement of faculty nearing retirement will be necessary to maintain stable programs.
- The number of university reactors has significantly declined over the past two decades. These research reactors are important assets to the nuclear engineering programs that have them and can substantially add to the undergraduate and graduate educational experience.

5

Outlook for Supply of Nuclear Engineers

The potential supply of nuclear engineers is primarily a function of the supply of those who obtain degrees in quantitative fields. "Quantitative fields" include engineering, mathematics, the physical sciences, and the computer and information sciences. In this chapter, the terms "nuclear engineer," "engineer," "mathematician," "computer scientist," and "physical scientist" are defined by the field of degree, not by activity subsequent to graduation. The minimum degree level considered in this study is the bachelor's level.

The number who obtain degrees in nuclear engineering varies, depending on such variables as (1) the perceived and actual demand for nuclear engineers, as indicated to students by such measures as wages and employer recruiting activities, (2) scholarship support for such training relative to support for training in related fields, such as other subfields of engineering or physics, (3) social attitudes toward nuclear energy, and (4) the size and vitality of the nuclear engineering educational infrastructure. The "swing" in the supply of nuclear engineers is also heavily constrained by the supply of those who have interests in and abilities to pursue quantitative fields.

Some questions about the future supply of nuclear engineers can be answered by examining the history of and projected future of quantitative degrees. To assess future supply, trends in degree completion over the last decade for all fields, quantitative fields, engineering, and nuclear engineering were examined. National Center for Education Statistics data bases were used to describe trends in all degrees, quantitative degrees, and engineering degrees. These statistics do not identify nuclear engineering as an engineering subfield, so to estimate past supply of nuclear engineers, Department of Energy (DOE) and Engineering Manpower Commission (EMC) data bases were also used (DOE, 1984 and 1989; EMC, 1979-1989; NCES, 1980-1989).

The committee also tried to establish the potential supply of quantitative degree holders, as indicated by trends in students' tested mathematics and verbal abilities that nuclear engineering undergraduate programs have identified as required to pursue such degrees. Although the past obviously does not necessarily predict the future, it can give some indication of future supply. (For example, Asian immigration rates will affect the number of quantitative degree holders, but it is difficult to predict these rates and, therefore, their degree consequences.) To simplify the following discussion, many of the data tables on which this chapter is based are found in Appendix F.

DEGREE TRENDS FOR ALL FIELDS AND QUANTITATIVE FIELDS

The period from 1977 to 1987 shows an 8-percent increase (from 917,900 to 991,260) in the number of all bachelor's degrees awarded annually including both B.A.s and B.S.s, a 9-percent decrease (from 316,602 to 289,341) in all master's degrees (both M.A.s and M.S.s), and a 3-percent increase (from 33,126 to 34,033) in all Ph.D. degrees (see Appendix F, Table F-1). With nonresident aliens excluded from these numbers, the bachelor's degrees awarded are relatively unchanged, master's degrees awarded declines by 13 percent, and Ph.D.s awarded decrease by nearly 7 percent. Over this period, nonresident aliens increased their share of total master's degrees by almost 90 percent and their share of total Ph.D. degrees by over 70 percent (see Table F-2).

Table 5-1 shows a picture for quantitative degrees radically different from that for total degrees. Between 1977 and 1987 the number of quantitative degrees awarded increased substantially at all degree levels, regardless of whether nonresident aliens were taken into account. The number of quantitative degrees going to U.S. residents increased by 62 and 29 percent at the B.S. and M.S. levels respectively, while doctorates awarded remained stable (the increase in total Ph.D. degrees awarded is almost entirely attributable to nonresident aliens) (see Table F-3). An analysis of quantitative degrees awarded as a share of all degrees awarded, for all degree recipients, U.S. residents, and nonresident aliens, shows that this share increased between 1977 and 1987 for all degree levels and for all three groups (see Table F-4).

If a quantitative degree holder is viewed as a potential nuclear engineering student, then between 1977 and 1987 the potential supply of nuclear engineers increased substantially in absolute numbers and as a share of all degrees awarded.

TABLE 5-1 Quantitative Degrees Granted by Degree Level and U.S. Residency Status, 1977 and 1987

	Total			U.S. Residents[a]		
Degree Level	1977	1987	Percent Change	1977	1987	Percent Change
B.S.	91,191	149,944	64.4	86,474	139,945	61.8
M.S.	27,570	39,476	43.2	22,637	29,253	29.2
Ph.D.	6,952	8,575	23.4	5,368	5,379	0.2

[a] U.S. residents includes U.S. citizens and resident aliens.
SOURCES: U.S. Department of Education (1980, 1989).

DEGREE TRENDS IN ENGINEERING AND NUCLEAR ENGINEERING

As Table 5-2 shows, engineering degrees earned increased substantially between 1978 and 1988 at all degree levels, with the production of B.S. degrees in engineering peaking in 1986 at 78,178 (EMC, 1979-1989). During this period B.S., M.S., and Ph.D. degrees in engineering increased 55, 58, and 78 percent, respectively. Even with nonresident aliens excluded, there were substantial increases at all degree levels.

The number of engineering degrees awarded were not a main factor in the increase in quantitative degrees during the decade. Engineering degrees constituted smaller shares of quantitative degrees in 1987 than in 1977 for total engineering degrees at the B.S. and M.S. levels, for U.S. resident B.S. degrees, and for nonresident alien B.S. and M.S. degrees. In other words, although the absolute number of engineering degrees awarded at all levels increased during the decade, the increases in nonengineering quantitative degrees were generally greater. Thus, the increase in quantitative degrees is more significant (see Table F-6).

However, as engineering gained at all degree levels, nuclear engineering decreased at all degree levels except at the doctoral level. From 1978 to 1988 there were 44-and 52-percent decreases in nuclear engineering B.S. and M.S. degrees, respectively, while the number of total nuclear engineering doctorates remained relatively stable. Removing nonresident aliens from the numbers reveals the magnitude of the decline in M.S. and Ph.D. levels for U.S. residents: a 62 percent decline in M.S. degrees awarded and a 25 percent decrease in the number of doctorates awarded.

TABLE 5-2 Engineering and Nuclear Engineering Degrees Granted, by Degree Level and U.S. Residency Status, 1978 and 1988

	Total			U.S. Residents[a]		
Field and Degree Level	1978	1988	Percent Change	1978	1988	Percent Change
All Engineering						
B.S.	46,091	71,386	54.9	42,997	65,623	52.6
M.S.	16,182	25,616	58.3	12,603	18,338	45.5
Ph.D.	2,573	4,571	77.7	1,699	2,538	49.4
Nuclear Engineering						
B.S.	863	484	-43.9	822	463	-43.7
M.S.	486	232	-52.3	383	145	-62.1
Ph.D.	112	114	1.8	77	58	-24.7

[a] U.S. residents includes U.S. citizens and resident aliens.
SOURCES: Engineering Manpower Commission (1979-1989), for all engineers; U.S. Department of Energy (1984, 1989), for nuclear engineers.

DEGREE TRENDS BY GENDER, RACE, AND ETHNICITY

Historically, relatively small numbers of quantitative degrees have been awarded to women and non-Asian minorities. Even small changes in this pattern could provide long-term expansion of the supply of professionals in quantitative fields.

Degree Trends for Women

Degrees awarded to women increased in all fields between 1977 and 1987, both in absolute numbers at the bachelor's, master's, and Ph.D. levels, and as a share of total degrees awarded at all three levels. Over the same period, degrees awarded to men decreased at all three degree levels, both in absolute numbers and as a share of degrees (see Table F-7).

Between 1977 and 1987 the absolute number of quantitative degrees at all degree levels increased for both men and women. However, increases for women were proportionally greater at all degree levels, especially at the B.S. level (see Table 5-3). Since nonresident aliens earn a substantial fraction of the quantitative degrees awarded, especially at the M.S. and Ph.D. levels, and nonresident aliens are disproportionately male, eliminating nonresident aliens further increases the share of U.S. resident women's quantitative degree awards at all degree levels (see Table F-8).

TABLE 5-3 Quantitative Degrees Granted, by Degree Level and Gender, 1977 and 1987

	1977			1987		
Degree Level	Male	Female	Percent Female	Male	Female	Percent Female
B.S.	78,240	14,143	15.3	111,598	38,346	25.6
M.S.	24,703	3,366	12.0	31,506	7,970	20.2
Ph.D.	6,446	520	7.5	7,504	1,071	12.5

SOURCE: U.S. Department of Education, National Center for Education Statistics (1980, 1989).

Since women have increased their absolute numbers and shares of degrees in all fields, are their increases in quantitative degree numbers and shares simply attributable to increased numbers of women completing post-secondary degrees? An examination of women's quantitative degrees as shares of their total degrees shows that a woman who received a degree at any of the three levels in 1987 was more likely than her 1977 or 1981 counterpart to receive it in a quantitative field. Thus, the data show small, but positive, shifts of women toward quantitative fields (see Tables F-9 and F-10).

Women in 1988 earned substantially greater numbers and shares of engineering degrees, doubling or tripling their 1978 shares at all degree levels (see Table F-11), though again, even by 1988, the number of engineering degrees earned by women was still relatively small at all degree levels. Still, contrary to the downward B.S. and M.S. degree trends in nuclear engineering for men during the decade, women showed a small increase by 1988 in absolute numbers and in the fraction of nuclear engineering degrees they earned at the B.S. and M.S. levels.

Degree Trends by Race and Ethnicity

Relative to 1977, total degrees earned by White non-Hispanics and Black non-Hispanics in 1987 decreased at all degree levels, except for a minor increase for Whites at the B.A./B.S. level. All other groups—Hispanics, American Indians, and Asians—show increases at all degree levels (see Table F-12).[1]

A different result emerges from the data for quantitative degrees granted between 1977 and 1987 by race, ethnicity, and degree level. Relative to 1977, 1987 shows increases for all subgroups in quantitative degrees earned at the B.S. and M.S. levels (see Table F-13). The size of the college-age population is increasing for Blacks, Hispanics, and Asians relative to Whites. The Ph.D. level shows a mixed picture: losses for White non-Hispanics and Black non-Hispanics and gains for Hispanics and Asians. The absolute numbers are so small for American Indians that trends for this group are insignificant. The decrease for Whites and the increase for Hispanics and Asians seem relatively robust, but this is uncertain and it is difficult to separate the roles of changes in population bases and in degree production rates in these results.

Between 1978 and 1988 all subgroups also increased in the number of engineering degrees awarded at all levels (though American Indians showed no change at the Ph.D. level). Except for the White subgroup, the numbers are small, especially at the Ph.D. level, but trends in the number of engineering degrees are uniformly positive (Table 5-4).

The story is different for nuclear engineering. Except for Whites, who show significant losses in nuclear engineering degrees between 1978 and 1988 at all degree levels, the numbers are so small for all other subgroups as to render interpretation meaningless. The data do show that members of non-White subgroups are not rushing to fill nuclear engineering educational programs (Table F-14).

[1] To interpret these data, the total degree production rate for each subgroup is needed. For example, has the B.A./B.S. degree attainment rate per 1,000 American Indian college-age youth increased in this decade? Since the Hispanic and Asian subgroups have experienced substantial in-migration during this decade and U.S. decennial census data are almost 10 years old, we have no accurate measure of the size of Hispanic and Asian college-age cohorts. However, White cohorts are declining in size, American Indian cohorts are relatively stable, and the cohorts of all other subgroups are increasing, especially the Hispanic and Asian. The White degree decline can be partly attributed to this group's declining numbers, but the Black decline indicates a declining degree production rate. The American Indian degree increases—although the absolute numbers are small—could be attributable to an increased degree production rate. The Hispanic and ASian degree increases should be at least partly attributable to increases in the college-age population base; however, data gaps make it difficult to separate the contributions of increases in degree production rates and increased cohort sizes to increases in total degrees.

TABLE 5-4 Engineering Degrees Granted by Degree Level and Race and Ethnicity, 1978 and 1988[a]

	B.S.			M.S.			Ph.D.		
Subgroup	1978	1988	Percent Change	1978	1988	Percent Change	1978	1988	Percent Change
White, Non-Hispanics	39,799	55,193	38.7	11,777	15,700	33.3	1,481	2,195	48.2
Black, Non-Hispanics	894	2,211	147.3	199	364	82.9	15	29	93.3
Hispanics	1,072	2,441	127.7	239	475	98.7	25	36	44.0
American Indians	37	187	405.4	4	32	700.0	3	3	0
Asians	1,195	5,591	367.9	784	1,767	125.4	175	275	57.1

[a] Data exclude nonresident aliens.
SOURCES: Engineering Manpower Commission (1979-1989).

Summary

Table 5-5 summarizes degree trends for different subgroups, including U.S. residents, men, women, and different racial and ethnic groups. This table tells a striking story. Trends in nuclear engineering degrees are negative for most groups at all degree levels, especially if nonresident aliens are excluded. Trends in total degrees are negative or only weakly positive. However, the trends for quantitative degrees and for engineering degrees are strongly positive for virtually all groups at all degree levels. Even if only U.S. resident degrees are considered, the growth in quantitative and engineering degrees between 1977 and 1987 far outstrips any loss in nuclear engineering degrees during this period.

Nevertheless, if positive trends in the number of quantitative and engineering degrees continue, it cannot be assumed that future shortfalls in nuclear engineering can be—or should be—met by recruiting students from other quantitative fields. Even relative to the demand for quantitative degrees, the increase in the number of quantitative degrees awarded may constitute a shortfall. In this case, shifting students from other quantitative fields to nuclear engineering amounts to robbing Peter to pay Paul. It is also not known if special incentives will be needed to attract students to nuclear engineering, or whether standard incentives, such as market wage increases, will suffice.

TABLE 5-5 Summary of Degree Trends for Subgroups, 1977-1978 compared to 1987-1988

	Total Degrees			Quantitative Degrees Degrees			Engineering Degrees			Nuclear Engineering Degrees		
Subgroup	B.S.	M.S.	Ph.D.	B.S.	M.S.	Ph.D.	B.S.	M.S.	Ph.D.	B.S.	M.S.	Ph.D.
Total	+	-	~~	+	+	+	+	+	+	-	-	~~
U.S. Residents	+	-	-	+	+	~~	+	+	+	-	-	-
Non-Res. Aliens	+	+	+	+	+	+	+	+	-	-	+	
Men	-	-	+	+	+	+	+	+	-	-	-	~~
Women	+	~~	+	+	+	+	+	+	+	+	+	~~
Whites	+	-	-	+	+	-	+	+	+	-	-	-
Blacks	-	-	-	+	+	-	+	+	+	Numbers too		
Hispanics	+	+	+	+	+	+	+	+	+	small to be		
Amer. Indians	+	+	+	+	+	-	+	+	~~			
Asians	+	+	+	+	+	+	+	+	+	meaningful		

+ = positive trend
- = negative trend
~~ = stable trend

TRENDS IN SCHOLASTIC APTITUDE TEST SCORES

Trends in earned quantitative and engineering degrees are one way to define a potential pool of nuclear engineers. A much broader definition is to determine the share of college graduates who had the verbal and mathematical abilities at college or graduate school entry to successfully complete a nuclear engineering program. In the committee's survey of nuclear engineering degree programs, respondents specified the minimum Scholastic Aptitude Test (SAT) mathematical and verbal scores that they had found students needed to successfully complete the nuclear engineering B.S. program. Although responses varied, their range of variation was not large.

These scores can be used to define the proportion of the SAT test group that could successfully complete a B.S. degree in nuclear engineering. This proportion represents a potential pool. Note that the lowest SAT mathematics and verbal scores that nuclear engineering departments listed are used, a score of 550 in mathematics and a verbal score of 450. The proportion of SAT test-takers who have achieved both minimum scores cannot be identified, but data show the following (see Tables F-15 and F-16):

- The proportions of the SAT test group that met the verbal and mathematics minimums were stable from 1983 to 1988, for male and female, and for the various racial and ethnic groups.
- In 1988, about 30 percent met the minimum mathematics score, about 40 percent the minimum verbal score. For 1988, the "yield" was over 300,000 individuals who met the minimum quantitative requirement and almost half a million individuals who met the minimum verbal requirement.
- The percent that met mathematical and verbal minimums varied by gender, especially the mathematics minimum. In 1988 only about 23 percent of the female, but 37 percent of the male, SAT group met the mathematical minimum. Forty percent of the women and 45 percent of the men met the verbal minimum.
- The proportion that met mathematical and verbal minimums varied substantially by race and ethnicity. In 1988, 32 percent of the non-Hispanic whites met the mathematical minimum and 48 percent the verbal minimum. Asian Americans roughly reversed the white pattern: 45 percent met the mathematical minimum and 38 percent the verbal minimum. Non-Hispanic Blacks had the weakest performance: in 1988 only 8 percent met the mathematics minimum and 17 percent the verbal minimum. Puerto Rican SAT test-takers did only slightly better than Blacks; other non-Asian minorities performed somewhat better than Puerto Ricans, but not strongly.

Survey respondents often did not identify Graduate Record Examination (GRE) score minimums for expected nuclear engineering graduate program success. However, for whatever these data are worth, the average GRE verbal and mathematics scores of engineering B.S. graduates taking the GRE might indicate likely success in completing a master's degree or doctorate in nuclear engineering.

In 1986-1987 the average mathematics score of all engineering B.S.-degreed GRE test-takers was 680, their average verbal score, 518. Using a cutoff score of 500 for the minimum verbal score and 650 for the minimum quantitative score, of all 1986-1987 GRE test-takers, slightly more than one-fifth met the quantitative criterion and more than half met the verbal criterion. Again, there is substantial variation in test scores by race and ethnicity, for example, 42 percent of Asian, 23 percent of White, and 4 percent of Black GRE test-takers met the quantitative score criterion (See Table F-17).

PROJECTIONS OF THE SIZE, RACIAL AND ETHNIC COMPOSITION, AND HIGHER EDUCATION COMPLETION RATES OF YOUTH COHORTS

The size of the college-age cohort (14 to 34 years of age) will shrink in the next two decades, and its composition will become less White and more Black, Hispanic, and Asian. A major question about these demographic trends is their implication for college and graduate degree completion.

The total U.S. population is projected to steadily increase in absolute size between 1990 and 2010, but the 14-to 34-year-old age group is expected to decline in absolute size over this period. In 1980 those 14 to 34 years old were 37 percent of the total U.S. population; for 2010 this figure is projected to drop to 28 percent. Although the size of the college-age group is expected to begin to increase between 2000 and 2010, it will still be below the 1990 level in 2010 (see Table F-18 and Figure F-1).

