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Foreign and Foreign-Born Engineers in the United States

INFUSING TALENT, RAISING ISSUES

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INFUSING TALENT, RAISING ISSUES

Committee on the International Exchange
and Movement of Engineers

Office of Scientific and Engineering Personnel

National Research Council

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FOREWORD

The U.S. engineering enterprise is increasingly affected by forces at the world level. It is affected, for example, by the extent of opportunities to export our engineering services, by the use of global standards in products and processes, by the needs of U.S. firms to hire large numbers of engineers and to seek to make the best use of available skills in their work, by the desire of foreign-born engineers to study and work in America, and by the national interest in maintaining a large number of technically challenging, high-paying jobs in our country.

As this report points out, many real and perceived benefits and problems come with the international exchange and movement of engineers. Many questions arise: Are foreign engineers and engineering students displacing Americans? Does the presence of foreign engineers in the work force lower engineering wages? In what ways does industry benefit from the availability of foreign-born engineers? Should the dependence on foreign-born engineers in our universities and industry be of concern?

This report provides much sound factual information that will be valuable to our government, universities, and industry in addressing these controversial issues. It gives balanced judgments about engineers in our work force and in academe. It points out a number of neglected perspectives, for example, that foreign students arriving at our universities may, in effect, subsidize our system, in that a large investment in their educations has already been made by their home countries.

As the report makes clear, there are several areas in which we need to improve our data and information. It would be helpful to know more about career patterns of those foreign engineering students who do not remain in the United States. We should learn more about U.S. engineers studying and working abroad. We should examine more deeply the barriers to the most effective use of engineering talent in the United States. The marketplace for engineering skills can only become more global; and only through having unexcelled talent and productivity in engineering--in industry, academe, and government--can the United States be confident that the profession, and the highly desirable jobs that characterize it, will thrive here.

Robert M. White
Vice Chairman, National Research Council
President, National Academy of Engineering

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The Committee on the International Exchange and Movement of Engineers is grateful for the special assistance that it received from a number of individuals. Staff of the National Academy of Engineering (NAE) initiated plans for this study as a result of concerns expressed by members of the NAE Council. We particularly appreciate the guidance of Robert M. White, NAE president; Alexander H. Flax, home secretary of the NAE; H. Guyford Stever, foreign secretary of the NAE; and Jesse H. Ausubel, director of the NAE program office. Alan E. Fechter, executive director of the Office of Scientific and Engineering Personnel (OSEP), contributed significantly to the intellectual content of this report. Charles E. Falk, former director of the Division of Science Resources Studies at the National Science Foundation, served as a special consultant to the study committee, providing helpful insights in the areas of data collection and interpretation. Linda S. Dix, project officer in OSEP, provided administrative oversight for the study from its inception through production of the final report.

In addition, we are indebted to the research community for information provided in the form of published reports, papers commissioned by this committee, and participation at the committee's workshop on July 7, 1987. The commissioned papers written by seven individuals knowledgeable about this topic were presented and discussed at the workshop, leading to additional insights that guided the committee in its deliberations. The committee expresses much appreciation to the authors: Peter Cannon, Rockwell International Corporation, for his assessment of the role of foreign engineers in U.S. industry; Daniel C. Drucker, University of Florida-Gainesville, and J. Enrique Luco, University of California-San Diego, for their thoughts about the impacts of foreign faculty and foreign students on engineering departments in U.S. universities; Michael G. Finn, Oak Ridge Associated Universities, for his analyses of the participation of foreign engineers in the overall U.S. labor force; Glenn W. Kuswa, Sandia National Laboratories, for his assessment of the effects of employing foreign nationals in federally supported laboratories; and Charles T. Owens, Division of International Programs at the National Science Foundation, for his review of the experiences of American engineers in Japan.

Finally, the support of Yupin Bae, research assistant in OSEP, and Dee Cooper, program secretary, led to the timely publication of this report.

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Introduction

Immigrants have provided a transfusion of new talent throughout U.S. history to support our nation's economic and cultural growth and development. Their presence has generally been accepted as the norm in the United States, and immigrants have helped our nation to become the effective pluralistic society that it is today. However, the absorption of these successive groups of immigrants has often been accompanied by issues associated with their integration into our work force and our society.

In recent years, there has been a marked increase in foreign and immigrant engineers and engineering students, individuals especially qualified by advanced education and professional skills. A large proportion of these individuals remain in the United States and are becoming an increasingly important component of our engineering work force. Once more, their presence is creating not only real opportunities, but also possibly problems.

Motivated by a growing interest in the implications of the increasing prevalence of these foreign-born engineers in our society,[1] the National Academy of Engineering asked the Office of Scientific and Engineering Personnel (OSEP) to undertake a preliminary examination of the issues associated with this international movement. In particular, OSEP was asked to identify the major issues associated with this movement, to assess their validity or importance, and to suggest follow-on studies that may be needed for proper evaluation of the issues involved. The Committee on the International Exchange and Movement of Engineers (CIEME) was created to undertake this task. The work of the Committee included the compilation of relevant data, the commissioning of a set of papers examining the implications of this influx of foreign-born engineers on various sectors of the economy, and the convening of a workshop at which the data and papers were reviewed and discussed by the participants. The Committee's findings, conclusions, and

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[1] See Committee on the Education and Utilization of the Engineer, Commission on Engineering and Technical Systems, National Research Council, *Engineering Education and Practice in the United States: Foundations of Our Techno-Economic Future,* Washington, D.C.: National Academy Press, 1985.

recommendations are based on the information gathered through these activities.

Findings

Three basic findings emerged from the factual data examined by the Committee. First, there has been a gradual but substantial increase in the overall proportion of foreign-born engineers residing and working in the United States. For example, noncitizens constituted 3.5 percent of the total engineering labor force in 1982, about the same as in 1972, while the proportion of naturalized citizens grew from 5 percent in 1972 to 14 percent in 1982. The fraction of the engineering work force that is foreign-born has continued to increase since 1982.[2] The prevalence of these foreign-born engineers varies considerably with their level of academic achievement. In 1982, noncitizens and naturalized citizens together accounted for 15 percent of the bachelor degree holders, 22 percent of the masters, and 36 percent of the Ph.D.s in the American engineering labor force. The continuing increase in the number of foreign and foreign-born engineers reflects two facts: (1) many foreign students and professionals enter the United States with the primary goal of becoming permanent U.S. residents, and (2) many of the foreign engineering students, who initially came here to study, later changed their goals and decided to remain because of better living conditions and more attractive employment opportunities than are available in their home countries.

The second finding is that the recent increase in the number of foreign-born engineers has occurred disproportionately in the academic sector. For example, the proportion of foreign assistant professors of engineering younger than age 35 has increased from 10 percent in 1972 to over 50 percent during the period 1983-1985.[3] About two-thirds of the postdoctoral university appointees are not U.S. citizens. Also, the number of foreign applicants for graduate study in engineering is greater than the number of U.S. applicants, and about 60 percent of foreign students obtaining Ph.D. degrees in the United States remain here. Over 90 percent of undergraduates in engineering but only about 45 percent of new engineering Ph.D.s are U.S. citizens (about 4 percent of this latter group were naturalized citizens). The latter proportion is

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[2] The most reliable source of data on the foreign engineering labor force is the National Science Foundation's (NSF) Postcensal Survey, which in 1982 surveyed a representative sample of the total 1980 U.S. science and engineering labor force. These data are preferentially used in this report. The NSF makes available more recent estimates, which are model-generated and based on updated surveys of the postcensal cohorts and a number of more recent surveys. The latter, however, miss recent immigrants and some recent graduates of U.S. universities, especially those with foreign addresses.

[3] The number of foreign-born assistant professors who have become naturalized citizens is small (less than 5 percent).

small, even with selected efforts to restrict the number of foreigners admitted to graduate engineering education through imposition of admission ceilings at a number of major universities.

The third finding relates to the origin of these foreign-born engineering students. A disproportionately large number come from countries where the language and cultural backgrounds are likely to be significantly different from those of most native-born Americans. In 1985, for example, 31 percent of the foreign engineering students in U.S. schools came from the Far East, 6 percent from India, and 20 percent from the Middle East.

Issues

Dependence on Foreign-Born Engineers

Very significant, positive aspects arise from the presence of foreign-born engineers in our society. It must be recognized that with these foreign engineers the United States is attracting an unusually gifted group of individuals with high intellectual competence and diligence. The diversity of intellectual backgrounds and experience that other foreign-born engineers have brought in the past greatly contributed to U.S. engineering competence, and there are no reasons to believe that new immigrants will not contribute similarly.

Since these engineers provide definitely needed supplements to our labor force, their absence would lead to curtailment of important programs.[4] Without the preponderence of foreign-born individuals among faculty and graduate students in academe, American engineering schools would be unable to provide educational and research programs of the current magnitudes. The influence of foreign-born engineers has become highly significant also in industrial research and development (R&D), particularly in disciplinary areas that were viewed to be of secondary importance in the United States several years ago but are now criticial to our international competitiveness in selected fields, such as nonlinear optics and the associated manifold applications of laser technologies. A survey of the R&D directors of 20 firms that account for a large fraction of the technological output of the United States (see Peter Cannon, Appendix D) indicated that "their particular industries are, in fact, dependent upon foreign talent and that such dependency is growing." Thus, it is clear to the Committee that these foreign-born engineers enrich our culture and make substantial contributions to U.S. economic well-being and competitiveness and that without the use of noncitizen and foreign-born engineers, universities and industries would experience difficulty in staffing current educational, research, development, and technological programs.

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[4] This information was presented by numerous participants at the committee-sponsored workshop and the commissioned papers included in Appendix D, particularly "Foreign Engineers in U.S. Industry" by Peter Cannon.

Foreign Engineering Students

As already noted, about 45 percent of engineering graduate students in 1985 were foreigners with temporary visas, about another 10 percent held permanent residence visas, and 4 percent were foreign-born citizens. The relatively large proportions of foreign students in graduate engineering programs reflect a lack of interest on the part of American students in such programs. The well-paying employment opportunities for engineers with new bachelor's degrees are one of the major causes of this lack of interest in graduate education by American engineers. The potential pool of foreign graduate students is considerably larger than that of Americans, and their academic records and test scores are very high. Thus, American graduate students could become an even smaller fraction of the engineering graduate-student population without continuation of the current preferential treatment for American students or some financial incentives for Americans to enter graduate studies instead of immediate employment upon receipt of their bachelor's degrees.

Effects on Engineering Education

The productivity, growth, and international competitiveness of the U.S. economy are influenced by many factors. Although it was beyond the scope of this study to rank the relative significance of these factors, the Committee has taken as a premise that the quality and effectiveness of the U.S. engineering education system is important in maintaining and improving the current U.S. position in world affairs.

Troublesome problems could arise if the quality and character of engineering education were not maintained. Three particular issues surfaced during the course of this study. First, the large-scale use of foreign teaching assistants (TAs) has been reported to be detrimental to the instructional programs offered in major engineering schools because of language difficulties. It is clear, of course, that language and communication difficulties should be resolved before foreign teaching personnel are allowed to assume responsibility for classroom teaching. It has even been suggested that, because of their cultural backgrounds, some foreign-born engineering TAs may discourage female and minority students from entering the engineering profession. For this supposition, the Committee found both anecdotal support and counterexamples. The third issue arises from the fact that in some foreign cultures, science and technology training tends to be preferentially slanted toward engineering science rather than toward practice.

One of the strengths of the American system of engineering education has been and continues to be its acceptance of pragmatic solutions to engineering problems and its recognition of the importance of hands-on training in the design and operation of engineering systems. Thus, there is some concern that, as a result of the large and growing ranks of new foreign faculty members, some of the character of American engineering education could be changed (it must, of course, be remembered that new engineering junior faculty are selected by mostly U.S.-born faculty members). However, the Committee has not examined possible changes in engineering education and their potential, long-term effects. It should be noted that the suggestion has been made that U.S. engineering education does not respond properly to current needs and requires drastic revitalization of the type that occurred in the 1950s, when broadly based engineering-science curricula were first introduced. Just what this revitalization should involve is properly the subject of another study.

Given the importance of teaching personnel in the training of an essential engineering talent pool, any adverse effects could span generations. Consequently, careful monitoring of the development and performance of the academic engineering establishment--both indigenous and foreign-born--must be viewed as a continuing, high-priority obligation.

Limitations in the Engineering Supply Available to the National Security Sector

While the national security sector (both industrial and governmental) employs only about 20 percent of the total U.S. engineering work force, its intellectual health and vitality are essential for the maintenance of an adequate level of defense. A major issue has emerged from the increased prevalence of foreign engineers (temporary visas) among the new advanced-engineering graduates in our education system (27 percent of master's degrees and about 45 percent of doctorates) and the foreign-born constituent of our engineering labor force (22 percent of master's and 36 percent of doctorates). These individuals, especially foreign nationals and immigrants with close relatives in foreign countries, are reported to encounter long-term difficulties in receiving special-access security clearances. Therefore, a substantial fraction of the most highly skilled talent of this nation may not be available to enter critical areas of defense research and engineering. As a consequence, the necessary work in this sector may have to be undertaken by less highly trained engineers than is desirable. The net result is certainly a less than optimal use of available talent and, possibly, a reduced level of effort. Another consequence is a larger concentration of foreign engineers within the academic sector than might otherwise be the case.

International Interactions of American Engineers

Considerable concern was expressed at the workshop and by Committee members that both new American engineering Ph.D.s and engineers already in the U.S. labor force do not spend sufficient time abroad to benefit from the highly developed technologies of many foreign countries. In the case of the employed engineers, the view was frequently expressed that managers who initiated or approved foreign trips frequently did not appreciate the importance of these foreign visits. Available data on this type of foreign interaction indicate that only 1 percent of new engineering doctorates in 1983 selected postdoctoral study abroad. The Committee believes that, in a world where other nations' technological competence has increased significantly, international contacts among scientists and engineers are imperative for effective national development and international competitiveness.