These smaller college-age cohorts are also projected to change in racial and ethnic composition: (1) declining in White college-age cohorts from about three of every four 14 to 34 years old in 1980, to about two of three in 2010; (2) increasing in Black college-age cohorts from about one of eight in 1980, to about one of six in 2010; (3) increasing in Hispanic college-age cohorts from about one of fourteen in 1980, to about one of eight in 2010; and (4) increasing slightly in other races, including Asians, between 1980 and 2010 (see Table F-19).

Changes in cohort sizes and racial and ethnic composition matter only to the extent that they affect cohort degree production rates and field choices. A study that projects the number of B.A. and M.A./Ph.D. degrees for 1995 and 2005 indicates virtually no change between 1984, 1995, and 2005 in either B.A. or M.A./Ph.D. production rates. For example, in 1984 the 18-to 34-year old cohort had a B.A. production rate of 12.1 percent; for 1995 and 2005 this age group is projected to have B.A. production rates of 12.1 and 11.3 percent respectively. Thus, changes in cohort size, not in racial and ethnic composition, are projected to have the greatest effect. Since the 2005 college-age cohort is projected to be only 90 percent the size of the 1984 cohort, even at a constant rate of degree production, this future cohort will achieve smaller numbers of degrees (see Tables F-18 to F-20).

These data indicate the effects of changes in racial and ethnic composition on quantitative-degree production rates. If White quantitative-degree production rates are used as the baseline for estimating the quantitative field effects of population shifts toward minorities, the higher Asian production rates more than compensate for the lower rates of Blacks and American Indians at all degree levels. For example, the 14.1-percent production rate of quantitative bachelor's degrees for Whites can be used to assess the effect of lower rates for Blacks and American Indians. The 31.3-percent rate for Asians creates 5,610 more B.S. quantitative degrees than would be expected from the White rate, a number that more than compensates for the lower Black and American Indian rates, relative to the number of degrees that would have been expected using the White rate, which would yield 1,103 B.S. quantitative degrees.

The 1987 numbers suggest that population shifts away from Whites and toward minorities may have few effects—may in fact have numerically positive effects—on the production of quantitative degrees.

BALANCE BETWEEN SUPPLY AND DEMAND

There are a number of considerations and uncertainties in making supply and demand projections for nuclear engineering:

1. Market forces tend to correct for supply shortages if market signals are clear and consistent (e.g., increasing wages for nuclear engineers and an increasingly positive view in the United States of nuclear energy as an energy supply option). Corrections do take time, not a great amount in the case of the B.S. degree, because undergraduates can readily shift majors, but longer for the production of M.S. and Ph.D. nuclear engineers. Market forces alone can probably attract additional students up to the capacity of the educational institutions. However, market forces cannot, in the near-term, expand institutional capacity. As this capacity declines, the ability of market forces to compensate also declines.
2. Over the next 20 years, the total demand for quantitative degrees, especially in engineering, may be high, and there may be significant shortages of scientists and engineers. If predicted shortages develop in other engineering fields, the market forces needed to enhance nuclear engineering enrollments will have to be greater.
3. Standard ways to meet shortages, for example, by using foreign engineers or retraining engineers from other fields abroad have limited utility for nuclear engineering. The requirement for security clearances in many nuclear engineering jobs reduces the ability of employers to draw an increasingly international supply of professional labor. Additionally, the reemergence of nuclear power as a U.S. energy supply option may require a higher percentage of uniquely trained and fully accredited degreed nuclear engineers. Also, the countries from which these nuclear engineers might come could have their own increasing demand for this engineering pool.
4. Because of the need for security clearances and citizenship for many nuclear engineers in both government and industry, concerns about the supply of nuclear engineers are greater because of the decline in percent and numbers

of M.S. and Ph.D. degrees in the field being awarded to U.S. citizens. The large portion of the graduate student population that does not contain U.S. citizens has the potential of meeting future U.S. demand for nuclear engineering graduates by contributing to the supply of potential employees for non-sensitive jobs in the utility industry and in the nuclear equipment manufacturing sector. To the extent that these graduates can fill some of these positions, and are permanent residents or have a "green card," future demand in sensitive areas will have a better chance of being met by recruiting from the available U.S. citizen graduate pool. There are relatively few non-U.S. citizen graduates in nuclear engineering from foreign institutions that enter the U.S. work force without taking at least one degree from a U.S. institution. Thus, the potential for non-U.S. citizen degree holders is largely for the student who receives nuclear engineering training from U.S. institutions.

5. The projected decline and changes in composition of the college-age population could limit the number of degrees awarded in quantitative fields, leading to intense competition for qualified students. However, the trends in quantitative degrees are positive for all segments, and there is evidence that greater numbers of women and minorities are achieving these degrees. However, it is uncertain whether these shifts will continue, at what rate, and whether they will be enough to satisfy demand.

A number of major employers informed the committee that they were encountering no difficulty in recruiting nuclear engineers with the possible exception of Ph.D.s. The committee compared starting salaries for nuclear engineers with those for engineers from other disciplines and found them to be generally comparable (Table 5-6).

Although the supply and demand of nuclear engineers is in balance as of 1989, projections indicate a shortfall in supply under all scenarios (see Chapter 3) unless significant changes are made. Figure 5-1 shows actual and projected graduates available for employment and demand, and estimates of additional students that could be educated each year without additional faculty or facilities. This analysis assumes no further decline in the supply of new graduates. While the 1988 and 1989 enrollment and degree data seem to support the view that the decline has largely stopped, it is still too early to tell. While several schools report increases and more healthy programs, several other schools are still discussing phasing out their programs. These simple projections show that for the best-estimate demand scenario, demand will exceed supply before 1995, even if the decline in capacity slows. If annual demand stays at about 400 new labor market entrants, shortages will almost certainly develop before the end of the century. If it is assumed that

TABLE 5-6 Typical Starting Salaries for New Engineering Graduates, by Field and Degree (in dollars)

	B.S.				M.S.				Ph.D.			
Year	NE	ME	EE	CHE	NE[a]	ME	EE	CHE	NE[a]	ME	EE	CHE
1979	17,830	18,430	18,240	19,700	19,780	20,590	20,770	21,360	-	25,920	26,650	26,770
1980	20,020	20,440	20,280	21,610	21,970	22,720	22,940	23,360	-	26,110	30,410	29,420
1981	22,440	22,900	22,580	24,360	24,670	25,500	25,660	26,400	-	31,910	33,520	32,940
1982	24,470	25,180	24,770	27,070	27,600	27,900	28,430	29,510	-	35,510	37,190	36,230
1983	24,940	25,150	25,540	26,740	28,630	28,800	29,532	28,850	-	37,800	38,400	37,560
1984	26,390	25,220	26,560	27,420	29,650	30,290	31,010	30,680	-	38,390	41,160	38,870
1985	27,400	27,110	27,400	28,430	30,980	31,450	32,720	31,150	-	38,029	42,500	40,860
1986	27,700	27,860	28,370	29,260	35,200	32,880	34,210	32,140	-	41,220	46,140	42,680
1987	28,530	28,310	28,920	29,840	34,390	34,020	35,400	33,760	-	42,830	47,580	43,260
1988	28,740	29,410	29,690	31,010	31,860	34,000	36,100	34,450	-	46,240	49,340	45,600
1989	32,160	30,540	30,660	32,950	34,020	35,260	36,440	36,130	-	45,890	48,670	47,850

NOTE: NE, nuclear engineers; ME, mechanical engineers; EE, electrical engineers; CHE, chemical engineers.
[a] Survey cohort too small to provide meaningful data.
SOURCE: College Placement Council (1979-1989).

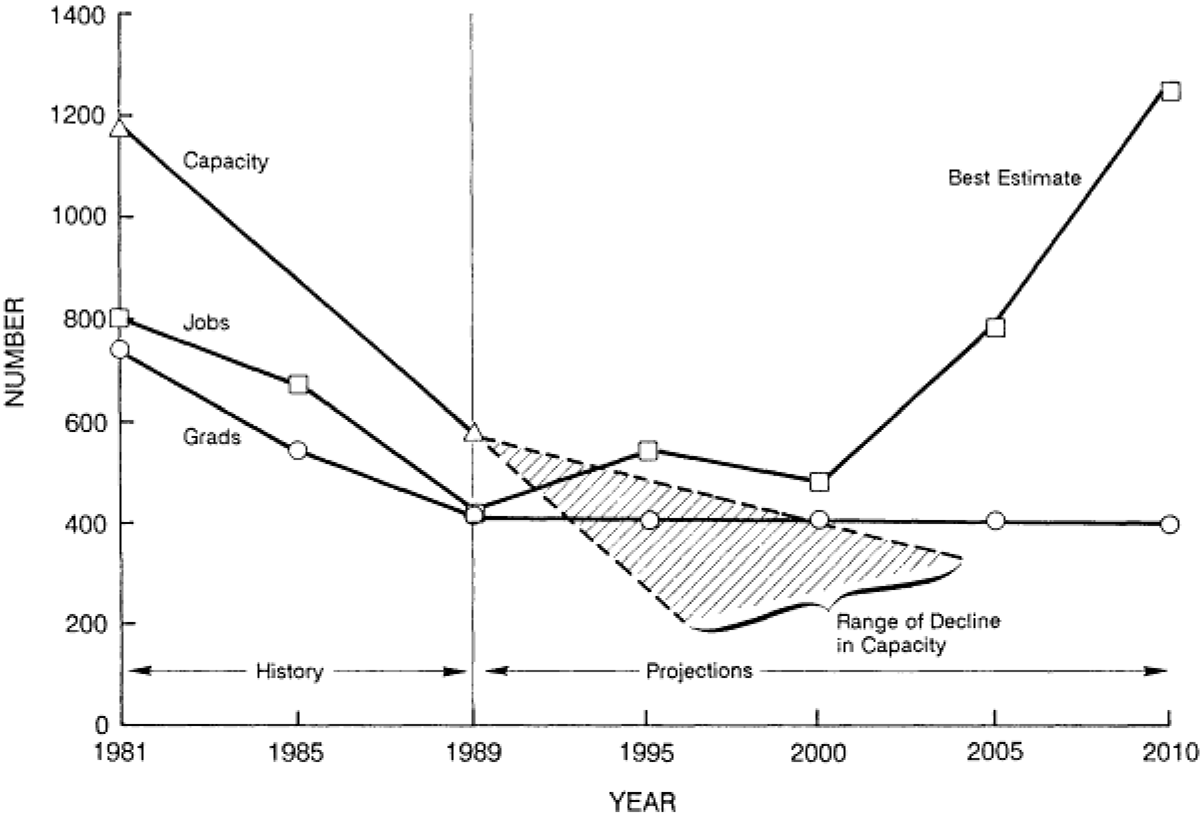


Figure 5-1
Supply and demand projections for new graduate nuclear engineers in the U.S. civilian labor force (see Table 5-7 for background).

FINDINGS

Committee findings regarding the future supply of nuclear engineers include the following:

- Current U.S. replacement needs for those with B.S., M.S., and doctorate degrees in nuclear engineering are about 400 new labor market entrants annually. This demand roughly balances the current output of the educational system.
- Although the number of degrees awarded in quantitative fields between 1978 and 1988 increased at all degree levels, the number awarded annually in

nuclear engineering decreased at the B.S. and M.S. levels and remained relatively stable at the Ph.D. level. For U.S. residents, nuclear engineering degrees decreased at all levels. If current demand trends continue, a shortfall in supply will occur and grow with time.

- The potential for increased demand is greater than the potential for increased supply, owing primarily to decreasing student populations. Significant shortages in nuclear engineers may be observed as early as the mid-1990s.
- Between 1977 and 1987, the absolute numbers and shares of total engineering and nuclear engineering degrees earned by women increased. The data also show small but positive structural shifts in women's field choices towards quantitative fields.
- Between 1977 and 1987 quantitative degrees earned by minorities increased and there are also shifts in their field choices toward quantitative fields. These trends present an opportunity to attract more minority candidates to nuclear engineering. The fact that an increasing proportion of the college-age cohort will consist of minorities makes such a strategy almost a necessity.
- Between 1977 and 1987 trends for quantitative degrees and for engineering degrees are strongly positive for virtually all groups at all degree levels. For U.S. residents, this growth outstrips any loss in nuclear engineering degrees. However, it cannot be assumed that any increased demand

TABLE 5-7 Calculations on which Employment Data in Figure 5-1 are Based

Year	Reported Employment	Three-Year Survey Moving Average	Annual Rate (growth + replacement = sum)	Estimated Job Openings for New Graduates
1977	7,450	n.a.		
1981	8,080	8,480		800
			496 + 314 = 810	
1983	9,920	9,443		
1985	10,330	10,630		675
			287 + 382 = 669	
1987	11,640	11,203		
1989	11,640[a]	11,640		425
			0 + 407 = 407	
1990	11,640[a]	11,640		

[a] Estimated.

for nuclear engineers will be met by attracting students from these other quantitative fields, because the demand from many other quarters for these quantitative degrees is also expected to rise.

- Simple projections show that for the best-estimate demand scenario, demand will exceed supply before 1995, even if the decline in capacity slows. If annual demand for nuclear engineers stays at about 400, new labor market entrants shortages will almost certainly develop before the year 2000.

6

Implications of Future Demand for Nuclear Engineering Education

The previous chapters have addressed the imbalance between projected demand and supply of nuclear engineers, an imbalance that will result if current trends in nuclear engineering education continue. Also, changes taking place in research directions have already been addressed. In this chapter, the committee identifies changes that appear to be needed in nuclear engineering education to maintain its vitality and to meet projected demands for qualified nuclear engineers.

NEEDED CHANGES IN THE UNDERGRADUATE CURRICULUM

The committee performed an analysis of the skills needed by nuclear engineers for prospective employers, after conducting a survey of institutions and firms hiring undergraduate and graduate nuclear engineers. Input was sought from a wide variety of respondents, which ranged from utilities and reactor vendors to national laboratories and government organizations. Respondents were asked to rank the importance of 10 different segments of the nuclear engineering curriculum.

Based on these responses and on the factors influencing the discipline that were mentioned in previous chapters, it is clear that some modest modifications in nuclear engineering curricula are needed. Almost universally, respondents indicated the need for improved oral and written communication skills. This problem may owe in some degree to the growth in the number of graduate students for whom English is not a first language. Such a response relates to engineers in general—in fact, to most professionals—and seems to indicate the need to enhance communication skills in this information age; it may also reflect the importance and widespread use of engineering teams in which communication is important. Courses should be designed for students to exercise and develop communications skills.

The survey also indicated that nuclear engineers at the undergraduate level need strong skills in reactor physics, reactor operations, health effects of nuclear radiation, reactor safety, and other areas germane to power reactor operation for energy production. The present curriculum seems to be generally successful in providing this training.

Respondents to the survey were asked the nature of the positions for which nuclear engineers were hired and whether graduates in other engineering disciplines could be used to fill those positions. The most uniform responses on this issue were from the nuclear industry concerning nuclear engineers with bachelor's degrees. These responses indicated that personnel trained in other engineering disciplines can be used to fill many positions within the industry; however, nuclear engineers are preferred for positions for which an understanding of system behavior is desirable. Such positions could include, for example, serving as shift technical advisor at an operating nuclear power reactor or performing safety analyses of the behavior of a reactor system. A reactor plant is an unusually complex system of interrelated components (e.g., electrical, radioactive, hydraulic, and mechanical) with immense energy potentially available for controlled or uncontrolled release. The design, maintenance, and operation of these systems and components require competence in physics, mechanics, thermal hydraulics, heat transfer, chemistry, and other disciplinary areas. Thus, understanding and capability in one field are not sufficient for some positions in nuclear power plants that focus on systems. The survey points out a need to strengthen systems education in the nuclear engineering curriculum.

In the main, however, the present U.S. undergraduate nuclear engineering curriculum appears to have the proper course content to educate for nuclear engineering. Further, despite the great differences in educational approaches in other countries, the basic technical curriculum content seems to be universal. Enhancements to the curriculum in the area of oral and written communications, reactor systems engineering, and biological effects of radiation, are indicated.

In spite of the reasonably satisfactory state of the present curriculum, some trends do not bode well for nuclear engineering programs. Faculties are ageing and decreasing in size, and there are few junior faculty being hired. As class sizes decline, university administrators often do not replace nuclear engineering faculty who retire or resign. When such faculty are replaced, the new faculty come from graduate programs with curricula that place less emphasis on commercial power reactor systems. These trends, if they continue, will weaken undergraduate teaching in reactor technology and may have a detrimental effect on the education of undergraduate nuclear engineers needed in the future. This conclusion suggests that adjustments might be made in research programs and graduate curricula to ensure understanding of reactor systems engineering.

NEEDED CHANGES IN THE GRADUATE CURRICULUM AND RESEARCH PROGRAMS

It was stressed earlier that nuclear engineering research programs are diversifying. Research related to commercial power reactors has substantially declined. Much of the funding available is directed to near-term objectives and is only marginally appropriate for the creative research required for a graduate degree. Funding for graduate fellowships has also declined. Although there are such positive arrangements as the Institute of Nuclear Power Operations (INPO) fellowships and the U.S. Department of Energy's (DOE) Office of Energy Research (OER) nuclear engineering research program, long-term reactor physics and engineering-oriented research support and student fellowship support are not sufficient. In particular, the funding available for research relevant to nuclear power reactors needs to be increased. The committee survey data indicate that increases in both fellowships and reactor-relevant research funding can be effective and the present infrastructure can accommodate more students.

These points do not imply that increases for reactor research funds need to be large. Nuclear engineering faculty can and should continue to seek research funding to address other issues. The broadening of the field is a healthy trend, finding new solutions to important problems. On the other hand, the national nuclear engineering research program has moved so sharply away nuclear power directions that some balance of activities seems to be in order. The 1990 Fiscal Year OER budget of $6 million for nuclear engineering research, fellowships, research reactor utilization and educational support is an excellent start. This funding, which was provided by congressional appropriation, needs to be added again to the administrations's annual budget submission to Congress. The $4 million research component of this program is sufficiently long-term to be appropriate for universities and is largely reactor-related.

The committee's judgment is that reactor-related research funding should represent about 25 to 30 percent of total research funds instead of the current 15 percent (Table 4-2). Thus, increasing the research component of the OER program by $7 million per year, from the present $4 million to $11 million per year, would result in about 27 percent of funding ([$6.5 + $7 million]/[$43 + $7 million]) being oriented toward reactor-related research. At about $28,000 per graduate student, this additional $7 million could support about 250 additional graduate students. The present infrastructure could absorb such an increase and the infusion of funds would be a major help in strengthening nuclear engineering education.

The National Science Foundation (NSF) presently supports 12.3 percent of research in nuclear engineering programs. This support is in research areas that are not closely related to nuclear reactors, but are vital to the long-term vitality of nuclear engineering education. The committee found that within the nuclear engineering academic community, NSF is perceived to consider support of nuclear engineering to be a DOE responsibility. An example given is the recent rejection of the Massachusetts Institute of Technology proposal for an NSF Engineering Research Center in Advanced Nuclear Power Studies. DOE was apparently perceived by NSF to be the proper sponsor of the proposed work.

With the emergence of nuclear engineering as a broad-based academic discipline, no longer tied solely to commercial nuclear power, and with improving prospects for commercial nuclear power, NSF should again review its policies toward funding nuclear engineering education. The results of the recent NSF workshop on this subject could be the starting point for NSF to more clearly define and promote its policy of support for education and research in nuclear engineering (NSF, 1989).

The OER, which has taken the lead in enthusiastically supporting the valuable, although rather modest, new research program in nuclear engineering, should monitor nuclear engineering research across all agencies to ensure adequate coordination. The recommended increase to an $11 million research program could help ensure a proper balance between reactor-related and other research in nuclear engineering programs. There also should be a balance between funding the research of individual investigators and funding that of larger centers. The NSF has found that such centers, which often involve several departments on campuses, can provide fresh approaches to difficult problems.

Research is closely tied to graduate education. In our survey of skills needed by graduate engineers, the ability to conduct independent research was the most widely needed skill identified. Again, strong communications skills and a thorough understanding of nuclear engineering systems were also indicated. Unless a job specifically requires the expert skills of another engineering discipline (e.g., the circuit design skills of an electrical engineer), an engineer from such another discipline could not simply replace the nuclear engineer without appropriate training. The committee believes that for jobs associated with power reactors, educational experience is ideally gained in a nuclear engineering program where at least some reactor research is conducted. The enhanced nuclear engineering research program described would lead to better balanced research funding in nuclear engineering programs, and a curriculum with greater attention to power reactor issues, yielding graduates better suited to potential employers' needs.

UNIVERSITY REACTORS

The number of university research reactors has declined significantly (NRC, 1988). As discussed in Chapter 4, access to a university reactor is an important element of both undergraduate and graduate nuclear engineering education. Because of the expense of supporting these reactors, it is not anticipated that every nuclear engineering department can have one. However, there should be a sufficient number of such reactors, located so that all nuclear engineering departments can gain access to one without undue costs.

THE ROLE OF INDUSTRY

The U.S. nuclear power industry, especially the utilities now operating the commercial reactors, has a vested interest in ensuring a strong manpower pool for the industry of the future. Although broad-based educational experience is appropriate for nuclear engineering programs, some component closely aligned with the commercial nuclear power industry is extremely important to produce graduates with the requisite training and education. Through INPO the nuclear power industry has established both graduate fellowship programs (totalling $380,000 per year) and undergraduate scholarship programs (totalling $510,000 per year) in nuclear engineering and health physics (INPO, 1989).

However, companies within the nuclear power industry, both utilities and suppliers, should be encouraged to reexamine and increase their involvement with nuclear engineering programs. Such involvement may be significant for their success in the future competition for graduate students. In addition to strengthening scholarship and fellowship programs, industrial organizations should be more visible on campuses, and faculty and students should participate in on-site industrial programs. Industry has interacted with nuclear engineering programs in several effective ways:

1. Cooperative education programs, in which students alternate between paid assignments in industry and full-time education. This arrangement affords the student first-hand experience in applied nuclear engineering in industry, and it affords the employing industry in-depth experience with a potential professional employee. Industry has often found that after graduation such students are among the best of new hires.
2. Summer employment of undergraduate sophomores and juniors.
3. Adjunct professors provided by industrial organizations from among their most experienced and capable personnel to add diversity to faculty and provide students with first-hand exposure to an industry perspective.
4. Two-year nuclear engineering technology programs established cooperatively by universities and industrial firms, to develop a continuing

supply of trained technicians. Pennsylvania State University, Duquesne Light, and Westinghouse Electric Corporation have cooperated effectively for a number of years in such an enterprise.

5. Advisory committees that promote closer relationships between nuclear engineering departments and nearby industrial concerns.
6. Small sponsored research programs in nuclear engineering departments to solve industry problems.

FINDINGS

In summary, then, a number of steps discussed here can strengthen nuclear engineering education; some are enumerated as recommendations in Chapter 7. Findings regarding nuclear education for future needs, based on discussion in this and previous chapters are as follows:

- Bachelor of science graduates need strong skills in areas relating to nuclear power reactors because they are very likely to be employed in the nuclear power industry. This is also true, though less so, of master of science graduates.
- Nuclear engineering curricula are properly focused on the fundamentals of the discipline but need modest broadening to respond to the following trends: the growing use of integrated systems approaches to evaluate reactor safety and risks, increased interest and concern about the biological effects of radiation, greater emphasis on radioactive waste management and related environmental remediation technologies, and the widely shared opinion of employers that graduates need improved oral and written communications skills (a concern common to all engineering disciplines and especially a problem given the many foreign students).
- Over the past 10 to 15 years, there has been a substantial decline in research related to power reactors. There has been some increase in research on fusion, space power applications, medical applications and waste management. Thus, although inadequate to the research support levels needed by the discipline, a broader program relevant to the applications of nuclear forces and processes has emerged.
- There is a significant and growing mismatch between the research interests of the faculty and the subject matter of the undergraduate curricula.
- The average age of U.S. nuclear engineering faculty is about 10 years greater than for all engineering faculty, and only 18 percent of the faculty qualified to teach nuclear engineering have less than five years of teaching experience. Failure to introduce young faculty will necessarily limit research development in many institutions and promises serious interruptions in future program continuity.

7

Summary and Recommendations

STATUS OF U.S. NUCLEAR ENGINEERING EDUCATION

The development of nuclear power after World War II made nuclear engineering a dynamic field until the late 1970s. Since then, several factors have deterred the further expansion of commercial nuclear power in the United States: the last order to construct a new nuclear power plant was placed in 1978. This trend has led to a decline in nuclear engineering enrollments and in the proportion of research funds available to faculty for research related to commercial power reactors. Nuclear engineering research now covers broader applications of nuclear forces and processes, and is reflected in graduate programs. Undergraduate programs continue to be relatively broad based, providing undergraduates with a good education on power reactors. The decline in enrollments over the past decade has resulted in a decline in the hiring of new faculty and an increase in the average age of faculty. In addition, at the graduate level, there is an increasing proportion of foreign students.

In summary:

1. While the committee has found no evidence of changes in the quality of U.S. nuclear engineering academic programs, there has been a decline in the number of schools offering such curricula, in the number of students—especially of U.S. students—studying nuclear engineering, in the rate of addition of young faculty, in the average age of the faculty, and in the number of research reactors for education. Emphasis of research funding has also shifted away from areas related to power reactors, and maintaining laboratories and equipment in support of nuclear engineering education has become more difficult.

2. Undergraduate nuclear engineering curricula are generally accredited by the Accreditation Board for Engineering and Technology (ABET) and contain much the same content across institutions. These curricula provide a broad background in basic sciences and engineering, and have a nuclear engineering course content that is heavily oriented toward power reactor applications. The basic undergraduate curricula are well suited to serve the needs of the industry in which most graduates find employment.
3. The graduate curriculum is far more diverse and varied from university to university, reflecting the many areas in which those with advanced degrees find employment. Graduate research programs have changed significantly over the past decade. There has been a dramatic decline in research related to power reactors, which now represents less than 15 percent of research funding in the field. Research in other nuclear engineering areas continues to increase: in medical diagnosis and treatment, space exploration, new energy generation and storage technologies, and radioactive waste disposal.

SUPPLY AND DEMAND

Currently, supply and demand for nuclear engineers is in balance. There are pressures to place more degreed engineers in power reactor control rooms, in technical advisory roles, and in management positions. The committee projects that demand will increase over the next 5 years because of the needs of the Department of Energy (DOE), and over the next 20 years depending on the rate of design and construction of new nuclear power plants. The supply of nuclear engineers is projected to fall below demand if current student population trends continue. Although it is difficult to make projections about the resurgence of nuclear power, the committee feels that it has made conservative assumptions in its "best-estimate" demand projection and that demand in 10 to 20 years could exceed the committee's projections. Even if these demand projections for the resurgence of nuclear power are not completely realized, there are still the near-term needs and other important reasons for maintaining strong nuclear engineering academic programs. For example, the employment market for Ph.D. graduates in nuclear engineering is diverse and the power reactor industry plays a much smaller role in this market than it does in the markets for B.S. and M.S. graduates. Nuclear engineers with Ph.D.s are employed by the national laboratories, in fusion activities, in Strategic Defense Initiative studies, and universities.

In summary:

4. At present the supply and demand for undergraduate nuclear engineers is in balance. Yet, even if there are no new reactor orders, the demand for undergraduate nuclear engineers is now increasing and will likely increase further. The committee's best-estimate projects 50-and 25-percent increases

in demand by 1995 and 2000, respectively, and if there is a resurgence of nuclear power in the United States, a doubling or trebling of current demand after the year 2000. If trends in nuclear engineering education continue, a rising demand for nuclear engineers will outstrip the supply within a few years.

The committee notes the uncertainties in the future scope and needs in the defense industry that may result from the recent changes in the international situation. The result may be the availability of some engineers for retraining to fill a portion of the needs in the nuclear field. However, the committee had no way at this time to assess the numbers of such engineers nor the time scale of their availability and retraining.

EDUCATION FOR FUTURE NEEDS

Considering the continuing need for safe, efficient operation of power reactors already built, the probability that additional reactors will be built in the future, the needs of the U.S. Department of Energy, and the increasing number of areas in which nuclear engineering is applied, the nation has a great interest in ensuring the continuity of nuclear engineering programs and their highly skilled faculties and adequate research and fellowship funding.

In summary:

5. Nuclear engineering programs must remain separate areas within engineering colleges to ensure the integrity and vitality of their unique educational goals.
6. Those that hire undergraduate nuclear engineers say these engineers need better oral and written communications skills, better knowledge of the nuclear reactor as an integrated system, and more education of the biological effects of radiation.
7. Current programs could be modestly expanded without increasing the faculty.
8. Greater funding for research related to nuclear power reactors is needed to reverse the decline of over more than a decade.
9. U.S. research reactors should be accessible to all nuclear engineering departments.
10. Industry has strengthened nuclear engineering programs, keeping them relevant to employers' needs, through (1) scholarship and fellowship programs; (2) campus activities such as industry-oriented seminars and

American Nuclear Society programs, and (3) faculty and student participation in on-site industrial programs.

RECOMMENDATIONS

To strengthen U.S. nuclear engineering education and reverse the decline of the last decade, the committee has identified a number of needed actions, which are stated as recommendations below. The responsibility for nuclear engineering education is shared by the federal government, private industry, and the academic community, and the recommendations below are directed to decision makers in each of these sectors. Because an expected near-term shortage (in the next 5 to 10 years) of nuclear engineers would largely owe to expanded government programs, DOE has added responsibility for near-term solutions.

Responsibilities of the Federal Government

The federal government, and especially DOE can directly influence the number of students and the direction of research through increased funding, helping to ensure an adequate student pool and access to research reactors for educational purposes. Adequate data bases will also be important to assess current and future issues. This study was slowed by the inadequacy, incompleteness, and incompatibility of existing data bases on the employment of nuclear engineers. The DOE data base maintained by Oak Ridge Associated Universities, which is an ongoing compilation of responses to its Survey of Occupational Employment in Nuclear-Related Activities, is not a new system, and efforts to upgrade it have been limited by resources. This data base does not cover military personnel or employees of educational or medical institutions, construction firms, or federal agencies other than DOE and the Nuclear Regulatory Commission. As a result, the committee had to solicit information through its own survey to complement these data bases.

The committee arrived at the following recommendations:

- Funding for traineeship and fellowship programs should be increased.
- Additional research funds should be made available to support work on nuclear power reactors, especially for innovative approaches. Increasing the existing DOE research program from $4 million to $11 million per year is recommended.
- Programs to attract women and minorities into nuclear engineering should be enhanced, a need sharpened by demographic trends.
- DOE should consider providing funds for nuclear engineering participation in minority-oriented science and technology initiatives, notably those being established by the National Science Foundation.

- DOE should assess supporting the access, for educational purposes, of all nuclear engineering departments to the research reactors in the United States.
- DOE should ensure that its personnel data base in nuclear engineering promptly and accurately reflects supply and demand. Several actions should help accomplish this:

  - The definitions of the discipline and job skill requirements should be revised and clarified to better match those used by the sectors being surveyed.
  - Survey methods should be revised to ensure that no temporary assignments or offices are excluded and that all sectors of nuclear-related employment and all appropriate employees more generally are included.
- - Survey questions and format should be reviewed both by professional questionnaire experts and by sector practitioners, to ensure thoroughness, consistency and clarity.
- - The present exclusion from DOE personnel data of those in the fields of fusion, education and academia, and the health-care industry, and of uniformed military personnel should be reexamined.

Responsibilities of Industry

While near-term needs will owe largely to government programs, any increased longer term need for nuclear engineers is likely to result from a resurgence of nuclear power. For this reason, electric utilities and the supporting industry can help to ensure the needed supply of properly trained people through appropriate actions.

The committee recommends the following:

- Electric utilities and the supporting industry should increase their participation and support of U.S. nuclear engineering education. Such support should cover cooperative student programs, research sponsorship, scholarships and fellowships, seminar sponsorship, and establishing and supporting academic chairs.
- Industry should continue working with the American Nuclear Society, and other professional engineering societies, such as the American Society of Mechanical Engineers and the Institute of Electrical and Electronic Engineers, in support of its strong advocacy for nuclear engineering education.

Responsibilities of Universities

The nuclear engineering undergraduate curriculum is appropriately broad in both laboratory and classroom instruction, and provides good training and education for employment in the nuclear power industry. The broadening of research in graduate nuclear engineering programs is a positive trend and should be encouraged. The imminent retirement of a significant fraction of the faculty jeopardizes both undergraduate and graduate programs.

Therefore, the committee recommends the following:

- Nuclear engineering curricula should continue to be broad based. At the undergraduate level, however, programs should increase emphasis on systems-oriented reactor engineering, study of the biological effects of radiation, and oral and written communication skills. At both undergraduate and graduate levels, more emphasis should be given to nuclear waste management and environmental remediation and restoration.
- Research programs should include more research in reactor-oriented areas.
- Nuclear engineering faculty should actively develop and seek support for research related to power reactors, to nuclear waste management, and environmental remediation.
- University administrators should develop innovative procedures, such as partial or phased retirement of older faculty to retain access to their special capabilities and skills, to allow the addition of junior faculty in a timely fashion.

Appendix A

Statement of Task

The study committee will conduct a study of nuclear engineering education in the United States and recommend appropriate action to the sponsors of this study. The committee will perform the following tasks:

- **Characterize the status of nuclear engineering education in the United States**. Take into account present faculty and student numbers, existing curricula, availability of research and scholarship/ fellowship funds, and other factors as appropriate.
- **Estimate the supply and demand for undergraduate and graduate nuclear engineering in the United States over the near to mid-term (5 to 20 years**). In so doing, take into account hiring patterns in the nuclear industry of both formally trained nuclear engineers and others trained in more traditional disciplines, such as mechanical engineering, and the ratio of advanced degree holders to baccalaureates being hired. Identify the roles, if any, of other programs in training individuals who will work in nuclear engineering, e.g., MEs, EEs, and physicists. Make this estimate for scenarios having various assumed trends in the nuclear power industry, the federal laboratories, the Navy, and the universities.
- **Address the spectrum of material that the nuclear engineering curriculum should cover and how it should relate to other allied disciplines** . In so doing, consider the implications to the nuclear engineering curriculum of the perceptions that the nuclear power industries are afflicted with management deficiencies, construction problems, and ethical shortcomings. Examine the curriculums used in France, Japan, and other countries, as appropriate, for strengths that might be applicable in the United States.
- **Recommend appropriate actions to assure that the nation's needs for competent nuclear engineers at both the graduate and undergraduate levels are satisfied over the near and mid-term**. Consider career opportunities, potential student base, research funding, and how to assure excellence in the student background in individual students.

Appendix B

Biographical Sketches Committee on Nuclear Engineering Education

Gregory R. Choppin (Chairman)

R. O. Lawton Distinguished Professor of Chemistry, Florida State University

Gregory Choppin has been with the chemistry faculty of Florida State University since 1956, where he is now R. O. Lawton Distinguished Professor of Chemistry. He received a B.S. in chemistry from Loyola University, a Ph.D. from the University of Texas, and honorary doctorate degrees from Loyola University (New Orleans) and Chalmers University of Technology (Sweden). Dr. Choppin has served as a visiting scientist at the Centre d'Etude Nucleaire Moleculaire in Belgium and the European Transuranium Institute in West Germany, and as a visiting professor at the University of Liege and the Science University of Tokyo. He is a consultant for several Department of Energy national laboratories and is a specialist in actinide and lanthanide chemistry. He serves on the editorial boards of eight scientific journals and has won national awards in nuclear chemistry, actinide separations, and chemical education.

Patricia A. Baisden

Group Leader, Inorganic Chemistry Group, Lawrence Livermore National Laboratory

Patricia Baisden is group leader of the Inorganic Chemistry Group at Lawrence Livermore National Laboratory, conducting applied research in inorganic chemistry and radiochemistry. She received a B.S. in chemistry and a Ph.D. in physical inorganic chemistry from Florida State University, and did postdoctoral studies at Lawrence Berkeley Laboratory. Dr. Baisden is a member of Phi Beta Kappa and the American Chemical Society, and has served since 1983 on the National Academy of Sciences Committee on Nuclear and Radiochemistry. Her research specialties are measurement of heavy element fission properties, solution chemistry of lanthanides and actinides, and heavy ion collisions leading to complete or incomplete fusion.

Wallace B. Behnke, JR.

Vice Chairman of Commonwealth Edison Company (retired) and Consulting Engineer, Kiawah Island, South Carolina

Wallace Behnke retired in July 1989 as Vice Chairman of Commonwealth Edison Company. He is currently a consulting engineer and is a registered professional engineer in Illinois. Mr. Behnke received the B.S. and B.S.E.E. degrees from Northwestern University. He is a director of Commonwealth Edison Company, of Duff and Phelps Selected Utilities, and of the Institute of Electrical and Electronics Engineers (IEEE). He is also a member of the Board of Governors of Argonne National Laboratory, the Advisory Committee for the Idaho National Engineering Laboratory, the Visiting Committee for the Massachusetts Institute of Technology's Department of Nuclear Engineering, and the U.S.-Japan Coordinating Committee for Development of Liquid Metal/Fast Breeder Reactors. He is a member and past president of the IEEE Power Engineering Society and of the Western Society of Engineers, and member of the National Academy of Engineering and the American Nuclear Society. A Fellow of IEEE, Mr. Behnke was elected Electric Industry Man of the Year in 1984 and received the John N. Landis Medal from the American Society of Mechanical Engineers in 1989.