Data Gaps

The study of this Committee was handicapped by major gaps in available data. Almost no quantitative information was found on the international movement of American engineers, career patterns of foreign graduates who returned to their home countries, and the exact magnitude of foreign applicants for engineering graduate education. More generally, data gaps exist on the value to the United States of educating foreign nationals, on the extent of the deficiency in foreign visitations by American engineers, and on the full imbalance in the pool of potential engineering graduate students. Procedures to overcome this data deficiency were identified by the Committee and should be implemented.

Decreased Work Opportunities for U.S. Engineers

The Committee became aware of a belief that salaries of U.S. engineers are substantially depressed by the willingness of foreign engineers to work for lower wages, or that U.S. engineers lose job opportunities to foreign engineers. This concept does not appear to be supported by evidence available to the Committee. Since foreign engineers as a group represent only 3.5 percent of the total U.S. engineering labor force, they are not displacing Americans to a significant extent. As for salary depression, a study of 13,000 engineers showed no evidence that foreign engineers earned either more or less than their American colleagues. One may, however, conjecture that salaries of U.S.-born engineers would have been somewhat higher, especially among Ph.D.s, if the foreign-born pool of applicants had not been available.

Subsidization of Foreign Students

A notion exists that foreign students, whether they remain in the United States or not, are unfairly subsidized. Although the Committee had only limited information on the issue, it did not consider the issue to be a valid one. The basis for this judgment lies in the Committee's findings that a substantial fraction of these trained students remain in this country and become productive members of our society.

An additional consideration motivating the Committee's conclusion was that most of these students received their undergraduate training abroad. The costs of this foreign investment constitute an offset to any subsidy provided for graduate training in the United States. Furthermore, if there were only U.S. students, current excess capacity in graduate engineering programs would be even larger, making the current marginal costs of educating foreign students relatively low.

Exclusion of U.S. Graduate Students
or Junior Faculty

There is a concern that qualified U.S. citizens are being excluded from scarce openings in engineering graduate schools. This concern is at variance with the preferred treatment accorded to qualified indigenous applicants through the use of either formal or informal ceilings on the number of foreign graduate students admitted. However, operation of normal engineering school appointment practices, which frequently favor expertise in engineering science and theoretical studies, may be limiting the appointments of U.S. Ph.D. engineers to faculty positions at major research universities because of the availability of a pool of especially well-qualified, foreign-born engineers.

Broader Considerations and Recommendations

During its investigation, the Committee discussed several issues that are of central importance in assessing the long-term impact of foreign engineers on the United States. These issues include the quality and appropriateness of the engineering curriculum in the United States, particularly at the undergraduate level; the need to make a larger part of the American public sensitive to the interactions between technology and society; and the relationships among engineering curricula, advanced training, and international competitiveness. These issues, although important, are beyond the scope of this study. They should, however, form the bases for subsequent inquiries by other groups.

Specific recommendations derived from this study are as follows:

- Competitive fellowship programs for U.S. students in engineering should be evaluated to determine what stipends are needed to make graduate study an attractive, cost-effective alternative to immediate employment. This approach could provide a significant increase in the number of American engineering graduate students.[5]

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[5] See Committee on the Education and Utilization of the Engineer, Commission on Engineering and Technical Systems, National Research Council, *Engineering Education and Practice in the United States: Foundations of Our Techno-Economic Future,* Washington, D.C.: National Academy Press, 1985, pages 56-59.

- University officials should rigorously monitor language proficiency of all teaching personnel, especially teaching assistants, and insist that communication problems be resolved before individuals are placed in teaching positions.

- It has been suggested that some foreign-born engineering teaching assistants may discourage female and minority students from entering the engineering profession. Although there is anecdotal evidence both to support and to refute the existence of such discouragement, the implications are sufficiently serious to warrant efforts to develop a firmer factual basis for evaluating the validity of this issue.

- Although the Committee recognizes the need for necessary and appropriate security clearances, the U.S. Department of Defense should examine ways to make the most effective use possible of the foreign and foreign-born talent pool that is potentially available for defense engineering.

- Major efforts are needed to improve the scientific and mathematical content and standards of precollege education for a larger portion of the population. Such improved training would provide students with better preparation for intelligent citizenship in a highly complex, technological society. Also, better trained precollege students are more likely to enter both undergraduate and graduate technical studies, and this influx is likely to augment the number of highly qualified, U.S.-born graduate engineering students. This influx may be important in view of demographic changes that will reduce the traditional cohort populations of U.S. undergraduates.

- Efforts should be made to fill data gaps on career patterns of foreign students who have left the United States, on the international movements and interactions of American engineers, and on foreign applicants to engineering graduate education. We should also obtain quantitative data on the reasons that such large numbers of foreigners choose to come to the United States for graduate education in engineering.

- More extensive studies should be initiated to assess or determine the reasons for the failure of many qualified American engineering undergraduates to enter graduate studies; the appropriate engineering curricula for the 1990s and beyond; and the relationships among engineering, engineering education, the international flow of engineers, and international competitiveness.

BACKGROUND

In considering issues related to engineers of foreign origin, it is important to examine all aspects of the engineering personnel system that are or could be affected by their influx. There are basically three categories: foreigners--those who are not U.S. citizens; naturalized citizens--foreign-born immigrants who have acquired U.S. citizenship; and indigenous citizens--those born in the United States. The first two of these groups may be aggregated and represent the total number of foreign-born engineers in the system.

In industry, government, and universities, questions have been raised about the magnitude and impacts of both foreign and foreign-born engineering groups. The foreign (noncitizen) component accounted for only 3.5 percent of employed engineers in the United States in 1982, which is a slightly smaller proportion than in 1972. However, the reverse was the case for naturalized immigrant engineers, a group that grew from 5 percent in 1972 to almost 14 percent in 1982.[6] The largest fractions of foreign engineers were employed in 1982 in electrical or electronic engineering and in mechanical engineering, with representations of about 28 percent and 23 percent, respectively, of all foreign engineers.

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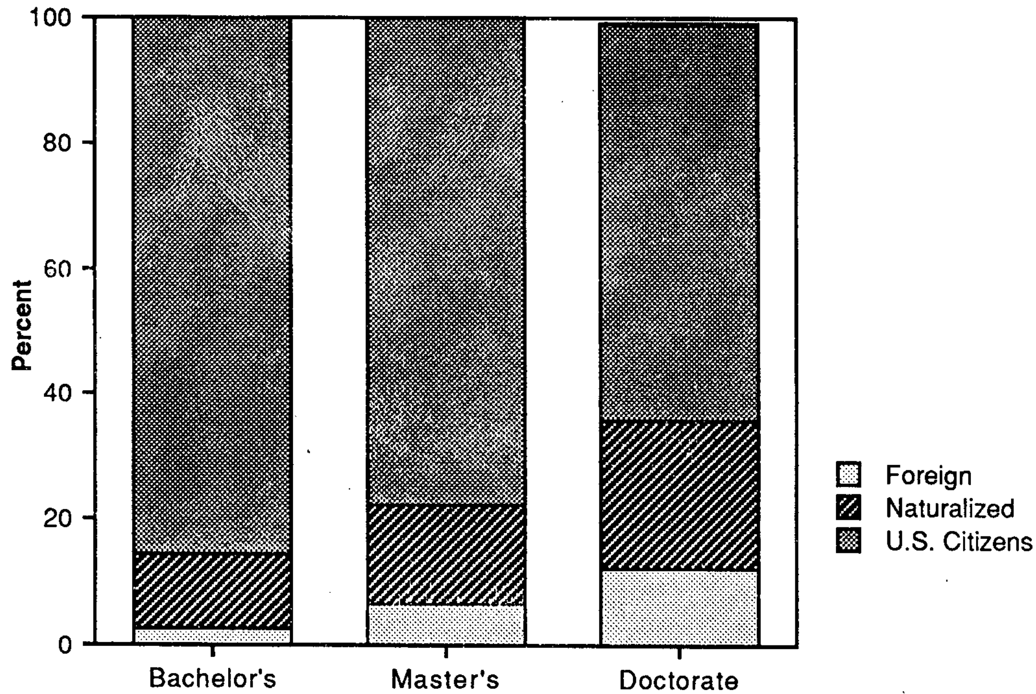
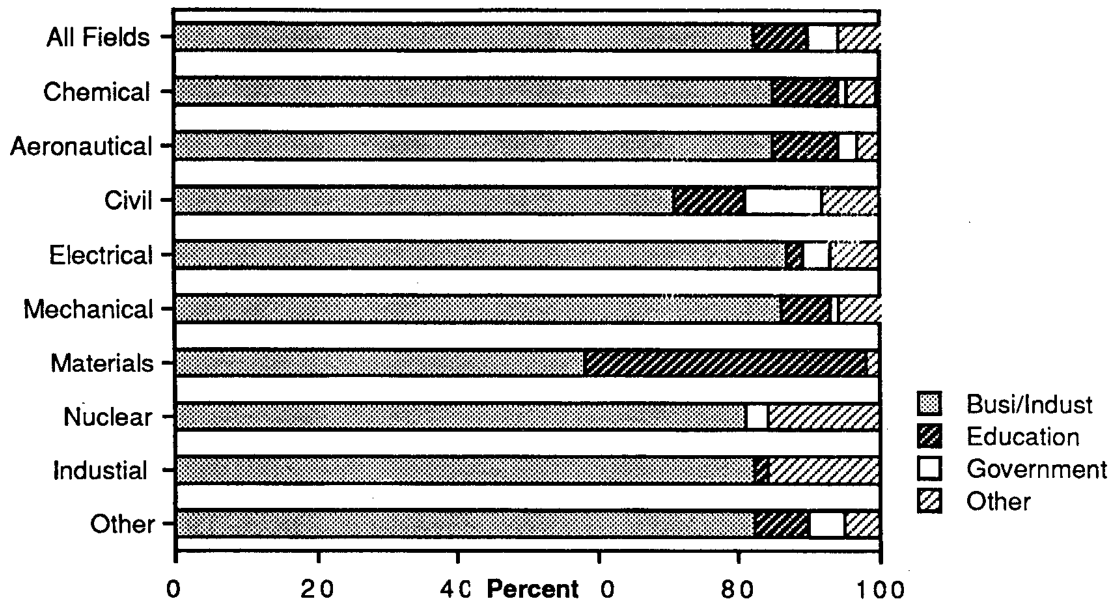
[6] The most reliable source of data on the foreign engineering labor force is the National Science Foundation's (NSF) Postcensal Survey, which was used in 1982 to survey a representative sample of the total U.S. science and engineering labor force in 1980. These data are preferentially used in this report. The NSF makes available more recent estimates, which are model-generated and based on updated surveys of the postcensal cohorts and a number of more recent surveys. The latter, however, miss recent immigrants and some recent graduates of U.S. universities, especially those without U.S. addresses. Where appropriate, the latest quantitative information from this model-generated information base (the latest is for 1984) is presented. It should be noted that most labor-force data refer to engineers employed as engineers. These numbers will always be smaller than those for all engineers, which include unemployed engineers and those not working in engineering occupations. The definition of "foreign" varies among different surveys. Thus, only the NSF data include among foreigners those with "permanent residence" visas. For all other data sources used in this report, "foreign" is equivalent to "nonresident alien."



NOTE: This figure includes only individuals reporting employment in engineering occupations in 1982.
SOURCES: Special tabulations from Oak Ridge Associated Universities, based on the National Science Foundation's 1982 Postcensal Survey.

FIGURE 1 Engineers in the U.S. labor force, by citizenship status and degree level, 1982.

The foreign engineering representation varies significantly according to degree level. Thus, the representation of foreign engineers becomes increasingly larger for holders of higher college degrees (see Figure 1). In 1982 the representation was small: 2.4 percent for baccalaureates, 6.4 percent for master's degrees, and 12.6 percent for doctorates. At the same time, the naturalized (foreign-born citizens) engineering population constituted 12.1 percent of baccalaureates, 15.9 percent of masters, and 23.8 percent of doctorates. Foreign-born engineers (i.e., naturalized and noncitizen engineers together) accounted in 1982 for 14.5, 22.3, and 36.4 percent of the holders of bachelor's, master's, and doctor's degrees, respectively. It is noteworthy that the percentages of noncitizens were about the same a decade earlier, while those of naturalized engineers had doubled since that time. Thus, in 1982, the United States depended significantly on the inflow of foreigners to supply its engineering labor force, especially at the doctoral level. Although we do not have definitive data for 1986, we suspect that the foreign-born population has become larger than in 1982, especially at the advanced degree level, and is increasing.

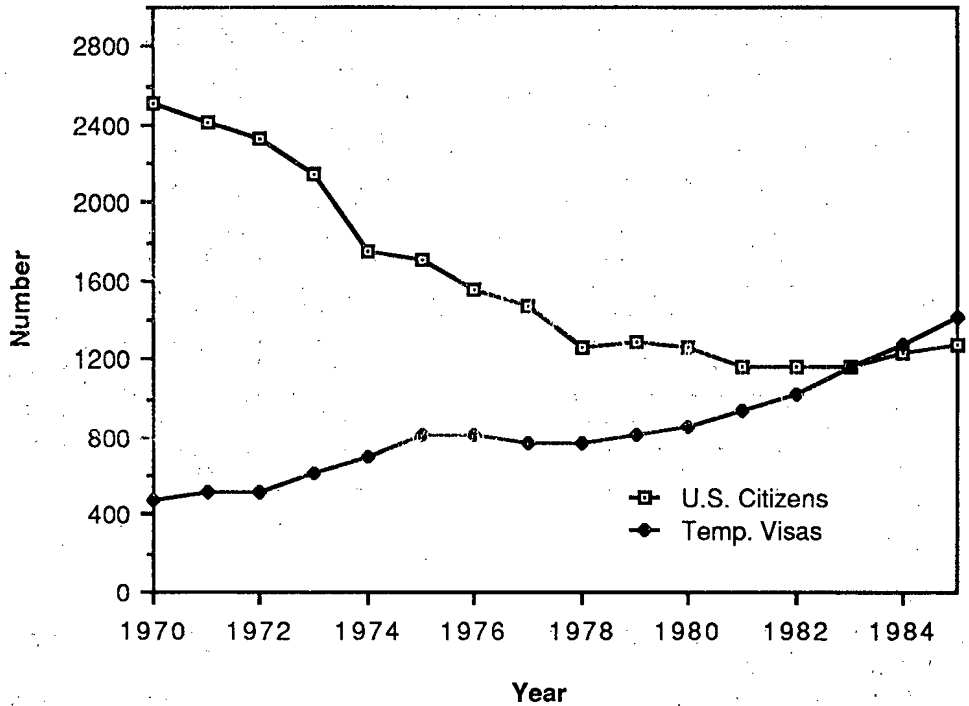


NOTE: This includes only individuals reporting employment in engineering occupations in 1982.
SOURCES: Special tabulations from Oak Ridge Associated Universities, based on the National Science Foundation's 1982 Postcensal Survey.

FIGURE 2 Distribution of foreign engineers, by sector of employment, 1982.

If we disaggregate the U.S. work force sector of employment (Figure 2), we see that most foreign and foreign-born engineers (82 and 78 percent, respectively) work in industry, as do their native-born counterparts. Recent surveys indicated that about half of the U.S. firms employing engineers have some foreign engineers among their employees, especially in R&D firms employing engineers.

Only about 9 percent of all of the foreign engineers and about 4 percent of the naturalized engineers were employed in 1982 in academia, and their proportions among all engineering faculty members were about 8.5 percent and 17 percent, respectively. The representation of foreign and naturalized engineers in the universities probably has increased rapidly in recent years. Among the primary 1982 work activities of foreign engineers were R&D, including R&D management (36 percent) and design (18 percent). This distribution was significantly different from that for U.S. citizen engineers, for whom these activities accounted for 24 percent and 13 percent, respectively.

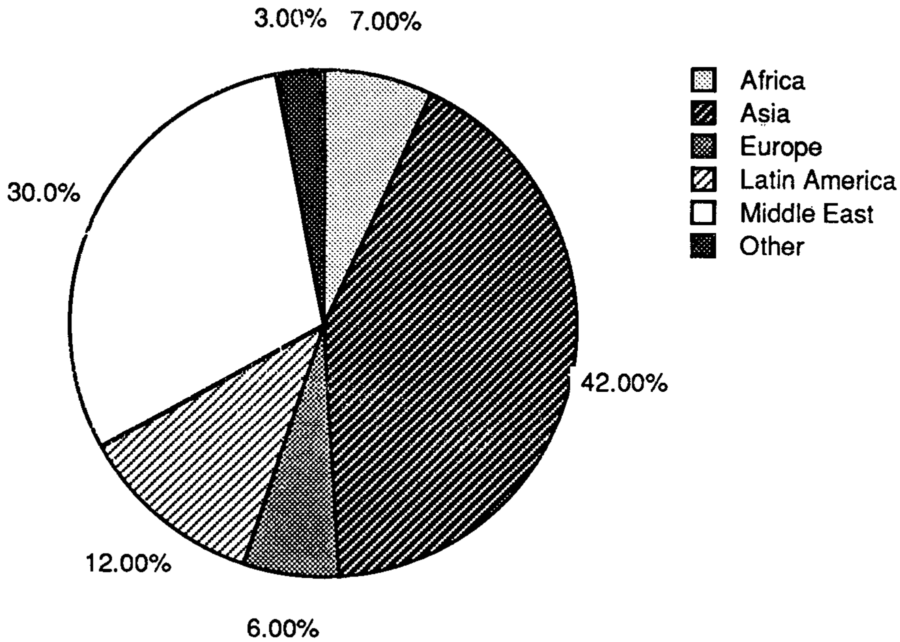


SOURCE: Unpublished tabulations from the National Research Council's Doctorate Records File.

FIGURE 3 Engineering doctorates awarded to U.S. citizens and those holding temporary visas, 1970-1985.

According to National Research Council data, a high proportion of new 1985 recipients of engineering doctorates had temporary visas (45 percent). Another 10 percent were on permanent visas. Of the 45 percent that were U.S. citizens, only about 4 percent were naturalized engineers. It should be noted that the proportion of foreigners among new doctorates has risen steadily while the number of U.S. doctorates (indigenous plus naturalized) has remained level since 1976 (Figure 3). Among 1985 engineering master-degree holders, the proportion of foreigners was only 27 percent.

It is interesting to identify the countries of origin of foreign engineers. In 1983-84, almost 75 percent of foreign engineering students came from the Far East, India, and the Middle East, with the Far Easterners and Indians together outnumbering the Middle Easterners by about 3 to 1 (Figure 4).



SOURCE: Institute for International Education, *Profiles, 1983/84*, New York: The Institute, 1985.

FIGURE 4 Foreign engineering students, by area of origin, 1983-84.

STAT

ISSUES AND FINDINGS

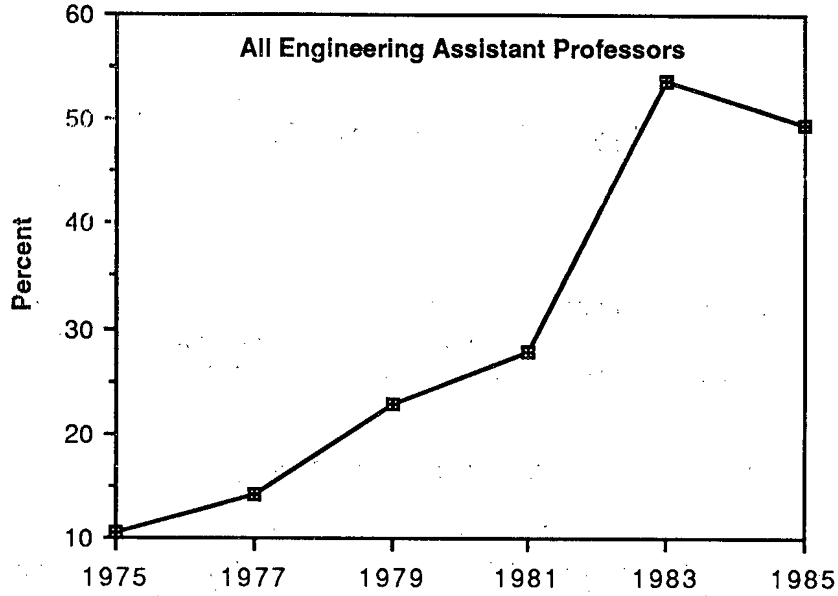
A number of issues emerged from the discussions of the Committee and presentations of invited speakers at a workshop sponsored by this Committee. These issues are developed more fully in this chapter.

Dependency of Institutions on Foreign Engineers

The production rate of U.S.-born engineers with doctorates is insufficient to meet the needs for qualified engineering faculty members in the universities and the requirements of industry and government. As a result, there have been rapidly growing noncitizen and naturalized American engineering populations in industrial organizations and, especially, in universities. In 1982, foreign engineers constituted about 3.6 percent of all engineers employed by industry, whereas 13.9 percent were naturalized. The proportions among engineering doctorates employed in industry were much higher: 15 percent were foreigners and 20 percent were naturalized. Thus, almost one out of three doctorate engineers employed in industry was of foreign origin, and that proportion is rising.

The influence of foreign-born engineers seems to have become profound in industrial research and development. This influence is especially apparent in disciplines that were considered of secondary importance in the United States some years ago but now stand at the focus of international competitiveness. An example is provided by innovations that have led to nonlinear optics and the associated applications of laser technologies. The Committee's survey of the R&D directors of 20 firms that account for a large fraction of the industrial technological output of the U.S. indicated that "their particular industries are, in fact, dependent upon foreign talent and that such dependency is growing." Several respondents stated that "foreign talent was a critical element of the firm's operations."

In universities, the dependence on engineers of foreign origin is even greater. Noncitizen and naturalized engineers constituted, in 1982, 8.5 percent and 17 percent, respectively, of all engineers employed in educational institutions. The increasing dependence in academe is dramatically portrayed by the fact that the proportion of noncitizen engineers among assistant professors younger than 35 years (Figure 5) has increased from 10 percent in 1972 to 50-55 percent in 1983-1985. About three-quarters of these noncitizen assistant professors have applied for U.S. citizenship. There were relatively few (5



SOURCE: National Research Council's Survey of Doctorate Recipients.

FIGURE 5 Foreigners as a proportion of all engineering assistant professors, age 35 or less, 1975-1985.

percent) naturalized engineering assistant professors in 1985. Further increases in the foreign and naturalized populations are likely to occur unless nonobjective selection criteria are adopted by the major research universities. The increase in noncitizen assistant professors of engineering is the result of the fact that, in recent years, foreign-born engineers received close to 50 percent of newly awarded engineering doctorates (naturalized citizens accounted for about 4 percent) and, furthermore, they entered academe in disproportionately large numbers.

Noncitizens represented almost two-thirds of the engineering postdoctorates in 1985. Noncitizen Ph.D. engineers often accept postdoctoral positions because other employment is unavailable until green cards are obtained. In several fields of engineering, the proportion of postdoctorates was greater than average; for example, in chemical and materials engineering, noncitizen engineers accounted for about 80 percent of the total postdoctoral populations.

Salaries paid to assistant professors of engineering have increased dramatically in recent years and are now comparable with, or superior to, those paid by industry, when allowance is made for summer-salary supplements and consulting income. In view of this dramatic improvement in salaries at major universities, it is not surprising to find large numbers of applicants for faculty openings at the research universities. Quoted numbers are 50 to 200 or more for each widely advertised position. The question arises why the normal academic selection procedures, when applied to openings for which there are so many potential applicants, have yielded a foreign and foreign-born component in excess of 50 percent, a component that is probably increasing. The answer may be found, at least in part, in faculty preferences for people with high analytical ability and/or particular skills in utilizing advanced instrumentation techniques and relative de-emphasis of what may be called the art of practical engineering as compared with engineering science. Thus, while maintaining "quality" in academe according to current preferences, the "character" of engineering education may well be changed dramatically. We believe that a careful assessment of the likely long-term impact of these changes forms an appropriate and urgent subject for evaluation.

Many of the noncitizen graduates with doctorates plan to remain in the United States. For example, among new 1985 noncitizen engineering doctorate holders, about 40 percent expected to work in the United States, a proportion that had increased from 11 percent in 1972. Furthermore, an additional 17 percent planned to stay on as postdoctorates, and most of these are also likely to remain permanently in the United States. Thus, almost 60 percent of new noncitizen engineering doctorate holders are likely to become part of the U.S. engineering labor force within a few years after graduation. Reliable data are not available for the other 40 percent of new noncitizen Ph.D. holders. Some of these probably return to the United States in later years, whereas others may be employed abroad in multinational firms. This type of information needs to be collected in order to determine their later contributions to the economic well-being and competitiveness of the United States.

It is apparent from these numbers that, without the use of noncitizen and foreign-born engineers, both research universities and industries would have difficulties in handling the educational, research, development, and technological programs that are currently supported. This must be realized in any governmental considerations to limit the inflow of foreign engineering students or graduate engineers.

Displacement of U.S. Engineers and Lowering of Salaries

The Committee addressed the issue of whether the ready supply of well-qualified, noncitizen engineering personnel constitutes an obstacle to U.S.-born engineers seeking engineering employment and tends to reduce salaries. Since noncitizen and naturalized engineers represent only about 3.5 percent of the total U.S. engineering labor force, their effect on job opportunities and salaries of U.S.-born engineers must be small, on the average. No data could be found to ascertain whether the same can be said about engineers working abroad for American firms, although anecdotal evidence indicates that a problem may exist in this regard.

The available data clearly show that U.S. citizens have generally been receiving preferential treatment for enrollment in engineering schools and for jobs. A number of universities limit their acceptance of foreign-student applicants, and most jobs in defense-oriented industries cannot be filled by noncitizens or even by immigrants with close relatives in foreign countries. Thus far, qualified U.S.-born engineers have not faced appreciably diminished opportunities in industry because of foreign-born entries. However, as we have noted, their entry into academe may well have been affected by the ready availability of highly qualified foreign engineers.

As for salary depression, a study of 13,000 engineers showed no support for the notion that foreign nationals with U.S. degrees earned less than their American colleagues. There was very weak evidence suggesting that noncitizen engineers without any degrees from U.S. universities might earn less. However, this is a small group, and the estimated earnings differential found was only about 3 percent.

Graduate Enrollments and Degrees

By 1985, the proportion of noncitizen full-time engineering graduate students was 42 percent. U.S. citizens (indigenous and naturalized) are present in relatively small and decreasing numbers because of declining U.S. male populations, difficulties in naturalization before completion of graduate training for foreign-born students, and fewer U.S. B.S. graduates choosing to enter graduate schools. In addition, large population groups--especially women, blacks, and Hispanics--have not entered either undergraduate or graduate engineering education in significant numbers. The many possible reasons for this disproportionately low representation require further study.