Sue E. Berryman

Director, National Center on Education and Employment Teachers College, Columbia University

Sue Berryman is director of the National Center on Education and Employment at Teachers College, Columbia University, where she also serves as adjunct professor in the Division of Philosophy, Social Sciences, and Education. Prior to 1986 she was a behavioral scientist at the RAND Corporation. She received a B.A. from Pomona College and a Ph.D. from The Johns Hopkins University. Dr. Berryman is a member of Phi Beta Kappa. Her research interests include education and occupational mobility, including the career mobility of women who have doctorates in economics.

John W. Crawford, JR.

Consultant in Nuclear Engineering

John Crawford is currently a member of the Defense Nuclear Facilities Safety Board. He resigned from the committee in October 1989 on receiving that appointment. While a member of the committee he was a consultant in nuclear engineering. He received a B.S. degree from the United States Naval Academy and master's degrees from Massachusetts Institute of Technology both in naval construction and engineering and in physics. He served in the U.S. Department of Energy as Principal Deputy Assistant Secretary for Nuclear Energy from 1979 to 1981, during which time he was chairman of the board carrying out a comprehensive assessment of the safety of DOE nuclear reactors. He previously held various technical posts at DOE and its predecessor agencies relating to nuclear energy and naval reactors. He received the DOE Exceptional Service Medal.

Arthur E. Humphrey

Provost Emeritus, Lehigh University

Prior to serving as Provost Emeritus at Lehigh University, Arthur Humphrey was director there of the Center for Molecular Bioscience and Biotechnology and adjunct professor of Chemical Engineering. He received B.S. and M.S. degrees from the University of Idaho, the Ph.D. in chemical engineering from Columbia University, and an M.S. degree from the Massachusetts Institute of Technology. Prior to 1980 he served at the University of Pennsylvania as a professor of chemical engineering and then as dean of its College of Engineering and Applied Science. Dr. Humphrey is a member of the National Academy of Engineering and was a Fulbright lecturer at the University of Tokyo and the University of New South Wales. His research interests include enzyme engineering, media sterilization, and the kinetics of the growth of cellular organisms.

William M. Jacobi

Vice President, Westinghouse Electric Corporation

William Jacobi became a vice president of Westinghouse Electric Corporation in 1986, and has served in his present post as vice president and general manager of government operations since 1988. In this capacity he directs all company activities in operating government-owned facilities. He joined Westinghouse in 1955 after receiving a Ph.D. in chemical engineering from Syracuse University. Subsequently he worked on the design of naval nuclear reactors, as engineering manager of the Fast Flux Test Facility, project manager for the Clinch River Breeder Reactor, and president of the Westinghouse Hanford Company.

Edwin E. Kintner

Executive Vice President, GPU Nuclear Corporation

Edwin Kintner became Executive Vice President of GPU Nuclear Corporation in 1983. He has served as chairman of the Electric Power Research Institute's Nuclear Power Divisional Committee and is presently chairman of the Utility

Steering Committee for the Advanced Light Water Reactor Program. Prior to 1983 he directed the magnetic fusion program in the U.S. Department of Energy and its predecessor agency. He received a B.S. from the U.S. Naval Academy, and two M.S. degrees from the Massachusetts Institute of Technology, one in nuclear physics, the other in marine engineering. Mr. Kintner retired from the U.S. Navy as a Captain after serving in the area of nuclear propulsion of ships. His current activities emphasize providing uniform policies and operational criteria for the safe and effective operation of utility nuclear facilities.

Milton Levenson

Bechtel Corporation (retired), now a Consulting Engineer, Menlo Park, California

Milton Levenson, currently a consulting engineer, began his work with the committee while an Executive Engineer at the Bechtel Corporation, a position he held from 1981 to 1989. He was the first director of the nuclear power division of the Electric Power Research Institute from 1973 to 1980. From 1948 to 1973 he was with Argonne National Laboratory, leaving as Associate Laboratory Director for Energy and Environment. From 1944 to 1948 he worked at what is now the Oak Ridge National Laboratory. He received the a B.S. in chemical engineering from the University of Minnesota. He is a member of the National Academy of Engineering and a past president of the American Nuclear Society, a member of the American Institute of Chemical Engineers and the winner of its Robert E. Wilson award.

Gail H. Marcus

Office of Commissioner Kenneth Rogers, U.S. Nuclear Regulatory Commission

Gail Marcus is currently Technical Assistant to Commissioner Kenneth Rogers at the U.S. Nuclear Regulatory Commission (NRC). She joined the NRC in 1985, where she has served in research planning, policy formulation, and regulation development and oversight. Dr. Marcus received S.B. and S.M. degrees in physics and the Sc.D. degree in nuclear engineering from the Massachusetts Institute of Technology. Prior to joining NRC she served as Assistant Chief, Science Policy Research Division, Congressional Research Service, as Deputy Manager, Support Services Division, Analytic Services, and as a physicist at the U.S. Army Electronics Command in the area of radiation damage to materials and devices. She is a member of the Visiting Committee for the Nuclear Engineering Department at the Massachusetts Institute of Technology and for the nuclear engineering program at the University of Lowell, and is a fellow of the American Nuclear Society.

Warren F. Miller, JR.

Deputy Director, Los Alamos National Laboratory

Warren Miller has served as Deputy Director of Los Alamos National Laboratory since 1986. Prior to that time he served there as Associate Director for Energy Programs and Associate Director for Physics and Mathematics. His areas of expertise include nuclear reactor physics and transport theory. He received a B.S. from the U.S. Military Academy and M.S. and Ph.D. degrees in nuclear engineering from Northwestern University. Dr. Miller is a member of the nuclear engineering visiting committees of the University of California at Berkeley and the Massachusetts Institute of Technology. He is a member of the Howard University Board of Trustees and many other educational and technical advisory committees, and is a fellow of the American Nuclear Society.

Robert L. Seale

Head, Department of Nuclear and Energy Engineering, University of Arizona

Robert Scale has served as head of the Department of Nuclear and Energy Engineering at the University of Arizona since 1969. He is a consultant to the Los Alamos National Laboratory and the Sandia National Laboratories. He received a B.S. from the University of Houston and an M.A. and Ph.D. from the University of Texas. Dr. Scale became a professor at the University of Arizona in 1961, prior to which he conducted research at General Dynamics. He is a registered professional engineer in Arizona and a member of the Education and Research Committee of Associated Western Universities.

Robert E. Uhrig

Distinguished Professor of Engineering and Department of Nuclear Engineering, University of Tennessee

Robert Uhrig has been Distinguished Professor of Engineering at the University of Tennessee in the Department of Nuclear Engineering since 1986. He also works as a Distinguished Scientist at the Oak Ridge National Laboratory. He received a B.S. from the University of Illinois and M.S. and Ph.D. degrees from Iowa State University. Prior to 1986 Dr. Uhrig was an executive with Florida Power & Light Company and Dean of the College of Engineering at the University of Florida. He has also served as Deputy Assistant Director of Research for the U.S. Department of Defense.

Appendix C

Committee Meetings and Briefings to the Committee

First Meeting
March 17-18, 1989
National Academy of Sciences
Washington, D.C.

Friday, March 17, 1989

PRESENTATIONS BY STUDY COSPONSORS

Walter J. Coakley Institute of Nuclear Power Operations	Relationship of this study to INPO activities and needs
M. J. Ohanian University of Florida (on behalf of the American Nuclear Society)	Relationship of this study to ANS activities and needs
Richard E. Stephens U.S. Department of Energy	Relationship of this study to DOE Office of Energy Research activities

PRESENTATIONS ON BEHALF OF THE U.S. DEPARTMENT OF ENERGY

David M. Woodall Idaho National Engineering Laboratory	DOE nuclear engineering research support program
Larry M. Blair Oak Ridge Associated Universities	Status of and outlook for the nuclear engineering labor markets

William M. Porter U.S. Department of Energy	Identifying and developing U.S. technical expertise for participating in international nuclear organizations

PANEL DISCUSSION Identification of key study issues by the above speakers

SPEAKER

F. Karl Willenbrock American Society for Engineering Education	A Commentary on Engineering Education in the United States and Abroad

Second Meeting
May 18-19, 1989
National Academy of Sciences
Washington, D.C.

Thursday, May 18, 1989

PANEL DISCUSSION ON PERSONNEL SUPPLY ISSUES

K. Lee Peddicord
Texas A&M University

Thomas G. Williamson
University of Virginia

Barclay G. Jones
University of Illinois

(Prior chairman, past chairman, and chairman, respectively, of the Nuclear Engineering Department Heads Organization)

PANEL DISCUSSION ON PERSONNEL DEMAND ISSUES

Richard J. Slember
Westinghouse Electric Corporation

Robert H. Stone
Bechtel Power Corporation

Walter B. Loewenstein
Electric Power Research Institute

JOINT PANEL DISCUSSION ON STUDY-RELATED ISSUES

Discussion of key study issues by members of both panels and the committee

SPEAKER

Richard Berendzen American University	Problems and Solutions in U.S. Technical Work Force Preparedness

Friday, May 19, 1989

Robert L. Long GPU Nuclear	The accreditation process for U.S. engineering programs

Third Meeting
July 23-25, 1989
Bechtel Engineering Center, University of California
Berkeley, California

Monday, July 24, 1989

Kenneth C. Rogers Nuclear Regulatory Commission	Projected NRC personnel needs in nuclear engineering
T. Kenneth Fowler University of California at Berkeley	Remarks and tour of the nuclear engineering laboratory

Fourth Meeting
September 7-8, 1989
National Academy of Sciences
Washington, D.C.

Fifth Meeting
November 13-14, 1989
National Academy of Sciences
Washington, D.C.

Sixth Meeting
March 8-9, 1990
National Academy of Sciences
Washington, D.C.

Appendix D

Acknowledgment of data Sources

The committee acknowledges the invaluable assistance of the following persons in obtaining and analyzing data for this study:

Richard E. Stephens, Director, Division of University and Industry Programs, Office of Energy Research, U.S. Department of Energy; Larry M. Blair, Director, Labor and Policies Studies Program, Oak Ridge Associated Universities; William F. Naughton and Ling-Chih Liu, Commonwealth Edison Company; Alan E. Fechter, Michael Finn, and Joe G. Baker, Office of Scientific and Engineering Personnel, National Academy of Sciences; June S. Chewning, Consultant; Richard Ellis, Engineering Manpower Commission, American Association of Engineering Societies; Robert Kominski and Gregory Spencer, Population Division, U.S. Census Bureau; Kathy Windler, College Entrance Examination Board; Jacqueline Briel and Chris Karelke, Educational Testing Service; Duveen Shirley, Oak Ridge Associated Universities; Vance Grant, Norman Brandt, and Dennis Carroll, National Center for Education Statistics; Ryohei Kiyose, Professor, Department of Nuclear Engineering, Tokai University, Japan; and Atsyuki Suzuki, Professor, Department of Nuclear Engineering, Tokyo University, Japan.

The committee acknowledges with thanks the organizations employing nuclear engineers that responded to its employment survey:

FEDERAL AGENCIES

U.S. Department of Energy
U.S. Navy
U.S. Army
U.S. Air Force
Defense Intelligence Agency

Defense Nuclear Agency
Strategic Defense Initiative Organization
Defense Manpower Data Center
Institute for Defense Analysis

MANUFACTURERS

Babcock and Wilcox Company
Combustion Engineering
General Electric Company
Westinghouse Electric Company
General Atomics

ARCHITECT-ENGINEERING FIRMS

Bechtel Corporation
Sargent & Lundy Engineers
Stone & Webster Corporation
Ebasco Services Center

ENGINEERING CONSULTANTS

Impell Corporation
Quadrex Corporation
NUS Corporation
EI International
Nuclear Assurance Corporation
Management Analysis Company
Stoller Corporation
S. Levy

LABORATORIES

Argonne National Laboratory

The committee acknowledges with thanks the following organizations for their responses to its questionnaire on skills needed by nuclear engineers:

NATIONAL LABORATORIES

Argonne National Laboratory
Brookhaven National Laboratory
Pacific Northwest Laboratory
Idaho National Engineering Laboratory
Lawrence Livermore National Laboratory
Los Alamos National Laboratory
Oak Ridge National Laboratory
Sandia National Laboratories

Savannah River Laboratory
Westinghouse Hanford Company

GOVERNMENT

Nuclear Regulatory Commission

UTILITIES

Arizona Public Service
Duke Power Company
Wisconsin Electric Power Company
Alabama Power Company
Texas Utilities Electric Company
Commonwealth Edison Company
GPU Nuclear Company

VENDORS AND CONSULTANTS

Combustion Engineering
Babcock and Wilcox
Westinghouse
General Electric
Tenera

UNIVERSITIES

Nuclear Engineering Department Heads Organization

Appendix E

Assumptions and Forecasting Model for Estimating Projected Demand and Employment

Appendix E presents the basic assumptions used for projecting nuclear engineering employment in the civilian nuclear power and federal government sectors. Table E-1 lists the assumptions used for the civilian nuclear power sector. Table E-2 presents the assumptions made by the Department of Energy (DOE) in making projections. Tables E-3 and E-4 contain the DOE headquarters, field, and contractor data used for the high-growth and best-estimate scenarios, respectively. Table E-5 contains the Strategic Defense Initiative Organization (SDIO) data; only the higher numbers were used and only for the highgrowth estimate. In addition, the forecasting model used by the committee is described. Part of this model involves an estimate of exit rates of employment. The basis for such estimates is also described in a memorandum to committee consultant William Naughton from Larry Blair of Oak Ridge Associated Universities.

TABLE E-1 Calculating Growth Scenarios for the Civilian Nuclear Power Sector

High-Growth Scenario
For the civilian nuclear power sector, expansion rates for three periods were considered based on Electric Power Research Institute (EPRI) estimates of potential contributions of nuclear power to the nation's electrical needs. Each period is assumed to build on the previous period, that is, period B builds on period A, yielding an estimated total of 66 new reactors by the year 2005. P(t) = number of nuclear engineers employed in the civilian nuclear power sector at time t.

Period A: EPRI estimate for the year 2000, assuming 10 percent of any needed electric power plant capacity increment is nuclear

T_0 = 1995, time at which P(t) is expected to increase under this scenario

T_1 = 2000, time at which P(t) is expected to stabilize under this scenario

N_1-N_0 = 20, number of newly committed reactors between T_1 and T_0 (one-third passive, 10, and two-thirds evolutionary Advanced Light Water Reactors [ALWRs], 10)

Period B: EPRI estimate for year 2005, assuming 20 percent of needed increment is nuclear

T_0 = 2000, time at which P(t) is expected to increase under this scenario

T_1 = 2005 time at which P(t) is expected to stabilize under this scenario

N_1-N_0 = 46 number of newly committed reactors between T_1 and T_0 (one-third passive, 23, and two-thirds evolutionary ALWRs, 23)

Period C: EPRI estimate for year 2010, assuming 30 percent of needed increment is nuclear

T_0 = 2005, time at which P(t) is expected to increase under this scenario

T_1 = 2010, time at which P(t) is expected to stabilize under this scenario

N_1-N_0 = 54 number of newly committed reactors between T_1 and T_0 (one-third passive, 27, + two-thirds evolutionary ALWRs, 27)

Best-Estimate Scenario

Expansion rates for two periods were considered based on EPRI's estimates of potential contributions of nuclear power to the nation's electrical needs, taking into account an estimated five-year delay in implementation. The committee's delay assumption was derived from discussions with senior electric utility executives. Again, each period below is assumed to build on the previous period, that is, Period 2 builds from Period 1 to yield an estimated total of 66 new reactors by the year 2010.

Period 1: EPRI estimate for the year 2005 assuming 10 percent of needed capacity increment is nuclear

T_0 = 2000, time at which P(t) is expected to increase under this scenario

T_1 = 2005, time at which P(t) is expected to stabilize under this scenario N_1-N_0 = 20, number of newly committed reactors between T_1 and T_0 (one third passive, 10, plus two-thirds evolutionary ALWRs, 10)

Period 2: EPRI estimate for the year 2010, assuming 20 percent of needed increment is nuclear

T_0 = 2005, time at which P(t) is expected to increase under this scenario

T_1 = 2010, time at which P(t) is expected to stabilize under this scenario

N_1-N_0 = 46, number of newly committed reactors between T_1 and T_0 (one-third passive, 23, and two-thirds evolutionary ALWRs, 23)

Low-Growth Scenario

The low-growth scenario assumes that the number of nuclear power units in service remains at about 115 and that any plant retirements during the study period will be met by completion of the units now under construction.

TABLE E-2 DOE Planning Assumptions for Estimating Nuclear Engineering Employment

Best-Estimate Scenario
Environmental Remediation and Waste Programs
Waste Isolation Pilot Plant (WIPP) initially operational 1990; subsequent operation as per planning schedule.
Monitored Retrievable Storage/Terminal Repository Facility completed as per current schedules.
Site remediation/waste cleanup work proceeds as per Secretary's-ten point plan.
Defense Waste Processing Facility (DWPF) will start up and operate through the period.
The hot start-up of the Hanford Waste Vitrification Plant (HWVP).
New Production Reactors (NPR)
Heavy water NPR will be built at the Savannah River site (SRS).

Three existing SRS reactors will operate at increasing power levels until new SRS NPR starts up, at which point two reactors will be shut down; the third SRS reactor would not shut down until the Modular High-Temperature Gas-Cooled Reactor (MHTGR) comes on line at Idaho National Engineering Laboratory (INEL).

MHTGR operational at INEL in 2004.

Defense-Related Programs

Plutonium and tritium will be produced to meet requirements of current Nuclear Weapons Stockpile Memorandum.

Tritium contingency reserve will be produced, separated, and stored.

Demand for naval reactors fuel continues.

Hanford defense materials production missions are phased out as planned.

Phase-out of Hanford chemical processing mission continues as planned in the mid to late 1990s.

Nuclear Energy Programs

Naval Reactor Development Program will be stable during the planning period.

Development of Integral Fast Reactor/other advanced reactor technologies at INEL/Argonne National Laboratory-West and other laboratories continues.

Engineering and ground tests of space reactors increase.

High-Growth Scenario

The high-growth scenario assumes the greatest funding for the above initiatives through the end of this decade, a resumption in 1993 of new orders for civilian nuclear power plants, and new DOE fission/fusion reactor R&D programs beyond those in the current plan.

Low-Growth Scenario

The low-growth scenario assumes that DOE and DOE contractor nuclear engineering employment will remain unchanged over the study period.