As we have noted, the international pool of applicants has become very large and includes carefully screened groups from major population centers in the Far East, India, the Middle East, and elsewhere. Qualified U.S. applicants to engineering graduate schools constitute a clear minority in this potential student pool and, even after substantial preliminary screening, the foreign-to-domestic ratio for qualified graduate student applications at major engineering schools is typically substantially larger than unity. Information received from selected engineering departments indicates that the ratio of noncitizen to U.S. applicants is much larger than the ratio of noncitizen to U.S. admissions. As a result, it is possible that the successful foreign-born applicants constitute, on the average, an intellectually superior group. With selected imposition of admission ceilings, the current representation of U.S.-born Ph.D. students in the U.S. graduate schools of engineering is typically 40 percent of the total. There are substantial disciplinary and regional variations from these averages.

At the undergraduate level, U.S.-born engineering students constitute upward of 90-95 percent of the student population, since most noncitizen candidates for engineering graduate schools are trained in their home countries.

Selections for admissions to U.S. graduate schools have been and continue to be made by committees dominated by older and, generally, native-born faculty members. However, the result of searching for the best-qualified applicants, even in an atmosphere characterized by clearly preferential treatment of U.S.-born applicants for graduate school admissions, has led to graduate schools of engineering with about 50 percent foreign-born graduate-student populations.

These changes represent both a potential opportunity and problem, depending on the point of view. The opportunity is the introduction into the U.S. population of highly intelligent, highly educated foreign-born engineers whose labors and achievements may be expected to exert a profound influence on our increasingly technological society for many years to come. This introduction of a population segment that may be well qualified to contribute to U.S. economic well-being and competitiveness in international markets is being accomplished at minimal cost to the U.S. consumers for the following reason: the vast majority of the new immigrants are being trained through the B.S. degree in their home countries. Using U.S. costs, the total investment in a B.S. degree from birth is probably about one-third of the societal cost for a supported (through a teaching or research assistantship) Ph.D. graduate. Since more than 60 percent of the noncitizen engineering Ph.D.s ultimately become U.S. citizens, the cost to the United States of producing this pool of professionally trained people is evidently considerably smaller than that for an equivalent pool of Ph.D.s with baccalaureates from American engineering schools. The Committee also notes that if there were only U.S. students, current excess capacity in graduate engineering programs would be even larger, making the current marginal costs of educating foreign students relatively low. Thus, in view of substantial positive contributions that are likely to be made by these graduates through professional activities characterizing highly trained engineering populations, it is easy to conclude that the worldwide attraction of the best engineering talent to the U.S. constitutes a desirable and cost-effective activity.

There are, however, some aspects of the changes that have been viewed by some as a source of concern. One of the basic strengths of the American system of engineering education has been and continues to be utilization of pragmatic solutions to engineering problems and its recognition of the importance of hands-on training in the design and operation of engineering systems. There is, however, a tendency for all disciplines to move toward more fundamental engineering science, which is considered by some to be more prestigious. This creates a special paradox for engineering schools, which want to share in the prestige conferred by doing what is most valued in a university but which also have a need to remain practical and applied. This tendency may have led to a preference of some engineering schools to hire from foreign countries junior faculty whose basic outlook is slanted toward engineering science rather than toward practice. The Committee has not made a detailed study of needed changes in engineering education. It is noteworthy that it is not at all difficult to find significant examples of immigrant engineers who are outstanding experimentalists and have demonstrated the highest skills of entrepreneurial ingenuity in high-technology industries and development.

If present trends continue, the number of foreign graduates in the ranks of junior faculty is likely to increase at an accelerating rate. There are two factors that clearly contribute to this growth. First, the difficulties in securing industrial employment before achieving immigrant status generally make the academic world more accessible to foreign engineers immediately after graduation. Second, requirements for U.S. citizenship and security clearances severely restrict the range and number of industrial positions that are open to foreign-born engineers.

Federal Regulations Concerning the Use and Employment of Foreign Engineers

The fact that more than one-third of engineers with new graduate (master's and doctorate) degrees are of foreign origin poses special problems for industrial organizations engaged in defense research. Many of these graduates, including those who become citizens, may encounter difficulties in obtaining security clearances and may, therefore, be unsuitable candidates for employment in defense-related industries and on defense-related contracts. Thus, for example, the operative size of new additions to the doctorate manpower pool for defense-related activities is effectively reduced, on the average, by about 60 percent from what it would be for a group totally composed of U.S.-born students and, in terms of available quality for certain critical disciplines, perhaps substantially more. The Committee was unable to identify ready remedial measures, other than perhaps continued astute screening of foreign and foreign-born graduates with close relatives in foreign lands prior to their employment in selected, relatively less sensitive areas of defense engineering.

Defense industries and some federal laboratories also find it difficult, if not impossible, to engage in collaborative efforts with university departments populated by noncitizen research assistants and faculty members. Security and export control regulations provide major barriers impeding beneficial interactions with laboratories working in sensitive, classified, or competitive industrial areas. This problem extends also to interactions between national laboratories engaged in defense work and industries with foreign nationals or naturalized U.S. citizens without proper security clearance.

Relative Performance of Foreign and Foreign-Born Engineers

Industry

Noncitizen engineers are reported to perform in the labor market about on par with their U.S. colleagues in terms of preparation, skill, and professionalism. However, an important exception is language skill. Persistent deficiencies in oral and written communication skills constitute a visible problem area that may contribute to the fact that foreign-born engineers may encounter problems in consumer-oriented businesses and also may be slow to reach upper management positions in industry. Noncitizen engineers do not appear to be entering upper corporate management in proportional numbers at the present time.

Academe

Some problems associated with both foreign-born faculty members and noncitizen teaching assistants (TAs) have their roots in differences in native language and perhaps also in cultural backgrounds, as revealed in three particular issues that arose during the course of this study. First, large numbers of foreign-born engineering graduate students serve as TAs in undergraduate classes at universities and colleges, and some of these students have inadequate command of the English language. In addition, U.S. universities include some distinguished professors who speak English poorly. Second, it has been stated to us that, because of their cultural backgrounds, foreign TAs may be providing disincentives for American students to major in engineering disciplines; this problem could even be exacerbated for minority and female students because of possibly persisting cultural attitudes that contribute to ineffective cooperation with these students by selected ethnic groups. We have not seen solid evidence to support this last supposition. Finally, in many foreign cultures, science and technology training may be slanted somewhat more toward engineering science than to practice. In the United States, there may be wider recognition of the importance of hands-on training in the design and operation of engineering systems and pragmatic solutions to engineering problems. Thus, there is some concern that if the orientation to engineering science were to become still more prevalent as a result of the large and growing ranks of new foreign faculty, the strength of American engineering education could be diminished. Although the Committee has not seen any hard evidence either to support or to refute the existence of these problems, we suggest that an awareness of their possible occurrence be maintained.

It is recognized that the disproportionately large entry of foreign-born engineers into U.S. faculty ranks represents the uncontrolled operation of normal university selection procedures stressing especially professional excellence in research and presumably also interest and competence in teaching. Questions have nevertheless been raised about the effectiveness of many of these people in the classroom. With regular student reviews of teacher and teaching assistant performance in universities now the rule rather than the exception, university officials should be able to monitor teaching performance and enforce appropriate standards of instruction.

The Committee notes that most foreign-born assistant professors have been trained in the United States and concludes, therefore, that possible language and cultural problems noted for teaching assistants should have become largely ameliorated during the normal 5- to 6-year periods spent in U.S. graduate schools. It is likely that the U.S.-trained foreign-born engineering faculty members of all origins will have become properly assimilated as the result of their graduate school experiences.

International Movements and Contacts of American Engineers

The Committee tried to identify problem areas, if any, relating to engineering employment of U.S. citizens abroad. Two types of foreign contacts were considered: study abroad and long-term visits involving collaborative studies or development. Only limited information was obtained. This aspect of the study clearly requires further work.

Data from the National Research Council's Doctorate Records File showed that very few new engineering Ph.D.s had plans to extend their studies abroad. Of the small number of U.S. citizens choosing postdoctorate appointments, only 16 selected study abroad in 1983, and these accounted for about 1 percent of all U.S. engineering doctorate recipients for 1983. This small percentage did not vary significantly during the previous 15 years.

Internationally coauthored articles are one type of indicator for collaborative efforts. Definite change toward international collaboration is clearly evident. In the areas of engineering and technology, the proportion of internationally coauthored articles increased steadily from about 13 percent in 1973 to almost 20 percent in 1982. This rise should be viewed in the context of the overall U.S. propensity for coauthored work, which is significantly lower than that for many other industrialized nations--namely, 18 percent for science and engineering in 1982 compared to about 40 percent for such countries as West Germany, the United Kingdom, and France. It should be noted that Japan and the Soviet Union had foreign participation percentages similar to those of the United States.

We recognize that international conferences provide ample opportunities for information exchange for highly visible groups of engineers and scientists.[7] However, there was considerable concern expressed at the workshop that long-term (6 months or longer) visits by American engineers with colleagues in other highly developed countries were inadequate, considering that much could be learned. This opportunity is perhaps not appropriately appreciated, especially by managers in industry, who must approve foreign travel and longer-term visits. The data base for this type of information is clearly inadequate and should be expanded.

The Committee believes that the international movement of engineers is an essential component of information transfer with significant impacts on technical development and international competitiveness.

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7 See also National Academy of Engineering, Committee on International Cooperation in Engineering, *Strengthening U.S. Engineering Through International Cooperation: Some Recommendations for Action*, Washington, D.C.: National Academy Press, 1987.

RECOMMENDATIONS

Inflow of Noncitizen Engineers and Engineering Students

For the reasons stated in the preceding sections, the Committee notes that continued entry and immigration of highly educated and highly motivated engineers and engineering students into the United States provides desirable opportunities and perhaps problems. If current trends require changes, these should be implemented through the objective replacement of noncitizen graduate-school applicants by equally competent or superior U.S. applicants. The present situation works to the advantage of the United States when viewed from the perspective that superior, highly trained, well-motivated people are being added to a critical component of our labor force, without ascertainable interference with comparable opportunities for qualified U.S. citizens, except possibly in the academic labor market. The dollar cost to the country for acquiring the services of these unusually gifted individuals is relatively low, substantially less than the real cost of bringing a U.S. citizen to the same level of training and performance.

The public at large may perceive the existence of a problem when native-born students do not participate in adequate numbers in prestigious, important, intellectually rewarding, and relatively well-paying occupations that are of key importance to national defense and economic well-being. That these developments have occurred at all clearly reflects faulty policies and serious deficiencies in the U.S. educational and value systems. Federal policies bear some of the responsibility for the shift in balance to foreign-born engineers. By reducing the number of graduate fellowships restricted to U.S. citizens and by supporting graduate studies instead through research assistantships that are generally open to all graduate students, federal policies have contributed to the decline of U.S.-born student populations in engineering in favor of increased foreign-born engineering student populations.

The Committee notes two drastic remedial measures--a short-term measure that will be almost immediately effective and a long-term approach. The latter would have the desirable goal of creating a technologically competent society that will function as a world leader in international competition, while guaranteeing high standards of economic well-being and intellectual achievements for its citizens.

Short-Term Changes: Increasing Fellowships With Adequate Stipends for U.S. Graduate Students

The size of the pool of B.S. engineering graduates with U.S. citizenship is much larger than the number who apply to engineering graduate schools. One reason for this dearth of U.S. applicants has been the lure of immediate employment at very attractive salaries. To overcome this barrier, we recommend the establishment of well-paying graduate fellowships in engineering for U.S. citizens with stipends that would be (nearly) competitive with attractive opportunities for immediate industrial employment after completion of undergraduate studies. Engineering faculty members have enjoyed differential salary scales that are generally higher by 10-20 percent, depending on rank, than those of their colleagues at comparable ranks in other disciplines. Such allowances, however, have been made rarely, if ever, for graduate students. In view of the existence of a lucrative competitive employment market and noting that engineering graduate students are embarking on a lengthy and demanding career that is not overtly more desirable than early industrial employment, inducements may be needed to retain in academe some of the best of the B.S. graduates. A careful cost-benefit assessment of augmented stipends for indigenous graduate students of engineering has not been available to the Committee and should be performed.

It should be noted that the job market for engineering graduates changes periodically and that there are indications that some deterioration has taken place during the last 2 years. Nevertheless, nearly all baccalaureate holders who seek employment as engineers still seem to be able to obtain good engineering jobs. In implementing any newly recommended fellowship program, employment markets should be monitored and recommended programs changed appropriately if supply-demand relationships change.

The Long-Term Solution: Augmented Engineering Education for U.S. Students

The long-term solution is far more costly and will be far more difficult to implement. The long-term solution is a significant improvement in our entire educational system, from kindergarten through college, with students required to prepare themselves for intelligent citizenship in a highly complex technological society. The result, within a period of 10-15 years, will be a student body with much better background and interest in mathematically, scientifically, and technologically oriented subjects. The Committee believes that this development is likely to have two effects. First, it will probably produce a considerably larger number of undergraduate engineering students. Furthermore, it should produce a larger proportion of baccalaureate holders interested in graduate studies in engineering. At that point in time, any special fellowship program for superior U.S. graduate students should be phased out, and retention of superior foreign-born participants may also be reduced.

For an advanced technological society, engineering education should be viewed not only as a necessity for professional training but also as a cultural requirement for many other occupations. This desirable goal can only be achieved by raising the general level of engineering competence for all citizens.

Monitoring of Potential Problems Among Noncitizen Faculty and Teaching Assistants

It has been noted that significant language problems among noncitizen or foreign-born teaching assistants and faculty members may provide disincentives for U.S.-born students to learn effectively and even to major in engineering. This problem can be controlled by the proper monitoring of teaching performance through reviews. We suggest that university officials monitor student teaching reviews in order to detect and correct unusual problems, should they arise. This important function should probably be removed from the jurisdiction of individual departments, where it normally resides, and transferred to a central administrative office that is charged with the responsibility of enforcing the highest standards of excellence in instruction at all levels.

Trends in Engineering Education and U.S. Competitiveness in International Markets

A tacit assumption made in our evaluations is that engineering education plays a key role in ensuring international competitiveness. This tenet is unproved and cannot represent the entire story, or even a major part of it, because economic dominance was lost while engineering education (as measured in terms of numbers of faculty members involved, publications, research, budgets, and Ph.D.s trained) remained supreme in the world.

The suggestion has been made that U.S. engineering education does not respond properly to current needs and requires drastic revitalization of the type that occurred in the 1950s, when broadly based engineering-science curricula were first introduced. Just what this revitalization should involve is properly the subject of another study. Referring to items that may be important in economic competitiveness, it is certain that most U.S. engineering curricula are deficient in training in design, manufacturing, and economic evaluations, as well as proficiency in foreign languages. The first two of these deficiencies are currently made up, to some extent, by bringing from industry to the universities lecturers who are experts in these disciplines. More systematic efforts of this type should clearly be made.

Some people have argued that U.S. economic competitiveness in high-technology fields may be enhanced by the establishment of Engineering Research Centers that are designed to achieve excellence in targeted areas of research and associated applications. These centers often involve both U.S. and foreign companies as sponsors and will, of course, be populated by Ph.D. graduate students of whom currently a majority are of foreign birth. As we have noted, approximately 80 percent (about 45 percent U.S. citizens, 10 percent foreigners with permanent visas, and about 60 percent of the 45 percent foreign students with temporary visas) of the Ph.D. graduate students trained in these centers will ultimately remain in the United States. Assessment of the impacts of the Engineering Research Centers on international competition will require long-term monitoring.

University graduate-engineering curricula have tended to stress engineering science, especially at major research centers. As we have repeatedly noted, this emphasis may be further increased because the young, foreign-born engineers who are being added to the university faculties in large numbers often excel in engineering science rather than in engineering practice. That this is a matter for concern is certain, and that it is widely recognized as a potential problem is illustrated by presentations to this Committee and by discussions at its workshop relating to the need for a reevaluation of engineering education at both the undergraduate and graduate levels.

We strongly recommend an independent examination of trends in U.S. engineering education and their likely impact on U.S. economic well-being and competitiveness in international markets.

Data Gaps

There are considerable data on foreign engineers and engineering students in the United States. Nevertheless, major data gaps remain concerning the movement of engineers to and from the United States. Specifically, there seems to be no quantitative information on career patterns of foreign students who left the United States. We should know how many of these students returned to this country in order to assess whether the subsidy provided to their education produces a benefit to the United States at some later point in time and also to enable researchers in the United States to make long-term projections about the supply of engineers in our work force. Furthermore, for those who did not return, we should have some insights as to whether the American study exposure proved beneficial to the country of their subsequent residence, whether they achieved positions in which they could further economic or cultural cooperation with the United States, and whether their subsequent positions could harm American economic or military security through undesirable technology transfer. Career data are also unavailable for Americans who spent long periods abroad in professional activities--such as research, postgraduate or postdoctoral studies, long-term visits with industrial colleagues, or assignments at foreign locations of multinational companies--before returning to the United States.

The follow-up data on foreign students who have left the United States could be developed by using techniques already utilized in at least one existing survey. Specifically, the National Science Foundation's Survey of Recent Graduates obtains addresses of bachelor's and master's graduates after they have left the universities and then uses these in a mailed survey. While this technique has been used primarily to trace and survey those graduates who have stayed in the United States, there is no reason to believe that it cannot be used for graduates who leave the country. The same method could be used with the National Research Council's Survey of Earned Doctorates to develop follow-up data for Ph.D.s who are no longer residing in the United States. While applications of this method would undoubtedly be somewhat more difficult and expensive in foreign countries, it seems quite feasible, at least for recent graduates. Whether it could be used for individuals who graduated several years ago has to be tested. However, with continued address updating, even applications limited to new graduates would establish a data base for older graduates after several years.

As for data on the extent of foreign exposure of American engineers, feasibility studies would have to be undertaken to ascertain whether one could obtain such data from surveys of American employers (universities, industrial companies, and government agencies). Since American passports can be used freely for foreign travel without any information being collected on specific trips, it is not possible to obtain data from the U.S. Department of State. However, it may be possible to get data from those governmental agencies of other industrialized countries that handle information on incoming foreign visitors, be it in the form of visa applications or landing cards. Should employer surveys prove to be infeasible, surveys of individual engineers could be carried out; however, these would require relatively large samples and, thus, could be quite expensive.

Although it is our view that the policy issues that we have identified and discussed will not be substantially changed by improved data inputs on the international movement of engineers, efforts should nevertheless be made to supplement the existing data base in order to provide inputs and needed information that may be useful in a definitive future evaluation dealing with the nature and impact of the international movement of engineers.

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APPENDIX A
FOREIGN ENGINEERS AND ENGINEERING STUDENTS IN THE UNITED STATES

Charles E. Falk

CONTENTS

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HIGHLIGHTS

Introduction

The data presented here were compiled from existing publications and special tabulations prepared for this study by the National Research Council, the National Science Foundation (NSF), the Institute for International Education, Oak Ridge Associated Universities, and the American Association of Engineering Societies. The unfailing cooperation and assistance of these organizations are greatly appreciated.

The most reliable data source on the foreign-engineer labor force is the NSF's Postcensal Survey, which in 1982 surveyed the total 1980 U.S. science and engineering labor force. Consequently, these data are generally used to describe distributional characteristics. The NSF also generates more recent estimates, which are model-generated and based on updated surveys of the postcensal cohort and a number of other more recent surveys. The latter, however, do miss recent immigrants and some recent graduates of U.S. universities, especially those that do not have American addresses. Where appropriate, the latest quantitative information from this model-generated information base (the latest is for 1984) is presented.

It should be noted that most labor force data are for engineers employed as engineers. These numbers will always be smaller than those for all engineers, which include unemployed engineers and those not working in engineering occupations.

The definition of "foreign" varies between different surveys. Thus, only the NSF data include foreigners with "permanent residence" visas. For all other data sources used in this report, "foreign" is equivalent to "nonresident alien."

Labor Force

Only about 3.3 percent of all engineers employed in the United States in 1982 and 1984 were foreign nationals. The proportion varied from a high of about 5.2 percent in chemical engineering to a low of about 2.7 percent in industrial and aeronautical engineering (Figure A-1). In 1972 the proportion of foreign engineers was slightly higher--4.2 percent. In absolute terms, in 1982 the greatest number of foreign engineers were in electrical/electronics engineering and in mechanical engineering--about 28 and 23 percent, respectively, of all foreign engineers. The Immigration and Naturalization Service reports that 8,100 engineers immigrated to the United States in 1985 (Figure A-2).

In 1982 the representation of foreign nationals among employed doctorate and master's engineers was considerably higher (about 12 and 6.4 percent, respectively) than among baccalaureate holders (about 2.4 percent) (Figure A-5). These proportions were also slightly lower than those in 1972 (15 and 7.5 percent, respectively).

In order to judge overall foreign impact, it should be noted that in 1982 about 14 percent of employed engineers were naturalized citizens. This proportion varied from a low of about 12 percent for industrial engineers to a high of 17 percent of civil engineers (Figures A-3 and A-4). However, these proportions were much larger than their equivalents in 1972, when, for example, the proportion of all naturalized engineers was only 5.2 percent.

The presence of naturalized engineers is even more pronounced in the advanced-degree labor force (Figure A-5)--16 percent among master degree holders (only 7.2 percent in 1972) and 24 percent among doctorates (only 11 percent in 1972).

The greatest concentration (proportion of all engineers in a sector) of foreign engineers in 1982 was found in educational institutions (8.5 percent), the smallest in government (1.2 percent). However, in absolute terms, by far the greatest number of foreign engineers--about 80 percent of all--were located in industry (Figures A-6 and A-7). Among the most predominant primary work activities (Figure A-8) of foreign engineers in 1982 were R&D, including R&D management (36 percent) and design (18 percent). This distribution was significantly different from that of U.S.-citizen engineers, for whom these activities accounted for 24 and 13 percent, respectively. In terms of concentration, foreign engineers were most evident in teaching (8 percent) and R&D (5 percent) while comprising 2-4 percent in each of the other activities (Table A-5).

Academe

About 22 percent of foreign students in American universities study engineering, and this proportion has not changed significantly over the last 30 years (Figure A-12). Between 1955 and 1980 the number of foreign engineering students increased steadily by about a factor of 10 but has remained fairly constant at 75,000 since then (Figure A-13).

Most foreign engineering students came from Asia (42 percent) and the Middle East (30 percent) in 1983-84 (Figure A-15). Among undergraduate students they represented only about 7 percent in 1985 (Figure A-18). More than 40 percent of foreign engineering students are engaged in graduate studies (Figure A-14), and they constituted over 40 percent of all full-time engineering graduate students in doctorate-granting institutions in 1985 (Figure A-20). Foreigners with temporary visas received about 8 percent of baccalaureates, 27 percent of master's degrees, and 41 percent of doctorates granted by U.S. engineering schools in 1985 (Figure A-19). In 1985 the leading countries of origin of foreign recipients of doctorates from American universities were Taiwan, India, and Korea (Figure A-17).

About 57 percent of foreign graduate students, as compared to 47 percent of American graduate students, get their primary financial support from research assistantships. Similarly, about 15 percent of the foreign graduate students, compared to 8 percent of the Americans, obtain their main support from teaching assistantships (Figure A-22).

Two-thirds of engineering postdoctorates were foreign in 1985, with the greatest proportion (81 percent in metallurgical/materials engineering and the smallest (57 percent) in electrical engineering (Figure A-24).

About 60 percent of the 1985 foreign engineering doctorates had firm plans for postdegree activities. About 84 percent of permanent visa holders and 39 percent of those with temporary visas expected to have employment in the United States. This proportion was much greater than the 56 and 11 percent, respectively, who indicated planned U.S. employment in 1972 (Figure A-26). The situation was similar for master's degree recipients and a little less (42 percent) for baccalaureates in 1982 (Figure A-27).

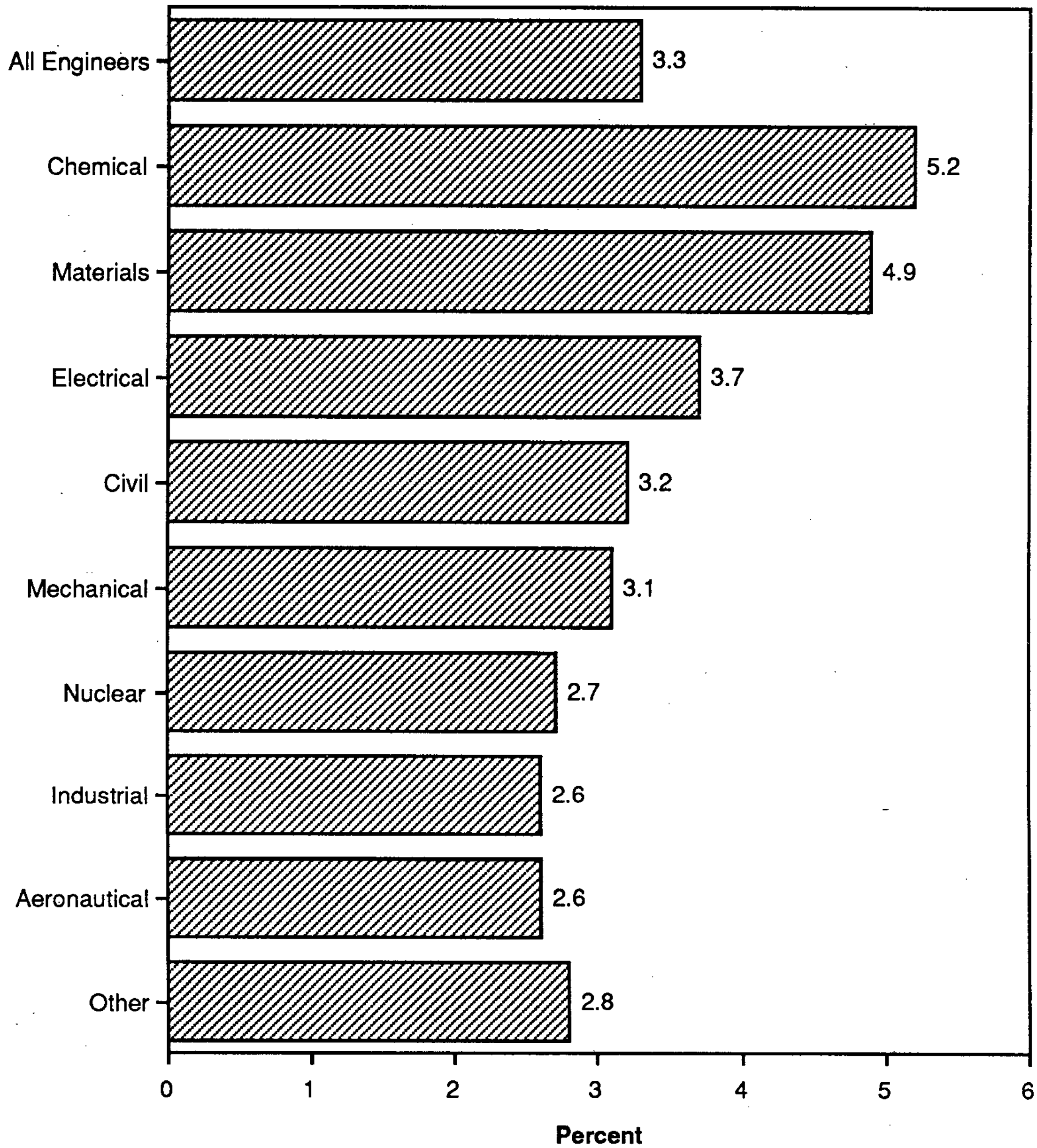
About 14 percent of doctorate faculty in engineering schools were foreign (both temporary and permanent visas) in 1986. This proportion was about the same in the subfields (Figure A-28). However, almost 50 percent of all engineering assistant professors, age 35 years or younger, were foreign--a fivefold increase over the last 10 years (Figure A-29). The proportions were much higher in some fields, such as electrical/electronics (83 percent), industrial (76 percent), and chemical (69 percent) engineering. Mechanical engineering showed only a 19 percent presence of foreign assistant professors.