Forecasting Model

The model described below is used to forecast employment at time t, E(t):

$$E(t) = P(t) + G(t) \tag{1}$$

$$P(t) = \begin{cases} PN_0 & t \leq T_0 \\ P\left[N_0 + \dfrac{N_1 - N_0}{T_1 - T_0}(t - T_0)\right] & T_0 < t \leq T_1 \\ PN_1 & t > T_1 \end{cases} \tag{2}$$

where

P(t) = number of nuclear engineers employed in the private sector at time t

T_0 = time at which P(t) is expected to increase under each growth scenario

T_1 = time at which P(t) is expected to stabilize under each growth scenario

P = 70, the number of nuclear engineers needed in industry per committed reactor (obtained from Table 3-1, 1987 column, less fusion research, weapons development and production, DOD and DOE employees, and DOE contractors, divided by N_0).

N_0 = initially 115 (number of committed reactors at date of study); current number of committed reactors at time T_0

N_1-N_0 = number of newly committed reactors, or change in reactors committed, per each EPRI estimate

The quantities T_0, T_1, and N_1 were derived from the committee's inquiries. Also,

$$G(t) = \begin{cases} G_0 & t \leq T_0 \\ G_0 + \dfrac{G_1 - G_0}{T_1 - T_0}(t - T_0) & T_0 < t \leq T_1 \\ G_1 & t > T_1 \end{cases}$$

where

G(t) = number of nuclear engineers employed by government at time t

T_0 = time at which G(t) is expected to increase

T_1 = time at which G(t) is expected to stabilize

G_0 = current level of government employment (obtained from Oak Ridge Associated Universities data)

G_1 = expected peak level of employment in the government reactor sector under each scenario

Again, T_0, T_1, G_0 and G_1 were derived from the committee's inquiries.

Demand at time t was then modeled by D(t):

$$D(t) = E'(t) + X(t), \qquad (4)$$

where E'(t) denotes the first derivative of E(t) when it exists and X(t) is an exit rate due to death, retirement, and new-graduate replacement needs. This exit rate is equal to 0.035 times E(t) and has been adjusted to avoid bias created by job switching by those who move from nuclear engineering to other fields and vice versa. Derivation of this exit rate is described next in a memorandum received from Larry Blair, Oak Ridge Associated Universities.

Utilizing the above model and assumptions, P(t), G(t), B(t), E'(t), X(t), and D(t) can be derived for the growth scenarios. Tables E-6 and E-7 show results for the high-growth and best-estimate scenarios respectively.

Annual job openings for new graduates are based on two factors: change in employment levels (growth or decline) and available replacement positions for jobs opened through attrition (owing to job switchers, death, retirement, and labor force exit). These job openings are expected to be filled by new entrants into the labor force (i.e., new graduates not already employed); job openings expected to be filled by job switchers and by re-entrants into the labor force have been netted out. While this approach obviously simplifies the true workings of the labor market, it is fairly straightforward and, given the data uncertainties in deriving the replacement rate and the fact that future employment estimates are used, the approach is probably as precise as necessary.

The average annual job openings for any given time period t to t + a are the sum of the annual average change in employment levels, $(E_{t+a}-E_t)/a$, and the annual average replacement of positions that arise because of attrition, 0.035 * $(E_t + E_{t+a})/2$, over the time period. Thus,

$$JO_i = (E_{t+a} - E_t)/a + [0.035 * (E_t + E_{t+a})/2] \qquad (5)$$

where

JO = the average annual number of job openings within the time period

i = any one year within the time period

E = the employment level for a particular year (either the first or last year of the time period)

t = the first year in the time period

a = the number of years in the time period (thus t + a is the last year in the time period)

0.035 = the fraction that provides the number of replacement positions expected for new graduates based on attrition owing to job switchers, death retirement, and labor force exits.

Change in employment between the first year in the time period and the last year in the time period is assumed to occur in equal amounts each year (i.e., the average annual employment change is used over the period). Also, the average annual number of replacement positions is based on the mean employment level for the time period $(E_t + E_{t+a})/2$, not on employment levels for each year.

Tables E-6 and E-7 show the results of calculations for the functions in the forecasting model and the demand projections that result.

TABLE E-3 High-Growth Estimate of DOE and DOE Contractor Employment of Nuclear Engineers, 1987-2010

DOE Sector	1987[a]	1995	2000	2005	2010
Headquarters		332	349	354	361
Field		361	424	480	609
Contractors		3,321	4,181	4,888	6,645
Total	1,640	4,014	4,954	5,722	7,615

[a] Breakdown not available.

TABLE E-4 Best Estimate of DOE and DOE Contractor Employment of Nuclear Engineers, 1987-2010

DOE Sector	1987[a]	1995	2000	2005	2010
Headquarters		308	321	322	325
Field		284	300	314	333
Contractors		2,345	2,516	2,592	2,652
Total	1,640	2,937	3,137	3,228	3,310

[a] Breakdown not available.

TABLE E-5 Strategic Defense Initiative Organization Projections for Nuclear Engineers, 1995-2010[a]

Year	Number
1995	200 to 300
2000	400 to 600
2005	1,000 to 1,500
2010	1,500 to 2,000

[a] Assuming implementation of nuclear-powered SDI space power systems
SOURCE: Data from Strategic Defense Initiative Organization, letter to Robert Cohen, National Research Council, August 24, 1989, from Lieutenant General George L. Monahan, Jr., U.S.A.F.; and from Richard L. Verga, Program Manager, Space Power and Power Conditioning.

TABLE E-6 Forecasting Model Results for the High-Growth Scenario

Year	P(t)	G(t)	E(t)	E(t)	X(t)	D(t)
1987[a]	8,030	3,610	11,640	0	407	407
1995	8,030	6,284	14,314	334	501	835
2000	9,450	7,524	16,974	532	594	1,126
2005	12,670	9,192	21,862	978	765	1,743
2010	16,450	11,585	28,035	1,235	981	2,216

[a] Actual figures.

TABLE E-7 Forecasting Model Results for the Best-Estimate Growth Scenario

Year	P(t)	G(t)	E(t)	E(t)	X(t)	D(t)
1987[a]	8,030	3,610	11,640	0	407	407
1995	8,030	4,907	12,937	162	453	615
2000	8,030	5,107	13,137	40	460	500
2005	9,450	5,198	14,648	302	512	814
2010	12,670	5,280	17,950	660	628	1,288

NOTE: As a sample calculation, consider the period from 2005 to 2010. For 2010, $E(t) = P(t) + G(t) = 12,670 + 5,280 = 17,950$. Then $E(t) = 14,648 + 660 (t-2005)$. Therefore, $E'(t) = 660$. Then $X(t + 1) = 0.035 [E(t + 1) + E(t)]/2$. Let $t = 2009$ to obtain $X(2010) = 0.035 (14,648 + 7 \times 660) + 0.035 \times 660 = 605 + 23 = 628$.
[a] Actual figures.

Oak Ridge Associated Universities
Post Office Box 117
Oak Ridge, Tennessee 37830

MEMORANDUM

TO: William Naughton, Commonwealth Edison

FROM: Larry M. Blair, ORAU/SEED/LPSP

DATE: August 8, 1989

COPIES TO: Rich Stephens, file

SUBJECT: EXIT RATES AND JOB OPENINGS FOR NEW HIRES FOR THE NATIONAL RESEARCH COUNCIL COMMITTEE ON NUCLEAR ENGINEERING EDUCATION, SUBCOMMITTEE ON SUPPLY AND DEMAND TRENDS

Re: Our telephone conversation of August 3, 1989.

OVERVIEW

Job openings are created by growth in number of positions in the field and by attrition which creates replacement needs. However, as shown on the attached schematic [Figure E-1], these job openings will not all be filled by new graduates. Many of these positions will be filled by persons who are "job switchers" (such as persons who in the past left nuclear engineering positions for positions in management, sales, computer science, different engineering, etc. and are now returning to nuclear engineering positions) and by persons who were unemployed or re-entering the labor force. Thus nuclear engineering job turnover or exit rates for a company, industry, or for the total employment field do not provide the data needed to assess the demand for new graduates. (Note that company level and single industry level [such as electric utilities] exit rates have even higher rates of job switching than for the total employment field of nuclear engineering because of persons leaving the specific company or industry for a nuclear engineering position in a different company or industry.)

Data on job openings available to new graduates are not available from any agencies or available studies. ORAU, over the last six or seven years, has collected related data from Department of Labor, Bureau of Labor Statistics published and unpublished information, and we have developed additional data for BS/MS and PhD levels from the National Science Foundation surveys of scientists and engineers data base which we maintain for DOE. We have used these data to develop information on exit rates and percent of job openings

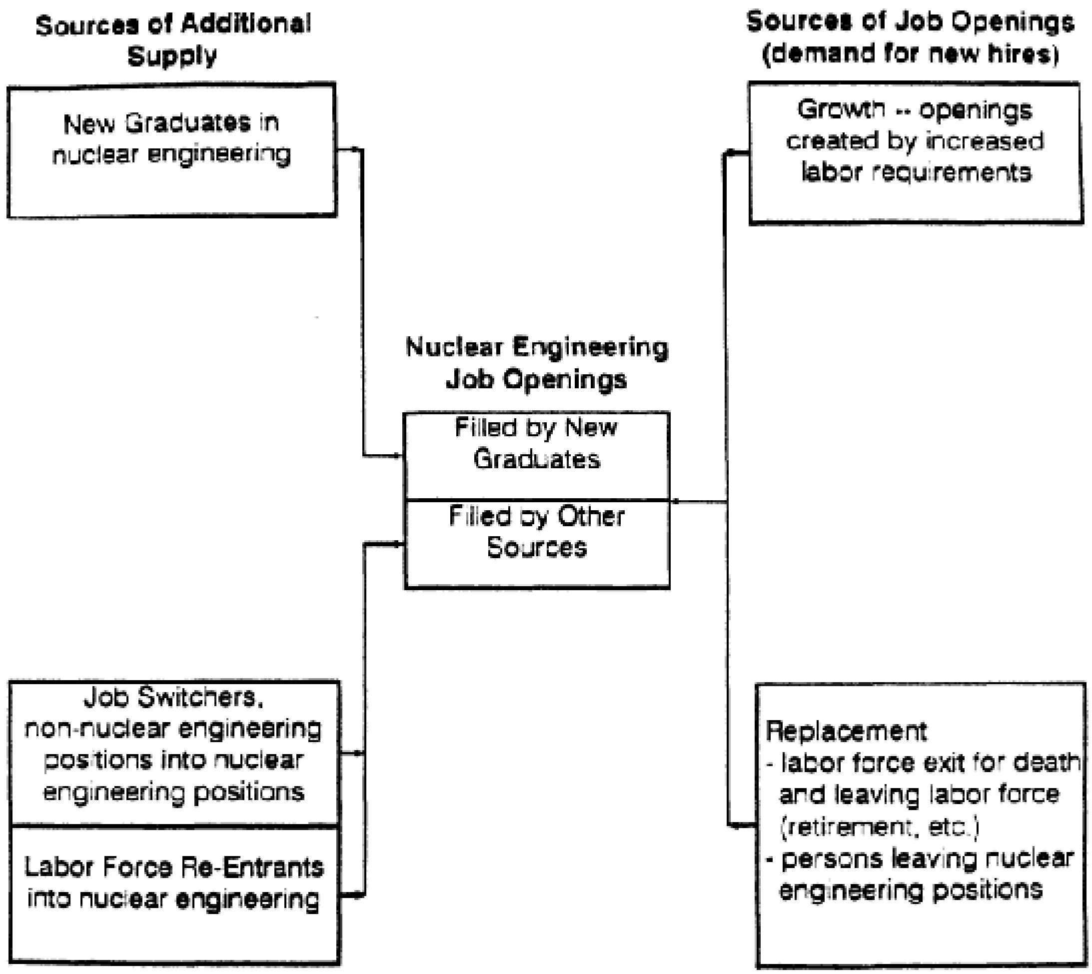


Figure E-1
Sources of Labor Supply and Job Openings in Nuclear Engineering Employment.

for new graduates. It must be emphasized that while these are the best estimates we can provide, the underlying background data is not perfect for this type of analysis and has deficiencies which lead to the need for judgments and caution when applying the resulting rates to labor market analysis.

INFORMATION ON NUCLEAR ENGINEERING EXIT RATES AND JOB OPENINGS FOR NEW GRADUATES

A. Exit Rate Information

Average exit rates for all engineering fields:

BS/MS = 6.8%

PhD = 7.2%

To get turnover rates specific to nuclear engineering, several judgmental factors must be taken into consideration. First, the NSF survey data base we maintain for DOE indicates that nuclear engineers are somewhat older, on average, than all engineers and have a death + retirement rate 1/2 percentage point (0.5% point) higher than for all engineers. Thus, we add 0.5% point to the rates as shown below.

Average exit rates for nuclear engineering fields corrected for higher exit rates due to higher death + retirement rates resulting from somewhat older, than average, age for nuclear engineers.

BS/MS approximately = 7.3%

PhD approximately = 7.7%

These exit rates are still biased low because they are based on the exit rates for all engineers which do not include the job switchers who stay within engineering fields (nuclear engineering to non-nuclear engineering and the reverse of non-nuclear engineering to nuclear engineering). Based on data from NSF surveys it appears that nuclear engineers have a somewhat higher than average outflow to other engineering fields and this would further increase the exit rates. In addition, the PhD rate also is biased low because the NSF survey question for employment field does not discriminate well for people who have moved into management or other professional positions outside of engineering per se. We have not developed any data estimates for these complicating bias factors. As indicated below, we have rounded up the job openings rate for new graduates to take into consideration these factors.

B. Job Openings for New Graduates

The exit rates listed above must still be adjusted for the replacement positions filled by non-new graduates. These adjustments are shown below, as based on available data.

Percent of positions filled by new graduates:

BS/MS = 47%

PhD = 37%

Applying these percentages gives these replacement rates for job openings to be filled by new graduates:

Replacement Percents for Job Openings for New Graduate Nuclear Engineers (with low biases still included):

BS/MS approximately = 3.4%

PhD approximately = 2.8%

As noted above there are factors in the survey data base which appear to cause these estimates to be biased low and therefore, we have simply used the rate of 3.5% for all nuclear engineers in our studies.

Actual Rate Used for Replacement Needs Percent for Job Openings for New Graduate Nuclear Engineers

BS/MS and PhD approximately = 3.5%

Therefore dem and for job openings for new graduates is equal to growth plus this replacement percent.

Number Job Openings for New Graduates = Number of Growth Positions + .035 times the number of current positions (for replacement demand for new grads)

REFERENCES

Energy-Related Science and Engineering Personnel Outlook, 1987, DOE/OR/00033-H1, U.S. Department of Energy, October 1987.

Baker, Joe G., "Accession and Separation of Selected B.S., M.S., and Technician Workers," ORAU Internal Working Paper, May 1983.

Baker, Joe G., "Occupational Mobility of Energy-Related Doctorate Scientists and Engineers," ORAU Internal Working Paper, June 1983.

Various published data tabulations from the NSF surveys of scientists and engineers (recent graduates, experienced worker survey, and doctorate survey).

Unpublished data from the Department of Labor, Bureau of Labor Statistics.

LMB:ajp

F

Additional Data on Nuclear Engineering Supply Trends and Curriculum

This appendix presents data that may be of interest to some readers, providing a more detailed view of some subjects presented in the report. Tables F-1 to F-20 present additional data on aspects of education that affect supply, such as degree trends, minority student trends, Scholastic Aptitude Test scores, and cohorts, while Tables F-21 and F-22 provide information on the nuclear engineering curriculum. Figure F-1 provides information concerning population trends and Figures F-2 to F-11 summarize data on nuclear engineering programs and on enrollments based on the results of the committee's survey (Appendix G provides a copy of this questionnaire).

TABLE F-1 Total Degrees Granted, All Fields, by Degree Level and U.S. Residency Status, 1977 and 1987

	Total			U.S. Residents[a]		
Degree Level	1977	1987	Percent Change	1977	1987	Percent Change
B.S.	917,900	991,260	8.0	902,186	961,954	6.6
M.S.	316,602	289,341	-8.6	299,258	259,443	-13.3
Ph.D.	33,126	34,033	2.7	29,379	27,446	-6.6

[a] U.S. residents include U.S. citizens and resident aliens.
SOURCES: U.S. Department of Education, National Center for Education Statistics (1988, 1989).

TABLE F-2 Number and Share of Degrees Awarded to Nonresident Aliens by Degree Level, 1977 and 1987

	Number of Degrees Awarded		Percent of Total Degrees Awarded	
Degree Level	1977	1987	1977	1987
B.S.	15,714	29,306	1.7	3.0
M.S.	17,344	29,898	5.5	10.3
Ph.D.	3,747	6,587	11.3	19.4

SOURCES: U.S. Department of Education, National Center for Education Statistics (1988, 1989).

TABLE F-3 Number and Share of Quantitative Degrees Awarded to Nonresident Aliens by Degree Level, 1977 and 1987

	Number of Degrees Awarded		Percent of Total Degrees Awarded	
Degree Level	1977	1987	1977	1987
B.S.	4,717	9,999	5.2	6.7
M.S.	4,933	10,223	17.9	25.9
Ph.D	1,584	3,196	22.8	37.3

SOURCES: U.S. Department of Education, National Center for Education Statistics (1980, 1989).

TABLE F-4 Quantitative Degrees as a Share of all Degrees Earned, by Degree Level and U.S. Residency Status, 1977 and 1987 (in percent)

	All Degree Recipients		U.S. Resident Recipients[a]		Nonresident Alien Recipients	
Degree Level	1977	1987	1977	1987	1977	1987
B.S.	9.9	15.1	9.6	14.5	30.0	34.1
M.S.	8.7	13.6	7.6	11.3	28.4	34.2
Ph.D	21.0	25.2	18.3	19.6	42.3	48.5

[a] U.S. residents include U.S. citizens and resident aliens.
SOURCES: U.S. Department of Education, National Center for Education Statistics (1980, 1989).

TABLE F-5 Number and Share of Engineering and Nuclear Engineering Degrees Awarded to Nonresident Aliens by Degree Level, 1978 and 1988

	Number of Degrees Awarded		Percent of Total Degrees Awarded	
Field and Degree Level	1978	1988	1978	1988
Engineering				
B.S.	3,094	5,763	6.7	8.1
M.S.	3,579	7,278	22.1	28.4
Ph.D	874	2,033	34.0	44.5
Nuclear Engineering				
B.S.	41	21	4.8	4.3
M.S.	103	87	21.2	37.5
Ph.D	35	56	31.2	49.1

SOURCES: Engineering Manpower Commission (1979-1989) for total engineering, U.S. Department of Energy (1984, 1989) for nuclear engineering.