Industry

In 1982, 82 percent of all foreign engineers in the United States worked in industrial organizations, where they represented 3.6 percent of all engineers (Figure A-7).

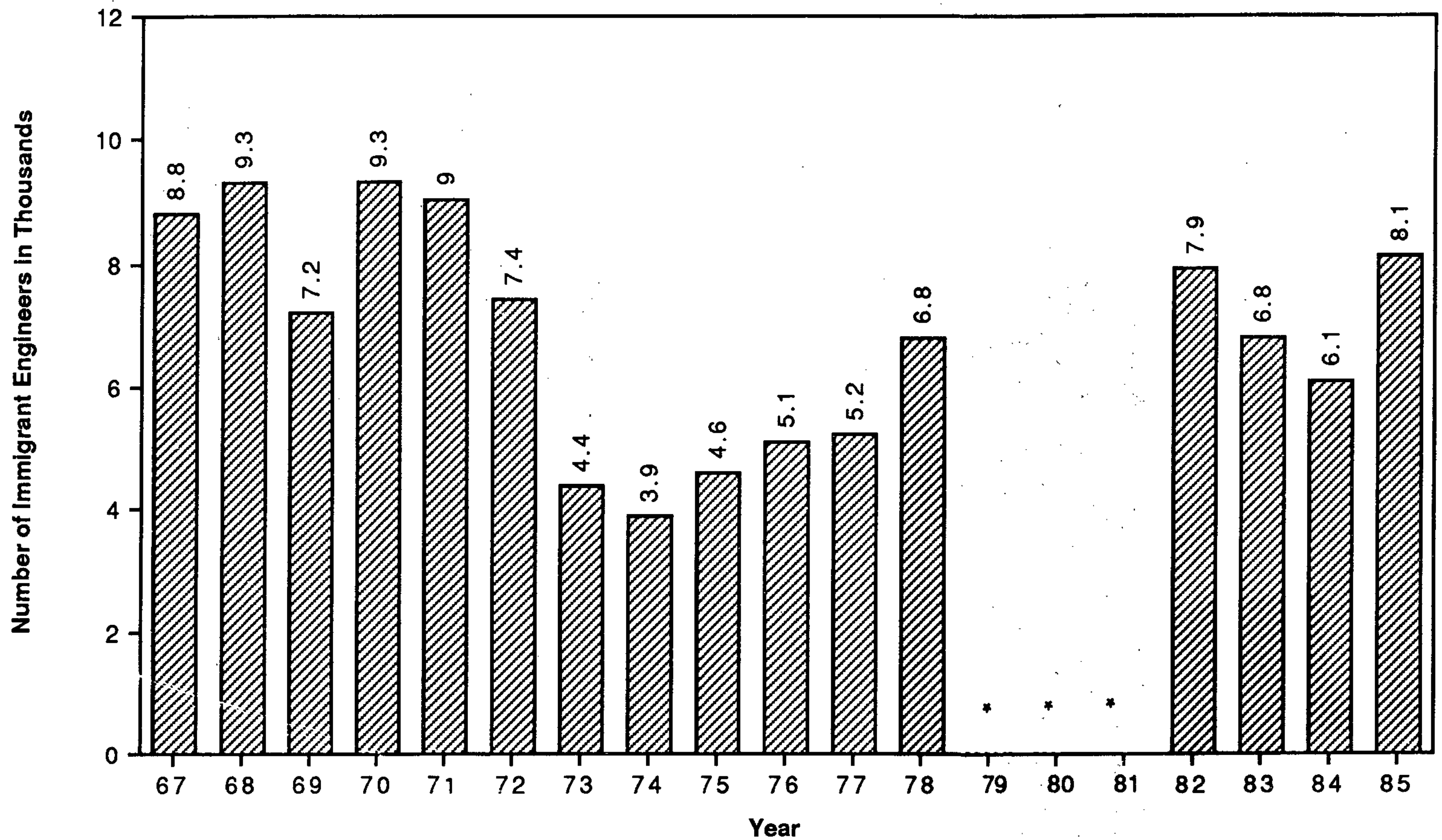
About 50 percent of a representative sample of all industrial firms employed foreign engineers in 1985. Among major employers this proportion, as shown in Figure A-9, varied from more than 70 percent in R&D laboratories to 43 percent in mechanical/transportation equipment industries.

Foreign citizens represented 8 percent of recent industrial hires in 1985. Among major employers, this proportion varied from 14 percent in computer/electronics firms to 7 percent among chemical/drug firms (Figure A-10).



NOTE: Includes all individuals reporting employment in 1982.
SOURCES: National Science Foundation, *U.S. Scientists and Engineers, 1984*, Washington, D.C.: U.S. Government Printing Office, 1985.

FIGURE A-1 Proportion of foreign engineers in the U.S. engineering labor market, 1984.



* Data are not available.
SOURCES: National Science Foundation, *Immigrant Scientists and Engineers: 1985*, Washington, D.C.: U.S. Government Printing Office, 1986; U.S. Immigration and Naturalization Service.

FIGURE A-2 Immigration rates of engineers, 1967-1985.

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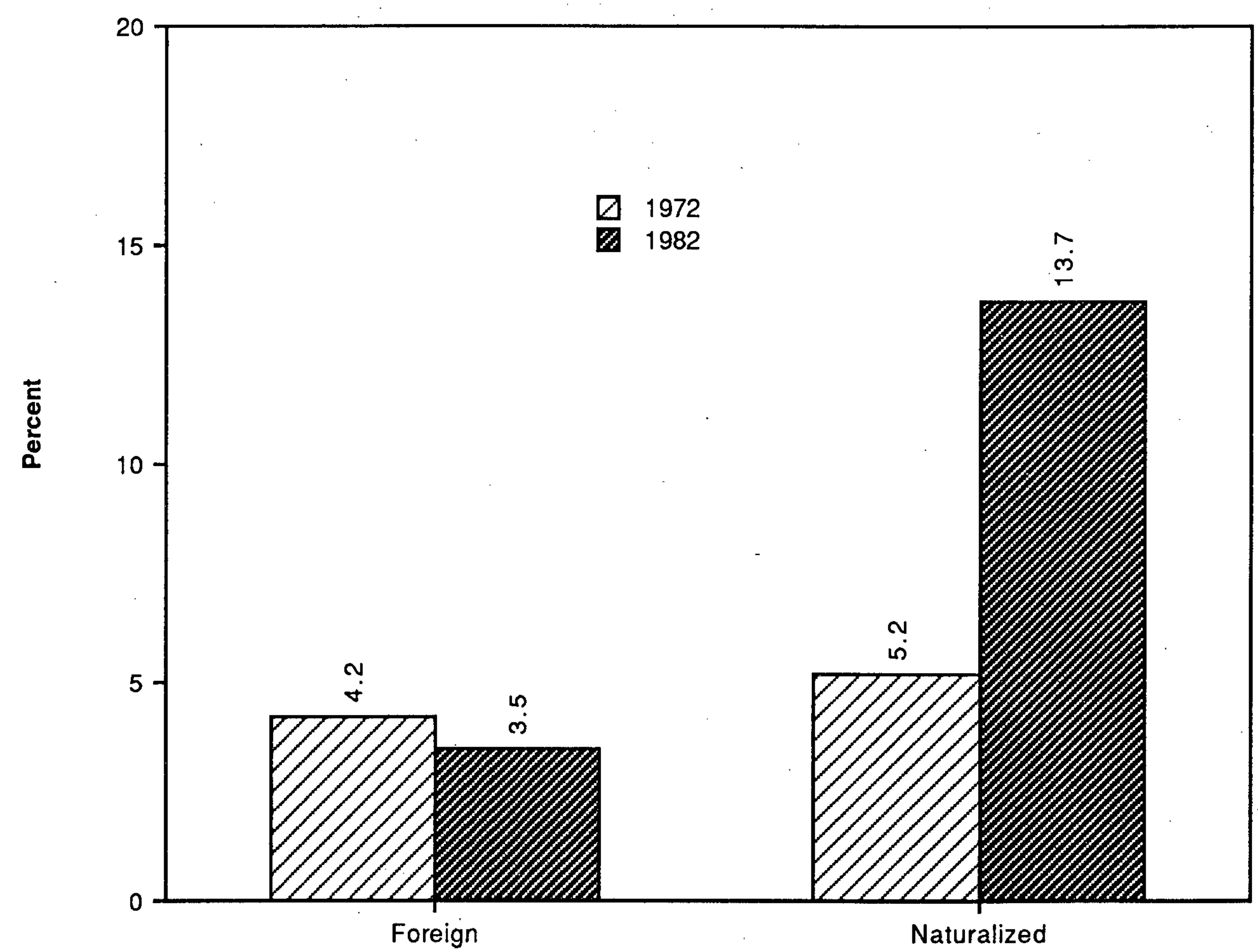

SOURCES: National Science Foundation, *U.S. Scientists and Engineers, 1984*, Washington, D.C.: U.S. Government Printing Office, 1985.

FIGURE A-3 Nonnative-born engineers in the U.S. labor force, 1972 and 1982.

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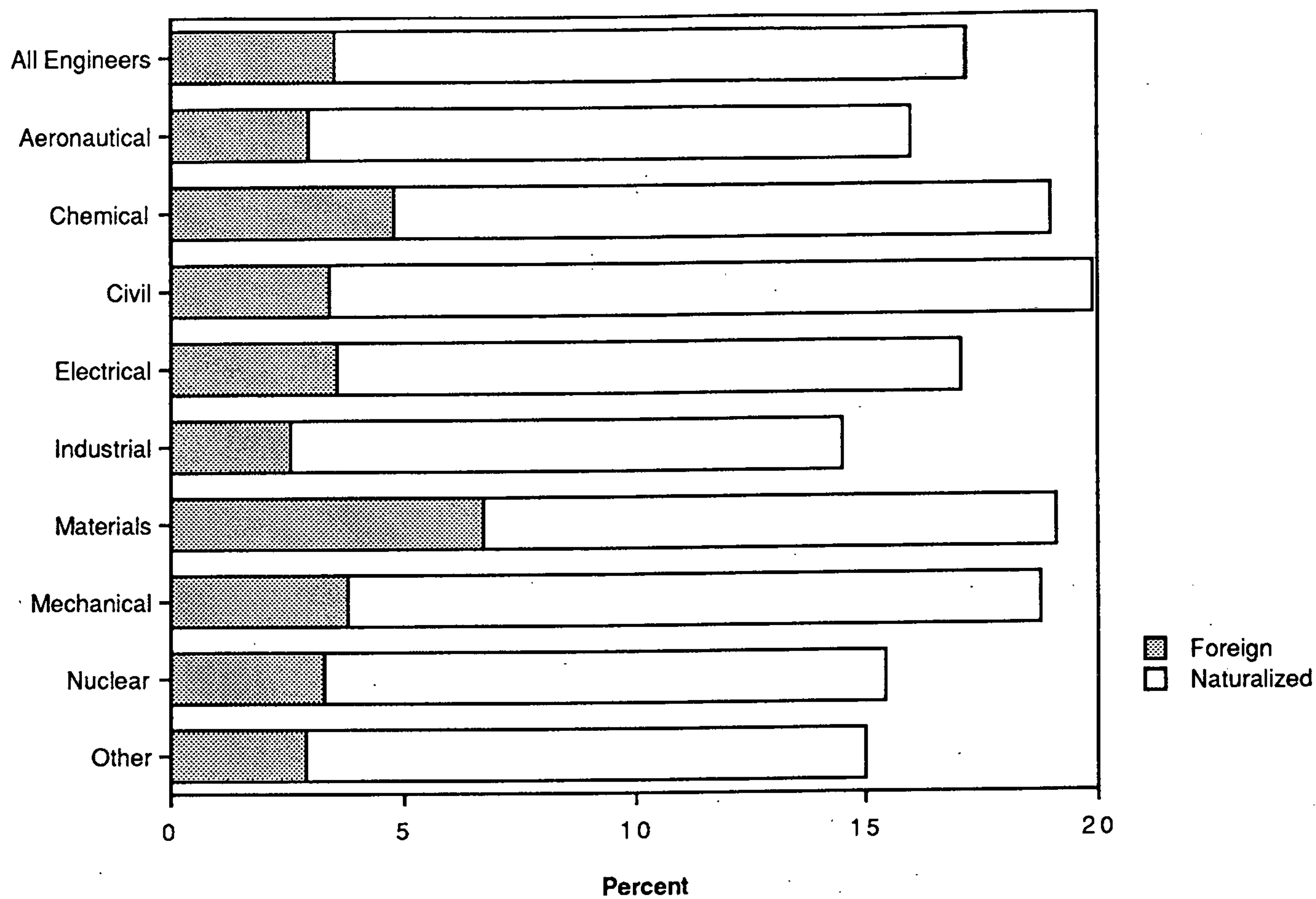

NOTES: Includes only individuals reporting employment in engineering occupations in 1972 and 1982 (see Table A-1).
SOURCES: Special tabulations from Oak Ridge Associated Universities, based on National Science Foundation's 1972 and 1982 Postcensal Surveys.

FIGURE A-4 Employed engineers, by field and citizenship status, 1982.

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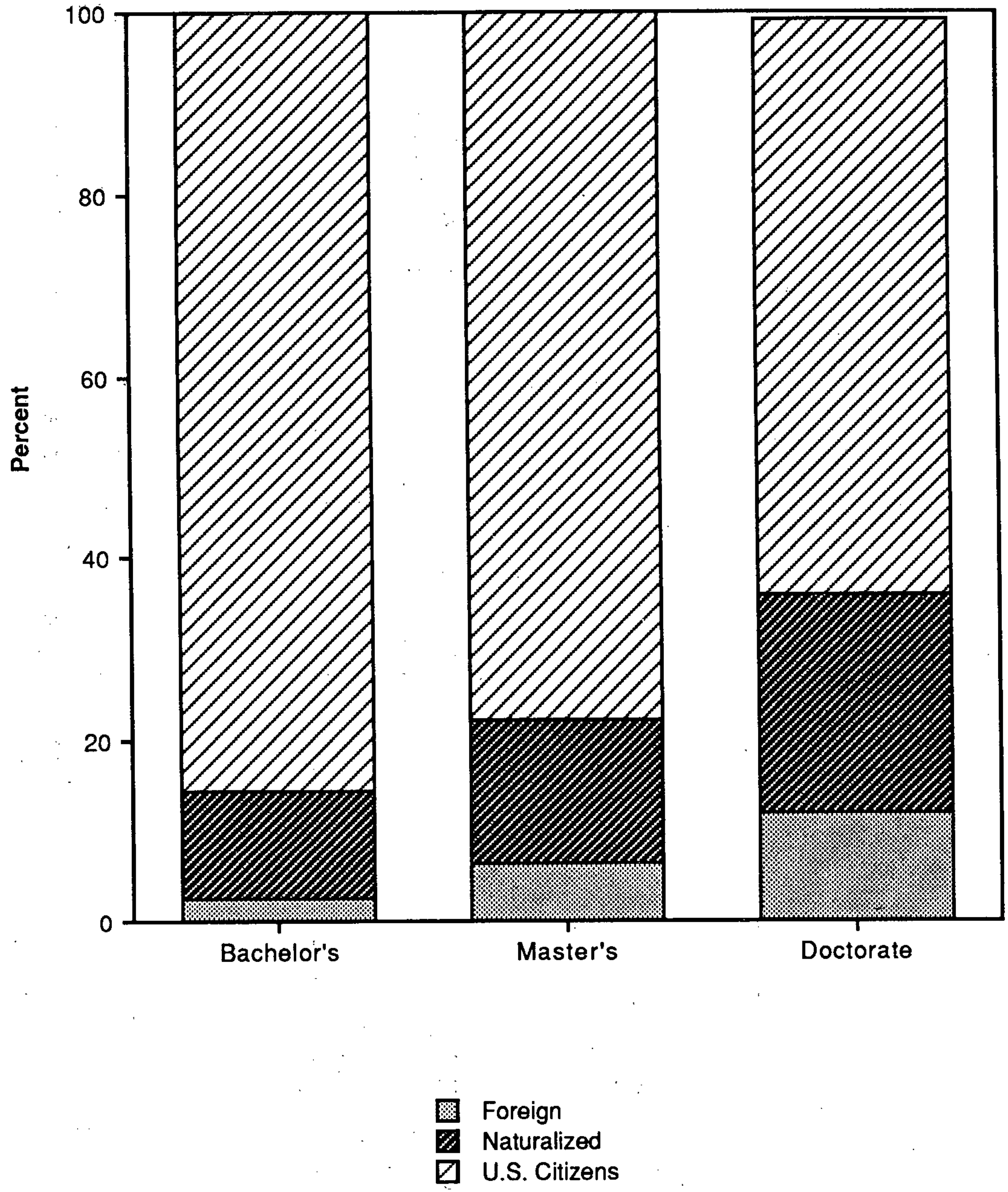
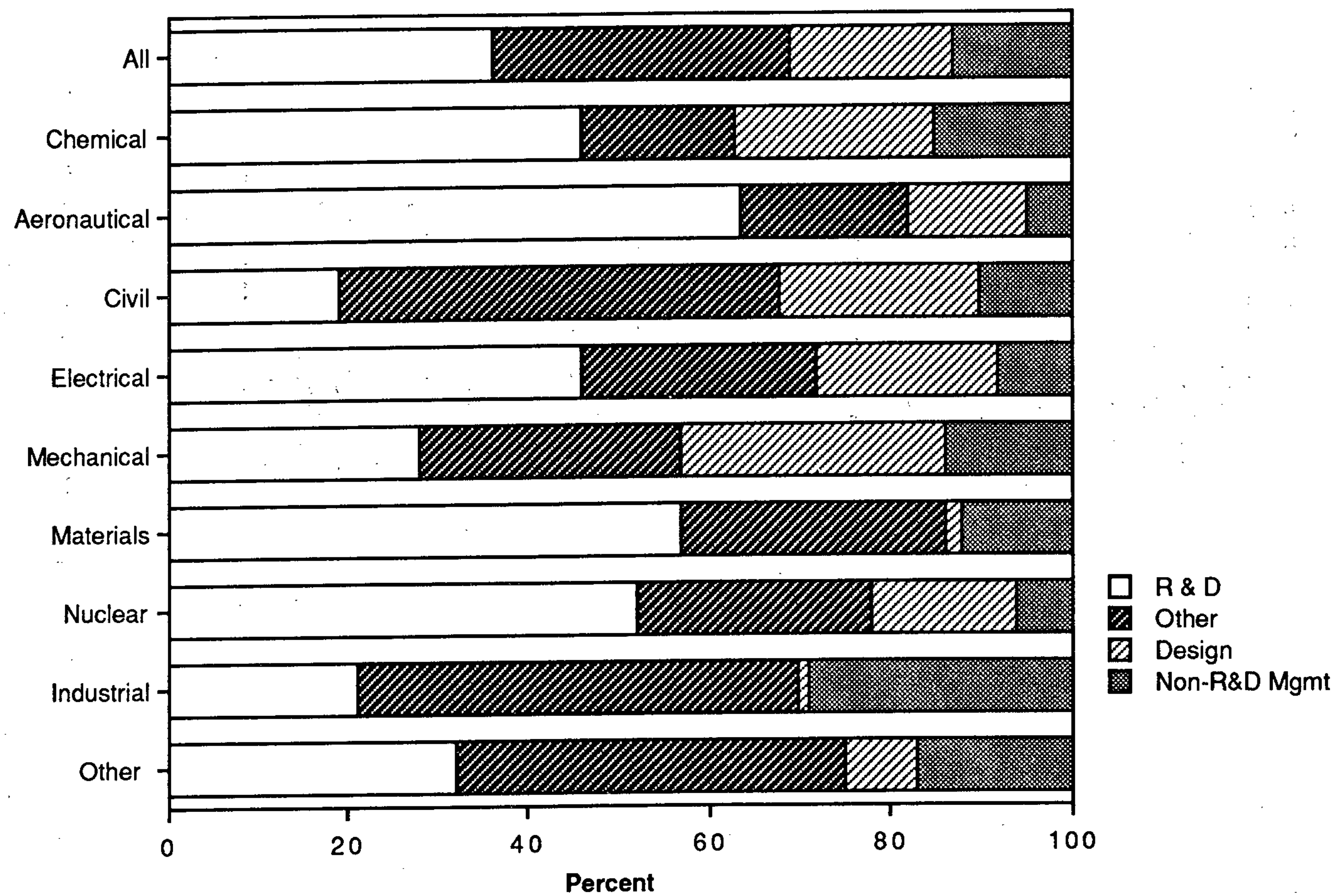


NOTE: Includes only individuals reporting employment in engineering occupations in 1982 (see Table A-2).
SOURCES: Special tabulations from Oak Ridge Associated Universities, based on National Science Foundation's 1982 Postcensal Survey.

FIGURE A-5 Foreign engineers in the U.S. labor force, by degree level, 1982.



NOTE: Includes only individuals reporting employment in engineering occupations in 1982 (see Table A-3).
SOURCES: Special tabulations from Oak Ridge Associated Universities, based on National Science Foundation's 1982 Postcensal Survey.

FIGURE A-6 Foreign engineers, by sector of employment and field, 1982.

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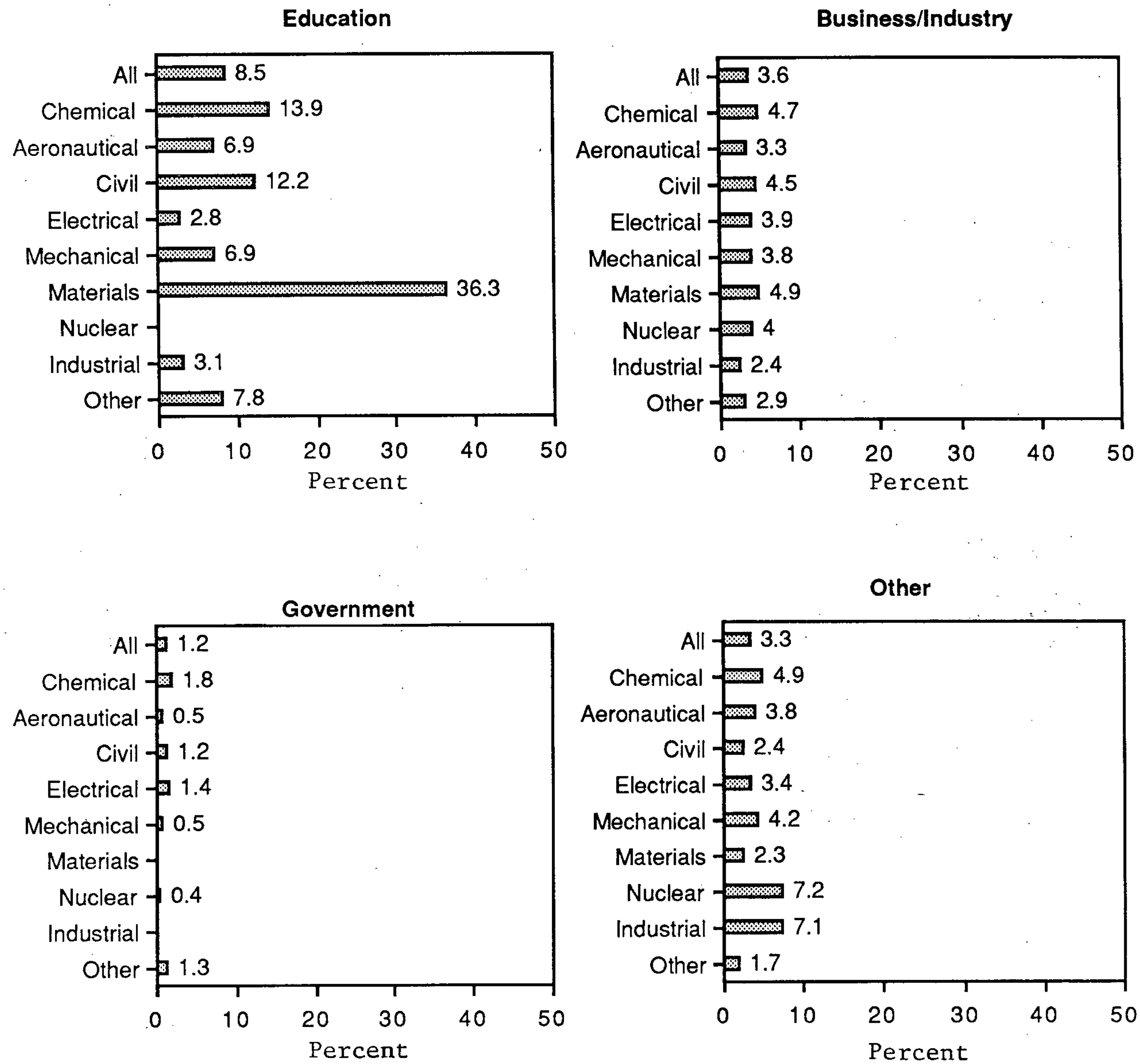
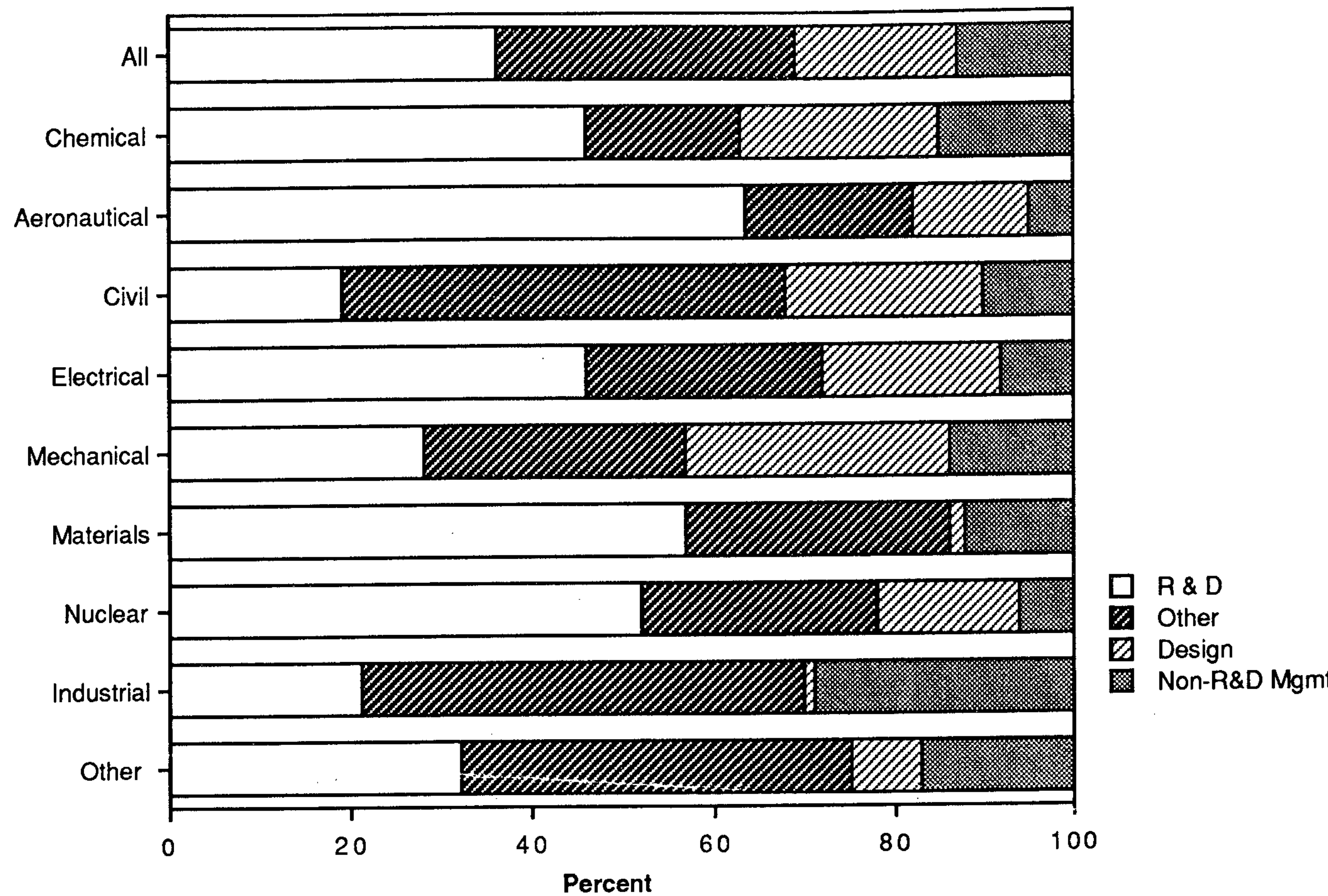