TABLE F-6 Engineering Degrees as a Share of Total Quantitative Degrees, by Degree Level and U.S. Residency Status, 1977 and 1987 (in percent)

	Total		U.S. Residents[a]		Nonresident Aliens	
Degree Level	1977	1987	1977	1987	1977	1987
B.S.	53.2	49.2	52.0	48.5	75.7	60.0
M.S.	57.6	55.8	54.4	54.8	71.8	58.8
Ph.D	37.0	44.3	32.2	37.7	53.5	55.6

[a] U.S. residents include U.S. citizens and resident aliens.
SOURCES: U.S. Department of Education, National Center for Education Statistics (1980, 1989).

TABLE F-7 Total Degrees Granted, Ail Fields, by Degree Level and Gender, 1977 and 1987[a]

	1977			1987		
Degree Level	Male	Female	Percent Female	Male	Female	Percent Female
M.S./M.A.	494,424	423,476	46	480,780	510,480	52
B.S./B.A.	167,396	149,206	47	141,264	148,077	51
Ph.D.	25,036	8,090	24	22,059	11,974	35

[a] Including both U.S. residents and nonresident aliens.
SOURCES: U.S. Department of Education, National Center for Education Statistics (1988, 1989)

TABLE F-8 Quantitative Degrees Granted by Degree Level and Gender, U.S. Residents Only, 1981 and 1987[a]

	1981			1987		
Degree Level	Male	Female	Percent Female	Male	Female	Percent Female
B.S.	93,817	22,358	19.2	103,380	36,565	26.1
M.S.	17,964	3,612	16.7	22,800	6,453	22.1
Ph.D.	4,459	501	10.1	4,544	835	15.5

[a] Earlier data were not available.
SOURCES: U.S. Department of Education, National Center for Education Statistics (1983, 1989).

TABLE F-9 Quantitative Degrees Awarded to Women as a Share of Total Degrees Awarded to Women by Degree Level, 1977 and 1987

	Quantitative Degrees as Percent of Total	
Degree Level	1977	1987
B.S.	3.3	7.5
M.S.	2.3	5.4
Ph.D.	6.4	8.9

SOURCES: U.S. Department of Education, National Center for Education Statistics (1980, 1989).

TABLE F-10 Quantitative Degrees Awarded to Women as a Share of Total Degrees Awarded to Women, by Degree Level, U.S. Residents Only, 1981 and 1987[a]

	Quantitative Degrees as Percent of Total	
Degree Level	1981	1987
B.S.	4.9	7.3
M.S.	2.5	4.6
Ph.D.	5.2	7.7

[a] Earlier data not available.
SOURCES: U.S. Department of Education, National Center for Education Statistics (1983, 1989).

TABLE F-11 Engineering and Nuclear Engineering Degrees Granted, by Degree Level and Gender, 1978 and 1988[a]

	1978			1988		
Field and Degree Level	Male	Female	Percent Female	Male	Female	Percent Female
Engineering						
B.S.	42,811	3,280	7.1	60,446	10,940	15.3
M.S.	15,388	794	4.9	22,251	3,365	13.1
Ph.D.	2,522	51	2.0	4,258	313	6.8
Nuclear Engineering						
B.S.	835	28	3.2	433	51	10.5
M.S.	477	9	1.9	211	21	9.1
Ph.D.	108	4	3.6	108	6	5.3

[a] Data include both U.S. residents and nonresident aliens.
SOURCES: Engineering Manpower Commission (1979) and U.S. Department of Energy (1984, 1989).

TABLE F-12 Total Degrees Granted, Ail Fields, by Degree Level, and Race and Ethnicity, 1977 and 1987[a]

	B.S./B.A.			M.S./M.A.			Ph.D.		
Racial/Ethnic Group	1977	1987	Percent Change	1977	1987	Percent Change	1977	1987	Percent Change
White, Non-Hispanic	807,688	841,820	4.2	266,061	228,870	-14.0	26,851	24,435	-9.0
Black, Non-Hispanic	58,636	56,555	-3.5	21,037	13,867	-34.1	1,253	1,060	-15.4
Hispanic	18,743	26,990	44.0	6,071	7,044	16.0	522	750	43.7
American Indian	3,326	3,971	19.4	967	1,104	14.2	95	104	9.5
Asian	13,793	32,618	136.5	5,122	8,558	67.1	658	1,097	66.7

[a] Excluding nonresident aliens.

SOURCES: U.S. Department of Education, National Center for Education Statistics (1988 and 1989).

TABLE F-13 Quantitative Degrees Granted by Degree Level, and Race and Ethnicity, 1977 and 1987[a]

	B.S.			M.S.			Ph.D.		
Racial/Ethnic Group	1977	1987	Percent Change	1977	1987	Percent Change	1977	1987	Percent Change
White, Non-Hispanic	79,554	118,529	49.0	20,588	24,571	19.3	4,945	4,681	-5.3
Black, Non-Hispanic	3,101	6,974	124.9	529	801	51.4	79	66	-16.5
Hispanic	1,533	3,776	146.3	388	824	112.4	82	143	74.4
American Indian	242	457	88.8	59	74	25.4	12	8	-33.3
Asians	2,044	10,209	399.5	1,073	2,983	178.0	250	481	92.4

[a] Excluding nonresident aliens.
SOURCES: U.S. Department of Education, National Center for Education Statistics (1980, 1989).

TABLE F-14 Nuclear Engineering Degrees Granted by Degree Level, and Race and Ethnicity, 1978 and 1988

	B.S.			M.S.			Ph.D.		
Racial/Ethnic Group	1978	1988	Percent Change	1978	1988	Percent Change	1978	1988	Percent Change
White, Non-Hispanic	808	439	-45.7	370	134	-63.8	74	53	-28.4
Black, Non-Hispanic	7	5	-28.6	5	1	-80.0	1	2	100.0
Hispanic	4	5	25.0	4	1	-75.0	0	0	0
American Indian	0	1	NA	0	0	0	0	0	0
Asian	3	13	333.3	4	9	125.0	2	3	50.0

SOURCES: U.S. Department of Energy (1984, 1989).

TABLE F-15 Percent and Number of SAT Test-Takers Whose Mathematics Scores Met the Minimum Required to Succeed in Nuclear Engineering, By Race and Ethnicity, and Gender, 1983-1988

Racial/Ethnic Group	1983	1984	1985	1986	1987	1988	Number of 1988 Test-Takers Who Met Minimum
American Indian	16	17	16	NA	16	16	2,008
Black	6	6	7	NA	7	8	7,385
Mexican American	14	14	15	NA	15	15	3,381
Asian American	41	44	44	NA	44	45	28,576
Puerto Rican	10	12	14	NA	11	12	1,308
Latin American	NA	NA	NA	NA	17	18	3,668
White	30	31	34	NA	33	32	265,838
Male	34	34	37	38	37	37	200,809
Female	19	19	22	22	22	23	134,448
Total	26	28	29	28	29	30	335,257[a]

NOTE: NA = not available.
[a] Includes those who failed to identify themselves as members of any racial or ethnic group.
SOURCES: Educational Testing Service (1988), College Entrance Examination Board (1983-1988).

TABLE F-16 Percent and Number of SAT Test-Takers Whose Verbal Scores Met the Minimum Required to Succeed in Nuclear Engineering, by Race and Ethnicity, and Gender, 1983-1988

Racial/Ethnic Group	1983	1984	1985	1986	1987	1988	Number of 1988 Test-Takers Who Met Minimum
American Indian	28	30	29	NA	28	27	3,301
Black	14	14	15	NA	16	17	16,619
Mexican American	24	25	26	NA	24	26	5,818
Asian American	34	34	36	NA	36	38	24,465
Puerto Rican	22	23	24	NA	20	18	2,087
Latin American	NA	NA	NA	NA	27	28	5,746
White	47	48	50	NA	48	48	390,180
Male	43	47	46	45	45	45	245,054
Female	41	40	42	41	41	40	235,734
Total	41	42	42	43	42	42	480,788[a]

NOTE: NA = not available.

[a] Includes those who failed to identify themselves as members of any racial or ethnic group.

SOURCES: Educational Testing Service (1983-1988), College Entrance Examination Board (1983-1988).

TABLE F-17 Percent of Test-Takers Who Met Minimum Quantitative and Verbal Scores of Engineering B.S. Graduates Who Took the Graduate Record Examination, U.S. Citizens Only, 1986-1987

Group	Quantitative Minimum	Verbal Minimum
American Indian	11.5	39.1
Black	3.6	13.6
Mexican American	10.0	28.3
Asian	42.4	43.5
Puerto Rican	7.5	15.2
Other Hispanic	14.9	39.3
White	23.1	55.0
Total	22.1	51.5

SOURCE: Educational Testing Service (1988).

TABLE F-18 Trends in College-Age Cohorts as Shares of Total U.S. Population, 1980-2010 (in percent)

	Age Cohort		
Year	14-17	18-24	25-34
1980	7.09	13.33	16.51
1985	6.17	12.00	17.51
1990	5.19	10.33	17.45
1995	5.43	9.13	15.61
2000	5.74	9.16	13.58
2010	5.29	9.76	13.06

SOURCES: Spencer (1986, 1989), U.S. Bureau of the Census (1982).

TABLE F-19 Trends in Racial and Ethnic College-Age Cohorts, 1980-2010

	Age Cohort		
Cohort and Year	14-17	19-24	25-34
White, Non-Hispanic			
1980	75.8	77.3	79.3
1985	74.3	75.2	77.2
1990	71.6	73.3	75.5
1995	70.7	71.3	73.6
2000	68.9	69.9	71.4
2010	65.8	67.2	68.3
Black, Non-Hispanic			
1980	14.1	12.9	11.2
1985	14.6	14.4	12.5
1990	15.0	14.7	13.5
1995	15.3	14.9	14.2
2000	16.5	15.3	14.6
2010	17.0	16.6	15.5
Hispanics			
1980	7.8	7.5	6.8
1985	8.7	8.2	7.8
1990	10.4	9.3	8.3
1995	10.7	10.6	9.2
2000	11.9	11.2	10.4
2010	13.8	13.0	12.2
Other Minorities			
1980	2.3	2.3	2.8
1985	2.9	2.7	3.0
1990	3.6	3.2	3.2
1995	3.9	3.8	3.6
2000	3.4	4.2	4.1
2010	4.2	4.0	4.7

SOURCES: Spencer (1986, 1989); U.S. Bureau of the Census (1982).

TABLE F-20 Past and Projected College-Age Population by Race and Attainment of Bachelor's or Higher Level Degree, 1984-2005 (in thousands)[a]

	Total Population			B.A. Degrees Earned			M.A. Degrees or Higher Earned		
Race	1984	1995	2005	1984	1995	2005	1984	1995	2005
White	NA	46,715	42,858	NA	6,502.8	5,689.4	NA	1,936.5	1,602.4
Black	NA	9,079	9,328	NA	594.7	569.2	NA	109.2	98.7
Hispanic	NA	6,228	7,289	NA	271.0	306.0	NA	107.5	118.0
Other	NA	2,201	2,516	NA	372.2	421.6	NA	103.8	116.5
Total	68,969	64,223	61,991	8,322	7,740.7	6,986.2	2,309	2,257.0	1,935.6

NOTE: NA = not available.
[a] Population of those 18 to 34 years of age.
SOURCE: Kominski (1988).

TABLE F-21 Course Requirements for Bachelor's Degree Programs in Nuclear Engineering

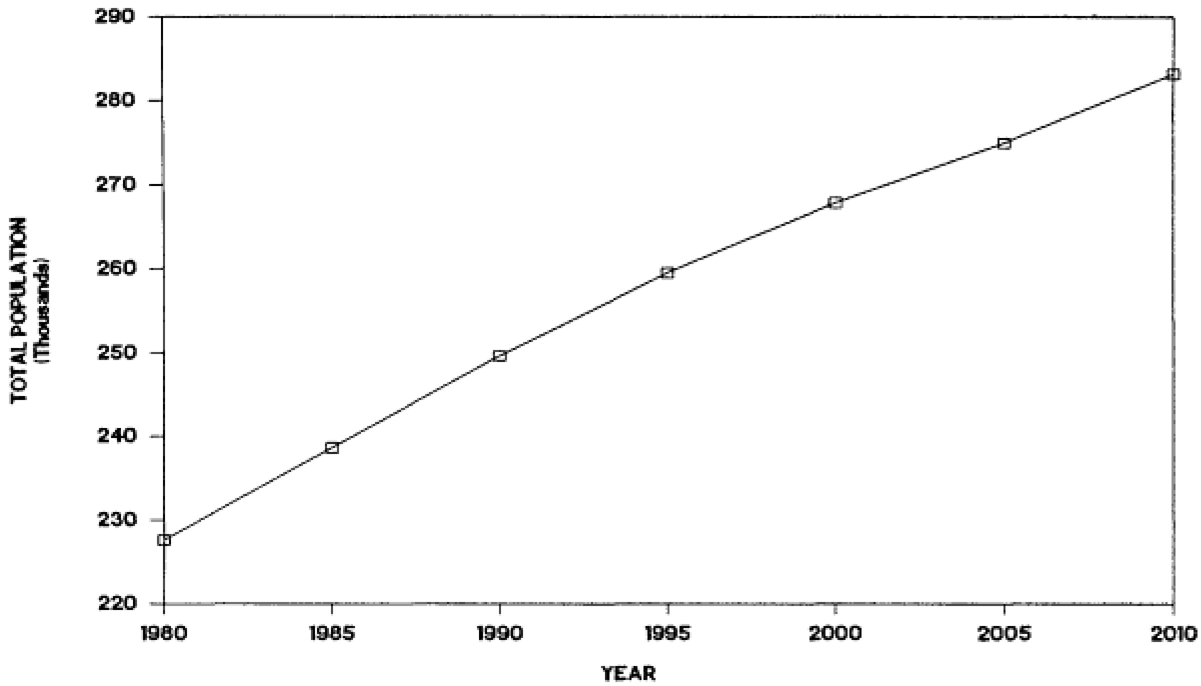
	Required Semester Hours		
Curriculum Area	Minimum	Average	Maximum
Calculus	8	12	20
Differential equations	3	4	6
Advanced mathematics	2	3	15
Introductory physics	6	9	15
Atomic and nuclear physics	0	3	6
Chemistry	3	9	14
Other basic science and mathematics	1	3	6
Computing	2	3	
Numerical methods	3	5	9
Statics	1	3	6
Dynamics	1	3	6
Fluid mechanics	2.5	3	8
Materials	0	3	6
Materials science	2	4	13
Electrical circuits	3	3.5	9
Electronics	0	3	6
Thermodynamics	3	4	8
Heat transfer	0	3	6
Nuclear physics	2	5	7
Reactor physics	3	5	8
Fusion	0	3	4
Radiation detection	0	2.5	5
Radiation effects	0	2.5	3
Health physics	0	2.5	4
System dynamics	0	3	7
Thermal hydraulics	0	3	7
Reactor engineering	3	5	10

SOURCE: Committee survey.

TABLE F-22 Average Semester Hour Requirements in Basic and Engineering Sciences for Different Engineering Disciplines

	Engineering Discipline[a]						
Curriculum Area	Mech	Elec	Civil	Ind	Aero	Marls	Nucl
Physics	10	12	10	9	7	10	22
Chemistry	6	8	7	6	7	11	7
Mechanics	12	3	9	5	11	5	7
Thermal science	12	2	2	2	6	5	9
Electrical and electronics	6	28	2	3	5	4	5
Nuclear science	0	3	0	0	0	3	6

a "Mech" = mechanical engineering, "Elec" = electrical engineering, "Civil" = civil engineering, "Ind" = industrial engineering, "Aero" = aerospace engineering, "Marls" = materials engineering, and "Nucl" = nuclear engineering.
SOURCE: Committee survey.



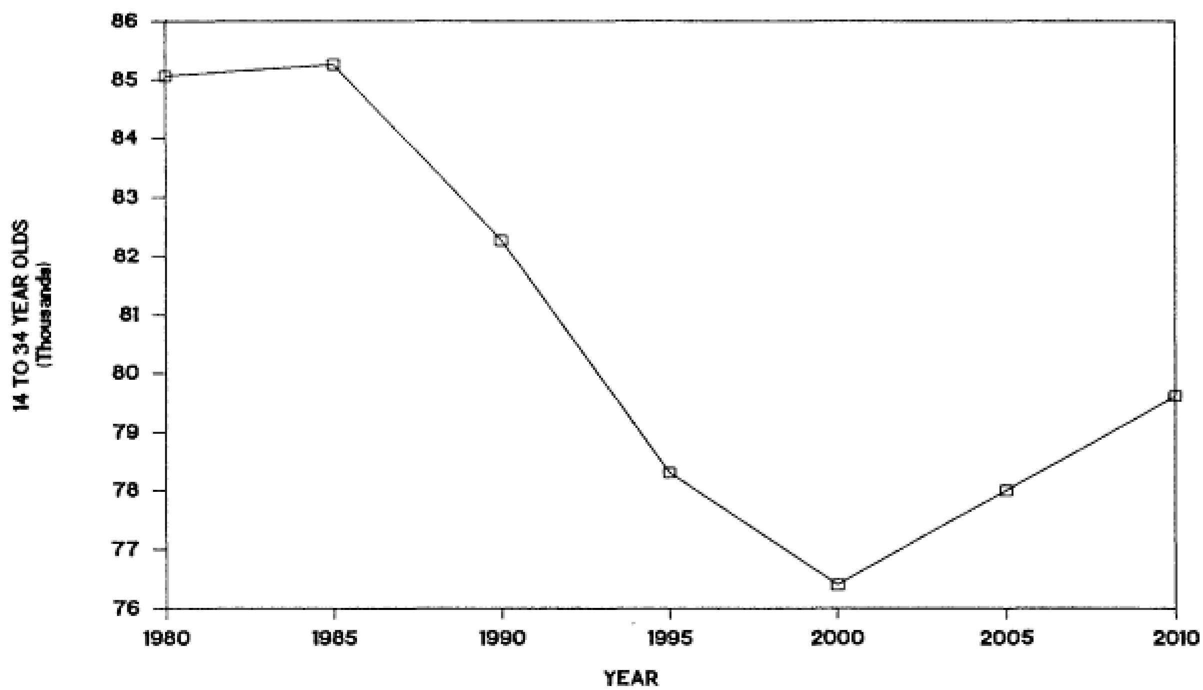


Figure F-1
Past and projected trends in the total and 14-34 year old U.S. population, 1980-2010 (in thousands).
Sources: Spencer (1986, 1989), U.S. Department of Commerce (1982).

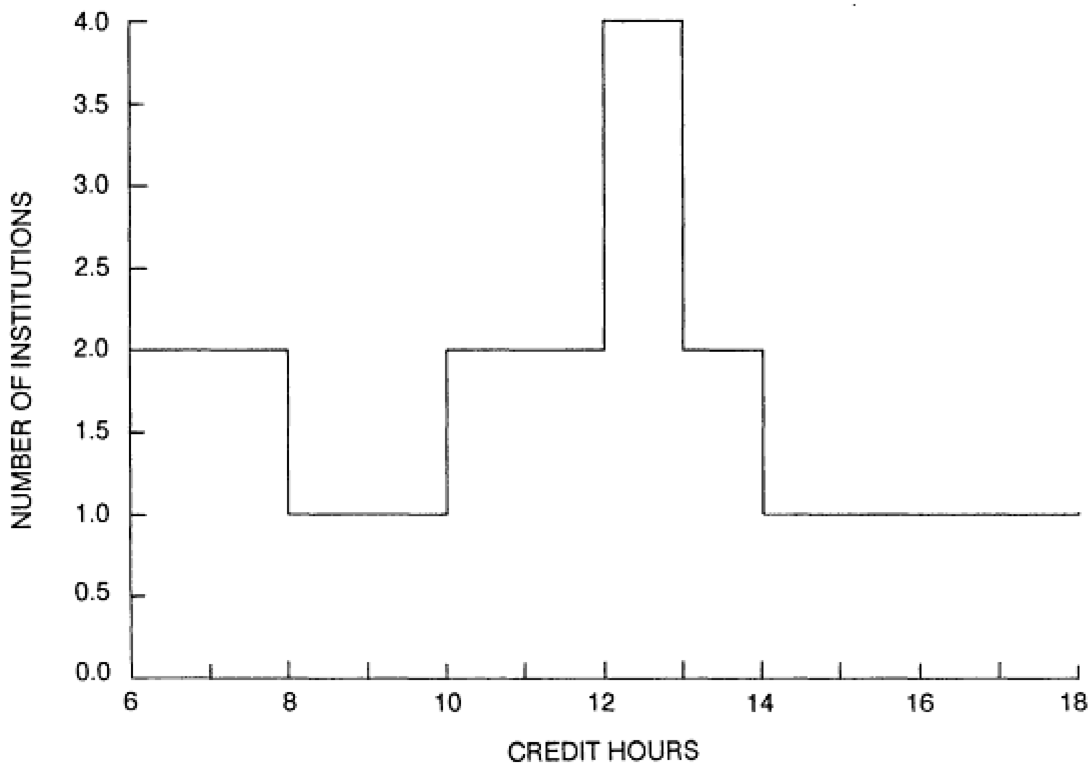


Figure F-2
The distribution of physics credit hours required for nuclear engineering degrees by several institutions.
Source Committee survey.

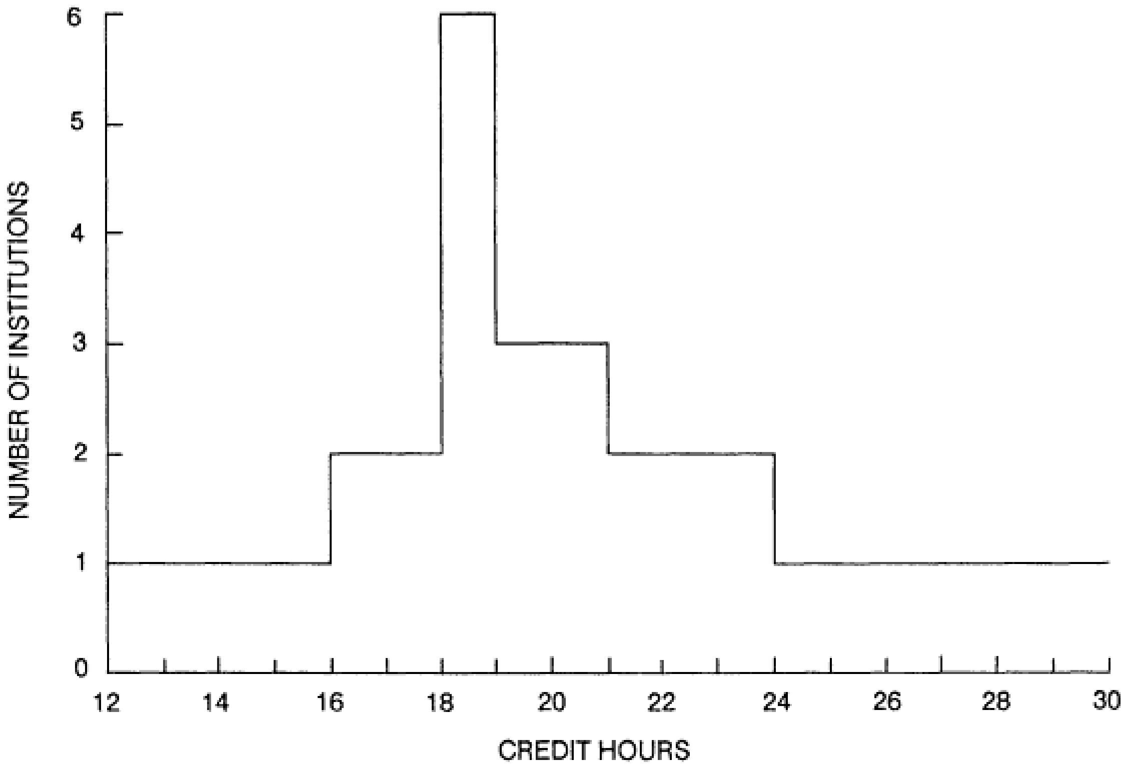


Figure F-3
The distribution of mathematics credit hours required for nuclear engineering degrees by several institutions.
Source Committee survey.

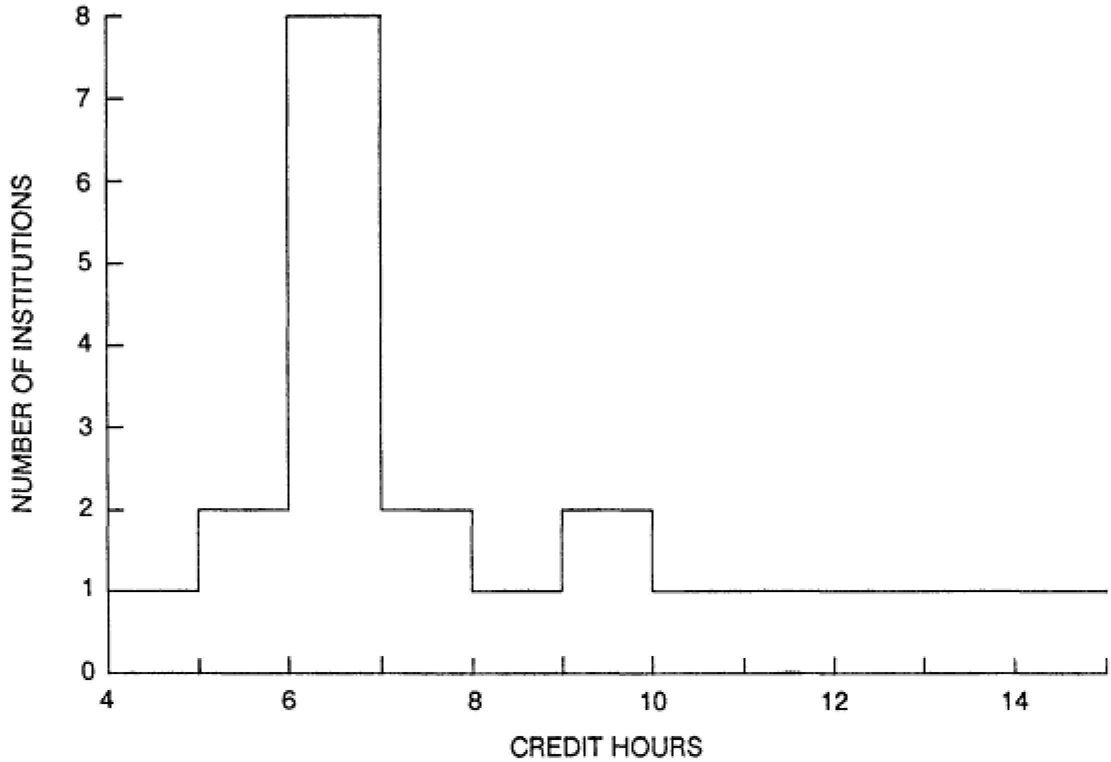


Figure F-4
The distribution of engineering mechanics credit hours required for nuclear engineering degrees by several institutions.
Source: Committee survey.

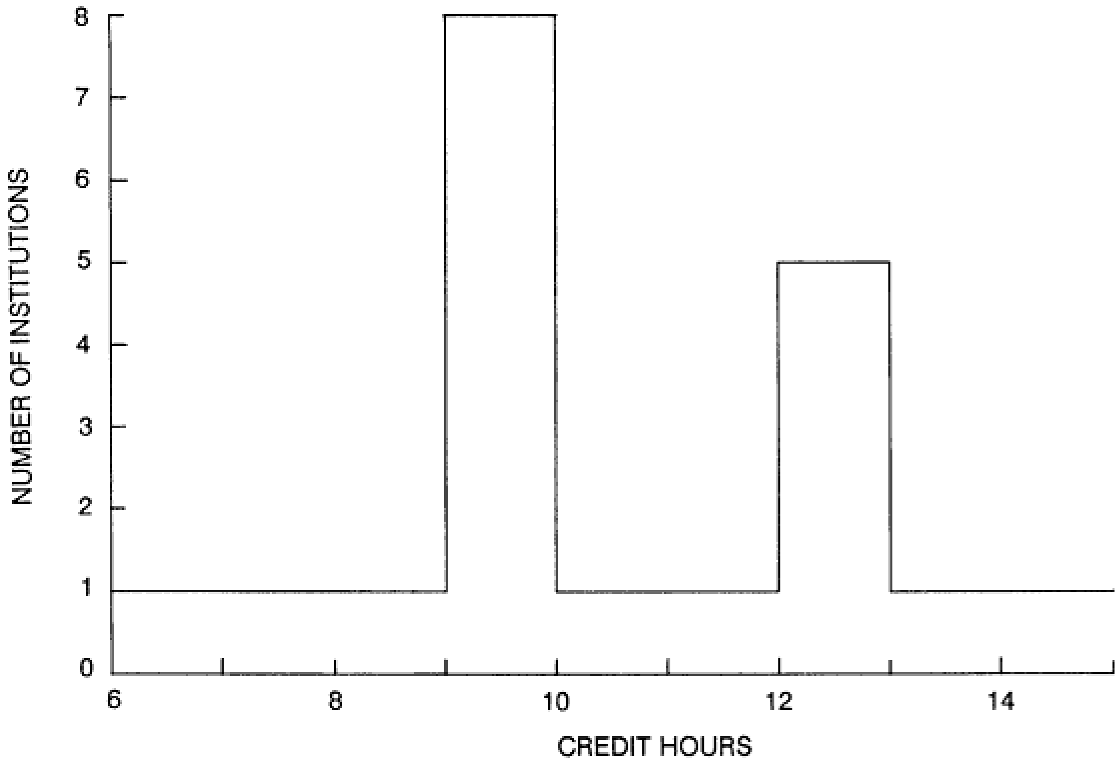


Figure F-5
The distribution of nuclear science credit hours required for nuclear engineering degrees by several institutions.
Source: Committee survey.

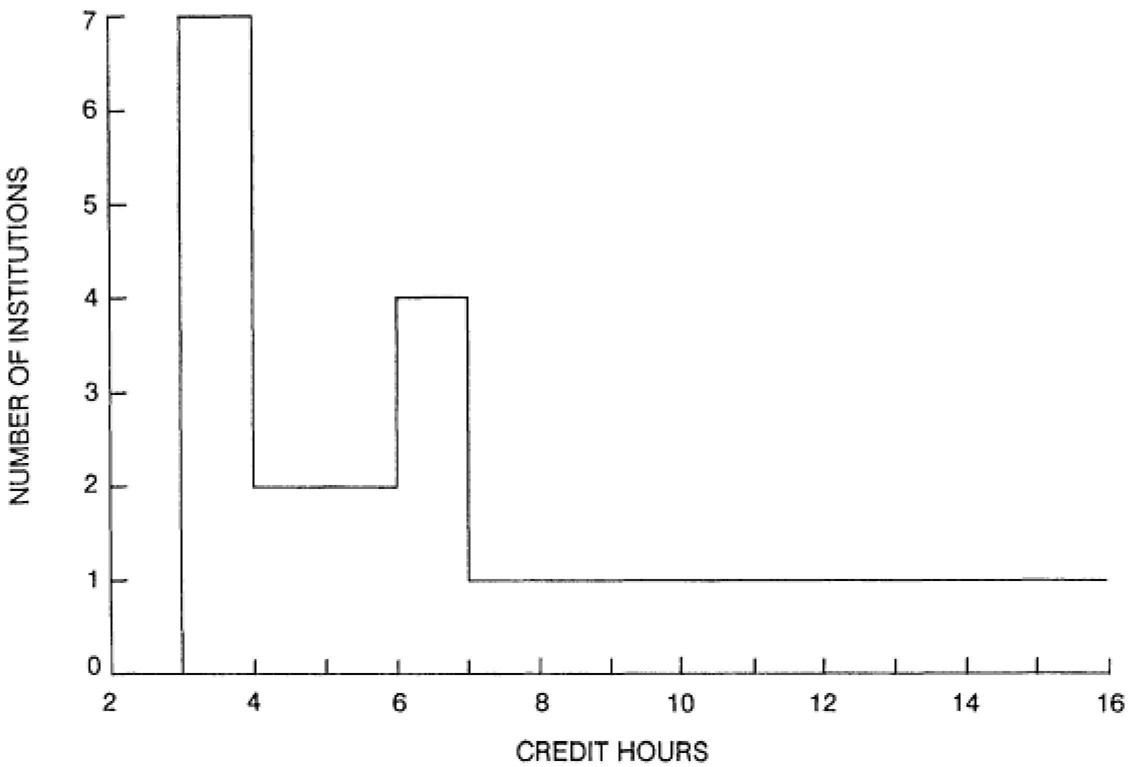


Figure F-6
The distribution of materials science credit hours required for nuclear engineering degrees by several institutions
Source: Committee survey.

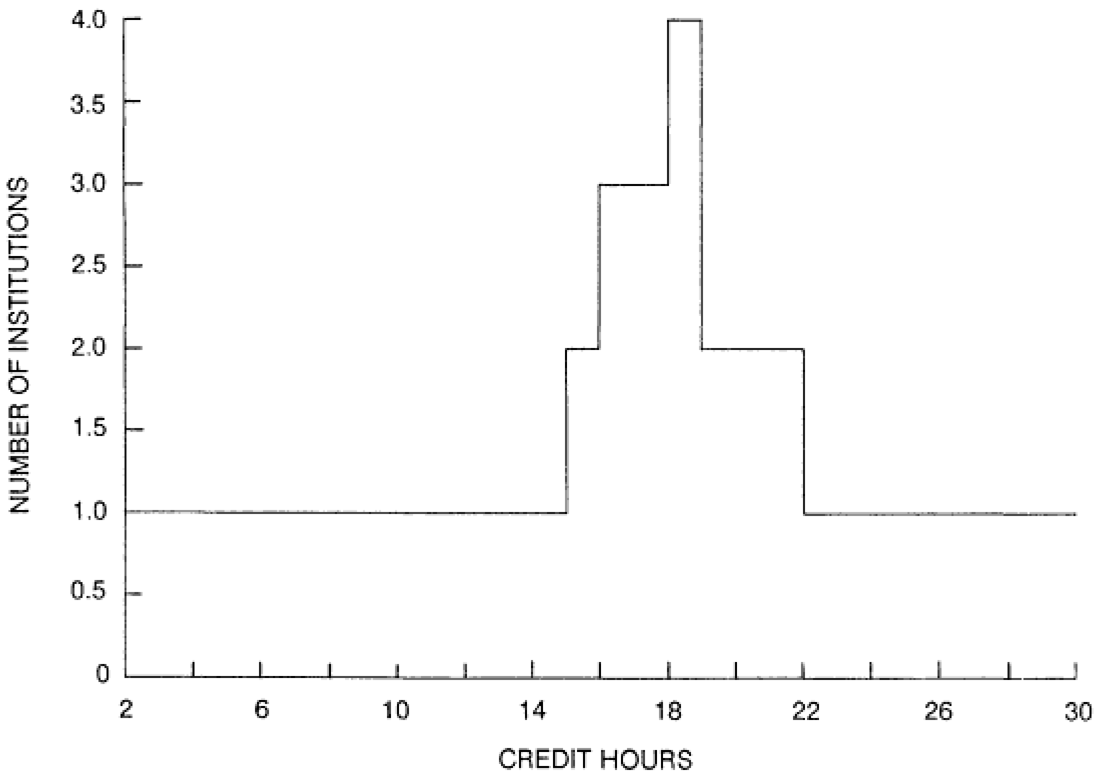


Figure F-7
The distribution of humanities and social science credit hours required for nuclear engineering degrees by several institutions.
Source: Committee survey.

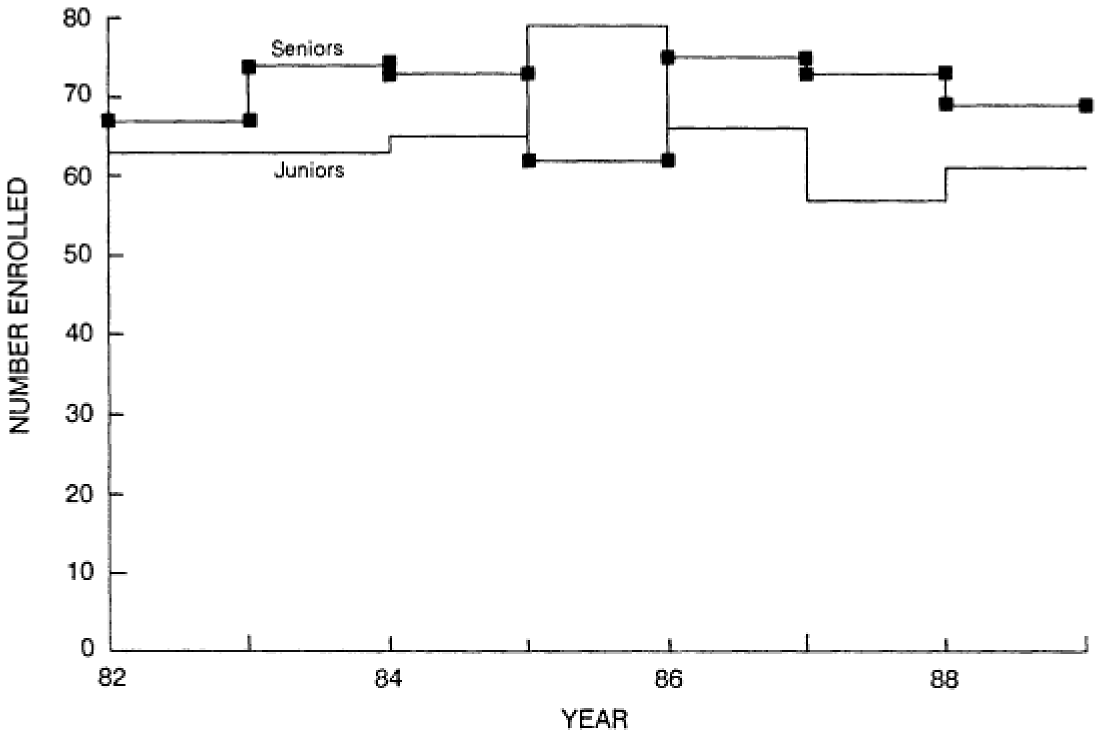


Figure F-8
Undergraduate enrollment of women in nuclear engineering for juniors and seniors, 1982 to 1988.
Source: Committee survey.

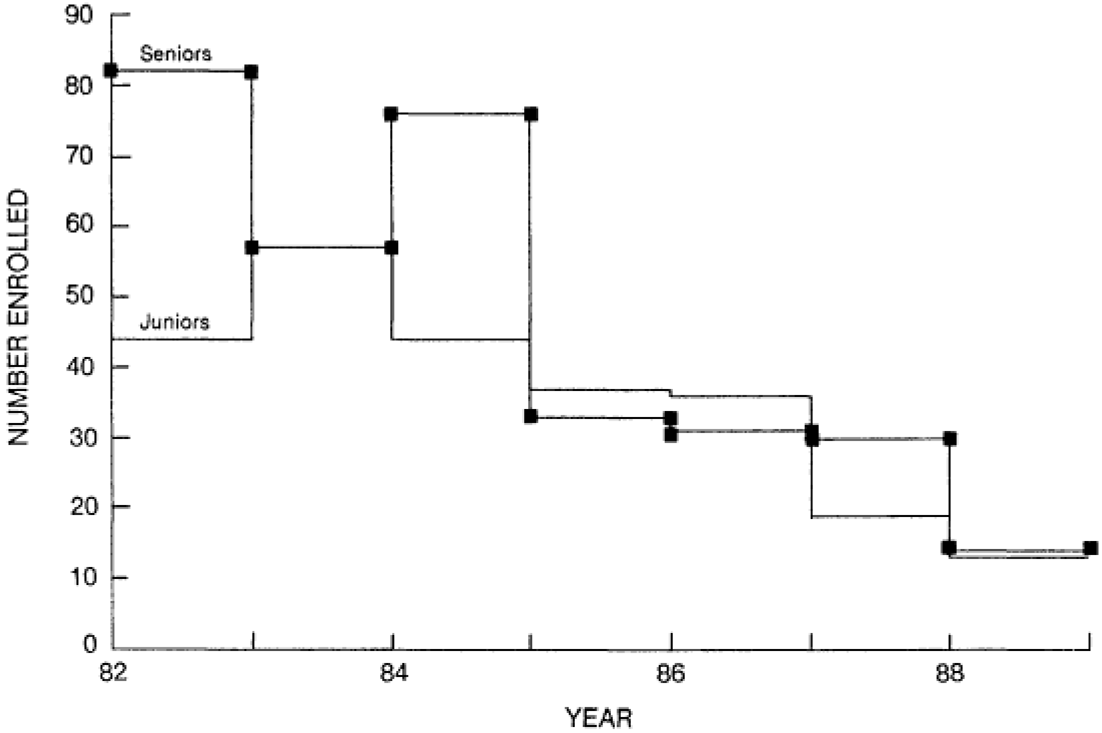


Figure F-9
Undergraduate enrollment of foreign nationals in nuclear engineering for juniors and seniors, 1982-1988.
Source: Committee survey.

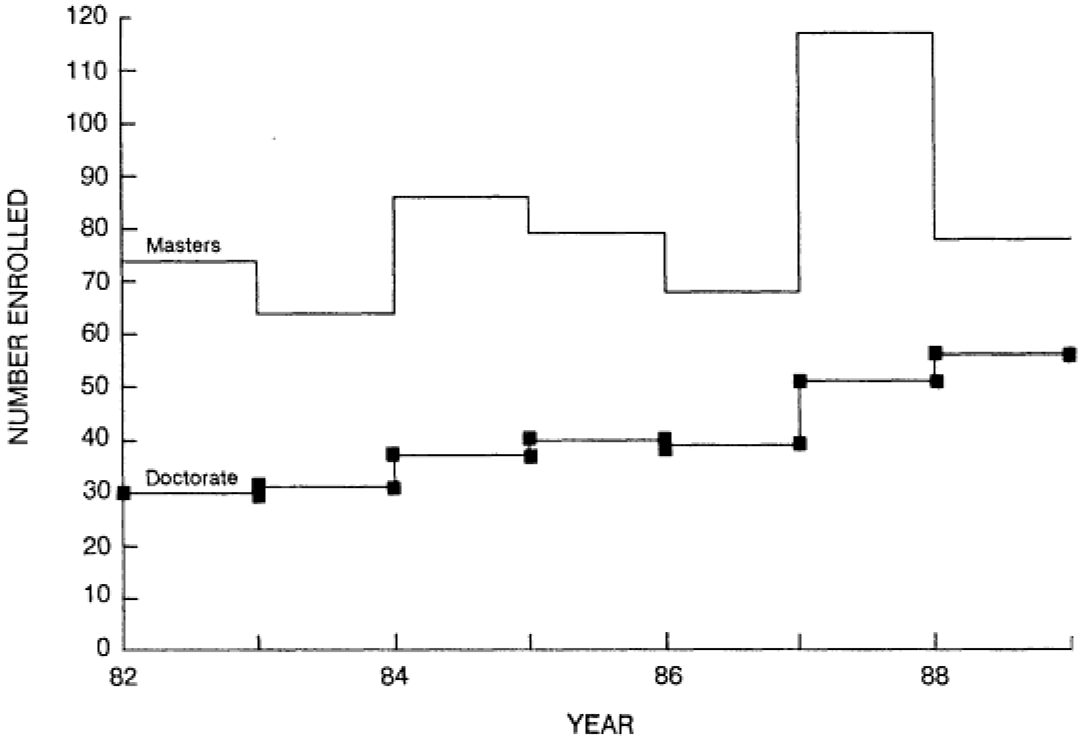


Figure F-10
Graduate enrollment of women in nuclear engineering 1982 to 1988.
Source: Committee survey.

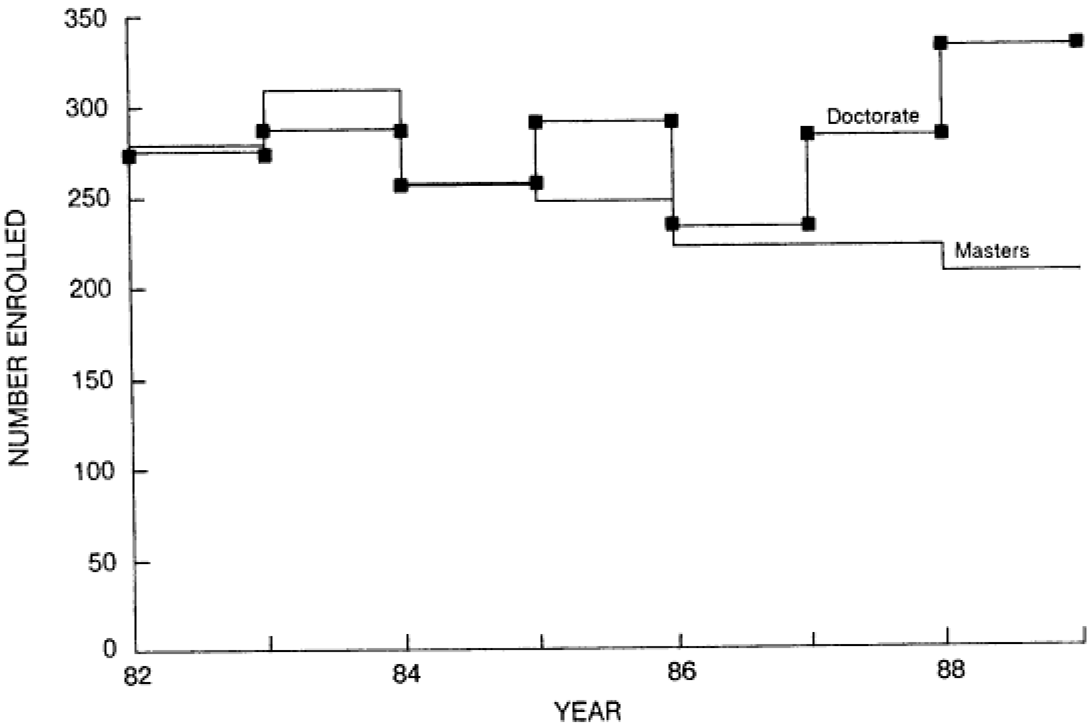


Figure F-11
Graduate enrollment of foreign nationals, 1982 to 1988.
Source: Committee survey.

Appendix G

The Committee's Questionnaire to Nuclear Engineering Departments

Letter Sent to Nuclear Engineering Departments and Programs

Committee on Nuclear Engineering Education

May 2, 1989

Dear------------:

The Commission on Engineering and Technical Systems of the National Research Council is engaged in a study of nuclear engineering education in the United States. The Statement of Task for this study and the roster of the study committee are enclosed for your information. The study is sponsored by the U.S. Department of Energy, the Institute of Nuclear Power Operations, and the American Nuclear Society.

The objectives of this study are to evaluate the present status of nuclear engineering education, to estimate future needs in that area for the next 5, 10, and 20 years, and to recommend appropriate actions that might be important to assure that the nation's needs for engineers with nuclear skills will be met. This letter is to seek your assistance in obtaining some essential information toward achieving the first of these objectives.

For that purpose, a subcommittee under Professor Robert L. Seale has drawn up the enclosed questionnaire. The questionnaire was formulated because the subcommittee recognized that, although U.S. educational programs in nuclear engineering education are similar in many respects, they differ widely. We ask your patience and cooperation in responding to the questions. In so doing, please be sure to provide your personal insights and identify unique features of your program.

In order to meet study schedules, please send your response by May 20, 1989 to Dr. Seale, who is Head, Department of Nuclear and Energy Engineering, University of Arizona, Tucson, Arizona 95721. If you have questions, please call him at (602) 621-2311. Thank you for your cooperation.

Sincerely,
Robert Cohen
Senior Program Officer

Enclosures as stated

NUCLEAR ENGINEERING PROGRAM QUESTIONNAIRE

University: ______________________
Department: ______________________
Address: ______________________
____
____

Provide a brief description of the organizational status of your program. Is your program in an independent department or is it part of a multi-discipline department? ______________________
____
____

PART I: Current Profile of Nuclear Engineering Program

UNDERGRADUATE

Please note that much of the information requested below is in the same format as that used in the current ABET Accreditation Report that is filed prior to an accreditation visit. Hopefully this will simplify the task of preparing this information. We appreciate your help.

ENGINEERING ENROLLMENT AND DEGREE DATA

Undergraduate enrollment will be taken from the DOE sponsored Oak Ridge Associated Universities survey. An updated version is due out shortly.

Based on present facilities and staffing levels, what annual enrollment levels could your program accommodate? ____________

What is the minimum SAT or ACT mathematics score that students need for success in your B. S. Nuclear Engineering program? ____________

What is the minimum SAT or ACT verbal score that students need for success in your B. S. Nuclear Engineering program? ____________

Where did your B.S. graduates of the last 5 years go?

Employer	Number	Percent
Graduate school	____	____
Utilities	____	____
National Laboratories	____	____
Reactor Vendors	____	____
Consultants	____	____
DOE	____	____
NRC	____	____
DOE Contractors	____	____
Military Services	____	____
Other	____	____

GRADUATE

Graduate enrollment data will be taken from the DOE sponsored Oak Ridge Associated Universities survey. An updated version is due shortly.

What are the undergraduate disciplines of the students that enter your graduate program? (Base your answer on the last 5 years enrollment.
_____% NE, _____% ME, _____% EE, _____% CE, _____% ChE,
_____% Other Engr, _____% Phys, _____% Math, _____% Chem,
_____% Other.

Based on current facilities and staffing levels, what graduate enrollment could your program accommodate? ____________

What is the threshold GRE score of successful graduate students in your program? ____________

Where do your M.S. and Ph.D. graduates of the last 5 years go?

Employer	Number	Percent
Utilities	____	____
National Laboratories	____	____
Reactor Vendors	____	____
Consultants	____	____
DOE	____	____
NRC	____	____
DOE Contractors	____	____
Academic Career	____	____
Other	____	____

What special efforts are used to recruit new students to your program? Please identify faculty or department efforts separately from those of student organizations. ____________

What student activities or organizational affiliations are there for your Nuclear Engineering students? ____________

What is the approximate Nuclear Engineering portion of the total enrollment in the College of Engineering (or equivalent unit) of your institution? _______%

NUCLEAR ENGINEERING PERSONNEL AND STUDENTS

1988-89 Academic Year

	Head Count FT	Head Count PT	FTE	Ratio to Faculty
Administrative	___	___	___	___
Faculty (tenure track)	___	___	___	___
Other Faculty (non-tenure)	___	___	___	___
Student Teaching Assts.	___	___	___	___
Student Research Assts.	___	___	___	___
Technicians	___	___	___	___
Office/Clerical	___	___	___	___
Others	___	___	___	___
Undergraduate Students	___	___	___	___
Graduate Students	___	___	___	___

NUCLEAR ENGINEERING EXPENDITURES

Expenditure Category / Year	1984-85	1985-86	1986-87	1987-88	1988-89
Faculty	___	___	___	___	___
Staff (Clerical)	___	___	___	___	___
Staff (Technician)	___	___	___	___	___
Operations	___	___	___	___	___
Travel	___	___	___	___	___
Equipment					
Institutional Funds	___	___	___	___	___
Gifts and Grants	___	___	___	___	___
Grad Teaching Assts.	___	___	___	___	___
Grad Research Assts.	___	___	___	___	___

List the major facilities and laboratories available for instruction and research in your Nuclear Engineering program. ______________________

____

____

What computing facilities are available in support of your program?

____

____

____

Part II: Profile of Present Faculty

RESEARCH INTERESTS OF FACULTY

Name	Highest Degree	Rank	Age	Years Teaching	Specialty Research/Consulting

Comment on the rank distribution of your faculty. ____________________

Comment on the age distribution of your faculty: ____________________

Comment on the strengths and weaknesses of your faculty: ____________________

Identify special awards received in the last 5 years by members of your faculty: ____________________

Are there deficiencies in the range of specialties covered by the faculty in your department? ____________________

PART III: Degree Programs

UNDERGRADUATE

Curriculum Elements	Credit Hrs Lec/Lab	Status Req/Elec
Basic Sciences and Mathematics		
Mathematics:		
Calculus	______	______
Differential Equations	______	______
Advanced Engineering Math	______	______
Physics:		
Introductory Physics with Calculus	______	______
Atomic & Nuclear Physics	______	______
Chemistry:		
Introductory Chemistry	______	______
Advanced Chemistry	______	______
Other Courses ______	______	______
______	______	______
______	______	______
Computer Programming		
______	______	______
______	______	______
Engineering Sciences		
Engineering Mechanics:		
Statics	______	______
Dynamics	______	______
Fluid Mechanics	______	______
Materials:		
Strength of Materials	______	______
Metallurgy/Materials Science	______	______
Thermal Sciences:		
Thermodynamics	______	______
Heat Transfer	______	______
Electricity and Magnetism:		
Circuits	______	______
Electronics	______	______
Nuclear Sciences:		
Nuclear Physics	______	______
Radiation Interaction	______	______
Reactor Physics	______	______
Fusion	______	______

	Credit Hrs Lec/Lab	Status Req/Elec
Applied Science and Design		
Radiation Detection & Instrumentation	___	___
Health Physics	___	___
Radiation Effects	___	___
System Dynamics	___	___
Thermal Hydraulics	___	___
Reactor Engineering	___	___
Nuclear Fuel Cycle	___	___
Systems Design	___	___
Other courses ___	___	___
___	___	___
___	___	___

Comments: ___

___

___

Humanities & Social Sciences		
Economics	___	___
___	___	___
___	___	___
___	___	___
___	___	___
Communication Skills		
English Composition	___	___
Technical Writing	___	___
Special Requirements	___	___
___	___	___
___	___	___

Comparison of Nuclear Engineering program with other disciplines in your institution. Indicate the required number of credit hours of each of the listed areas.

Degree Program	Requirements in Credit Hours				
	Mechanics	Thermal Sciences	Elec. & Electronics	Physics	Chemistry
Mech Engr	___	___	___	___	___
Elec Engr	___	___	___	___	___
Civil Engr	___	___	___	___	___
Indus Engr	___	___	___	___	___
Aero Engr	___	___	___	___	___
Matl Sci/Engr	___	___	___	___	___
Nucl Engr	___	___	___	___	___

GRADUATE

Advanced Degree Requirements

Degree	Course Units Beyond B. S.	Research Thesis or Dissertation	Average Time Required Beyond B. S.
Masters	_____	_____	_____
Doctorate	_____	_____	_____

What are the most common minors for your graduate students? List in the order of decreasing popularity. ____________________
____

Graduate Courses in Nuclear Engineering

Course Number Masters:	Name of Course	Core/Elective C/E	Last Year Taught
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

Course Number Doctorate:	Name of Course	Core/Elective C/E	Last Year Taught
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

Part IV: Research Activities in Nuclear Engineering

SUMMARY OF RESEARCH IN NUCLEAR ENGINEERING

Name of Research Topic	Personnel-FTE Fac.	Personnel-FTE Res. Asst.	Support Agency	Support Dollars

Comment on the trend in research. ____________________

Comment on the research climate as you see it at the present time. Your successes and frustrations in seeking funding are both of interest. Please be specific as general statements convey dissatisfaction but do not really suggest solutions or alternatives.

____

Part V: Industrial Interaction

Discuss the extent of industrial interaction with your faculty including instruction, consulting, and research. ____________________

Discuss the extent of industrial interaction and support of your student including scholarships, fellowships, summer employment, coop, etc.

____

Part VI: Summary

Based on impressions gained from contact with your students, please identify any consistent factors or influences that may have influenced their career choice. These might include role models, advisors at any level in school, interest in a specific technology, or a personal perception of the opportunity. Be as specific as you can. ____

Please make any comments you may wish to contribute to the deliberations of the Committee on Nuclear Engineering Education of the Energy Engineering Board of the National Research Council. Either add to this questionnaire or write a separate letter. We need and welcome your thoughts and insights.

Comments: ____

References and Bibliography

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