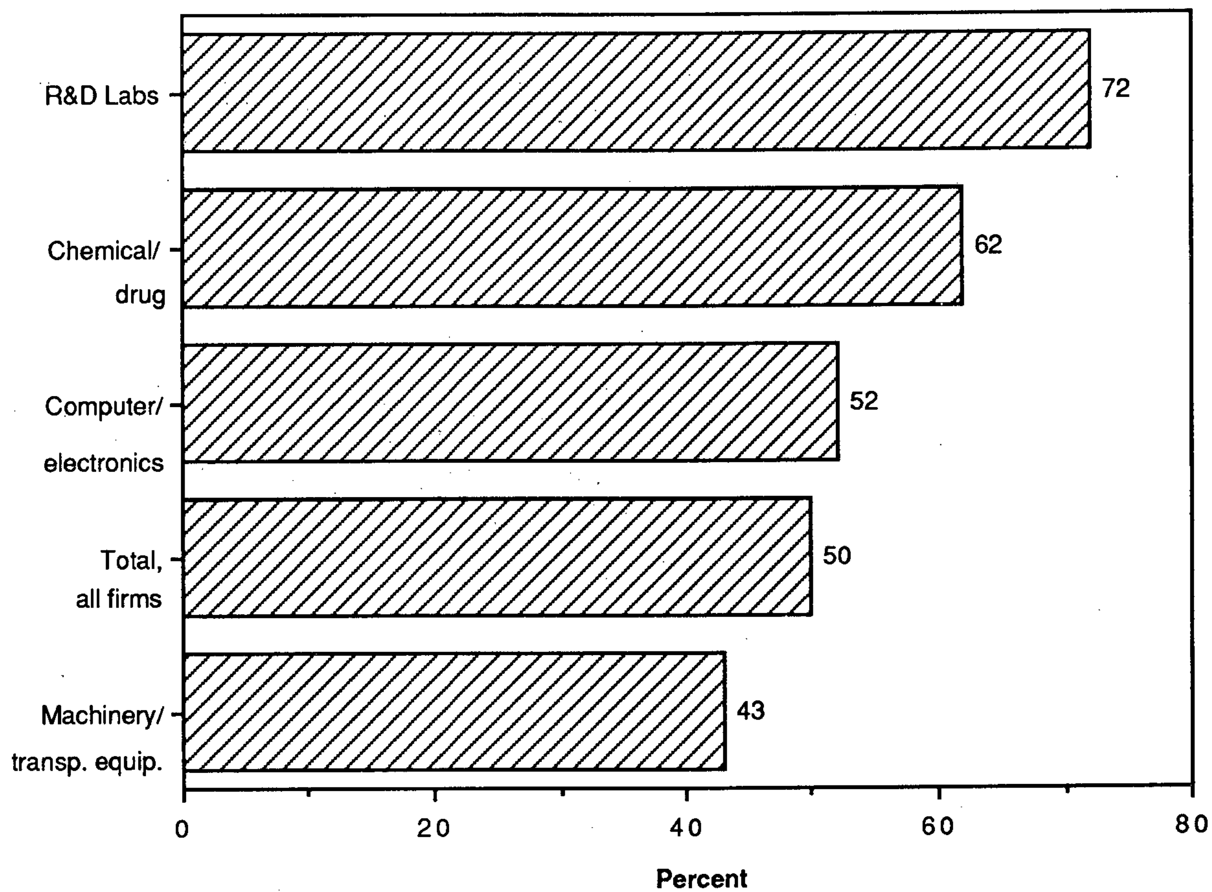
NOTE: Includes only individuals reporting employment in engineering occupations in 1982.
SOURCES: Special tabulations from Oak Ridge Associated Universities, based on National Science Foundation's 1982 Postcensal Survey.

FIGURE A-7 Proportion of foreign engineers, by sector of employment and field, 1982.



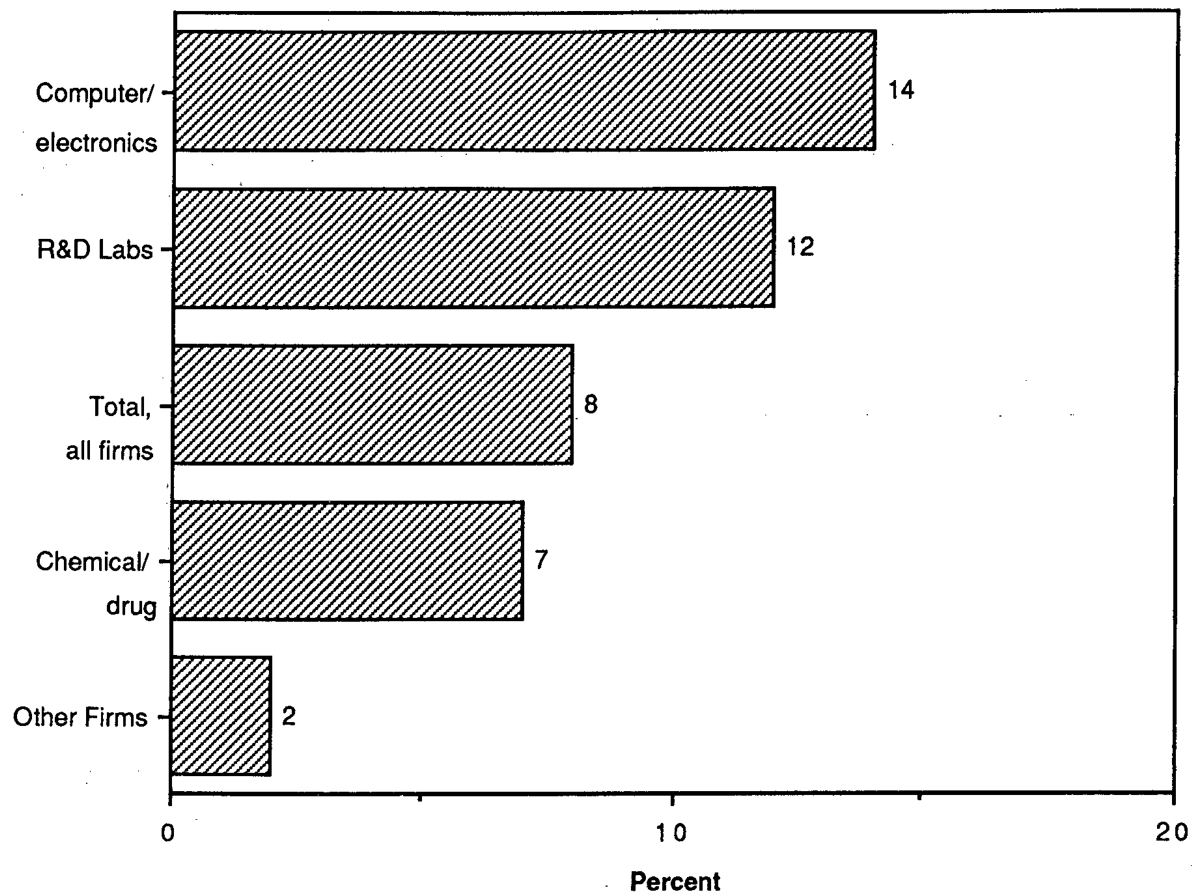
NOTE: Includes only individuals reporting employment in engineering occupations in 1982 (see Table A-4).
SOURCES: Special tabulations from Oak Ridge Associated Universities, based on National Science Foundation's 1982 Postcensal Survey.

FIGURE A-8 Foreign engineers, by primary work activity and field, 1982.



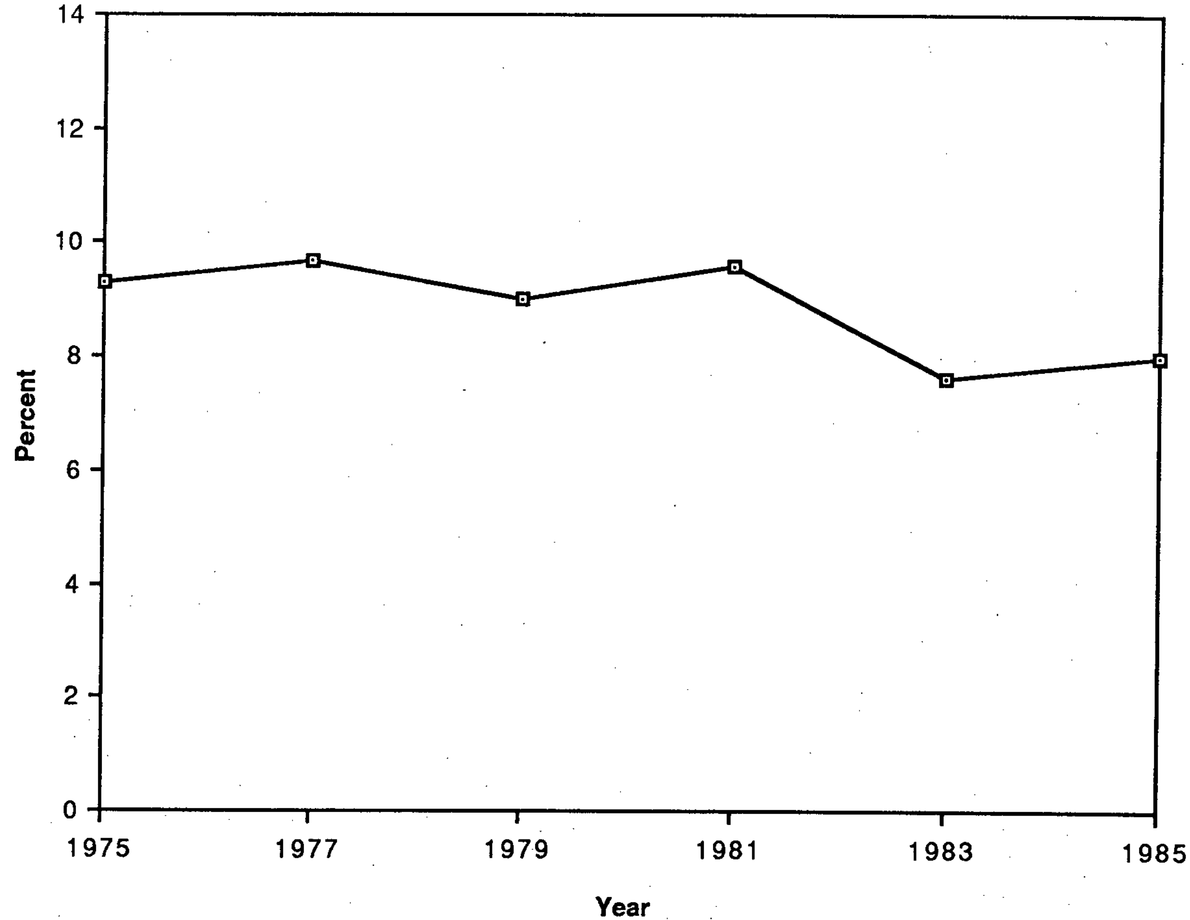
SOURCE: National Science Foundation, *Foreign Citizens in U.S. Science and Engineering: History, Status and Outlook*, Washington, D.C.: U.S. Government Printing Office, 1987.

FIGURE A-9 Proportion of firms employing foreign scientists and engineers, 1985.



SOURCE: National Science Foundation, *Foreign Citizens in U.S. Science and Engineering: History, Status and Outlook*, Washington, D.C.: U.S. Government Printing Office, 1987.

FIGURE A-10 Foreign citizens as percent of recent hires of scientists and engineers in firms that employed them, 1985.



NOTE: See Table A-6.
SOURCE: National Science Foundation, *Research and Development in Industry, 1985*, Washington, D.C.: U.S. Government Printing Office, 1986.

FIGURE A-11 Proportion of U.S.-company funded R&D performed by foreign subsidiaries, 1975-1985.

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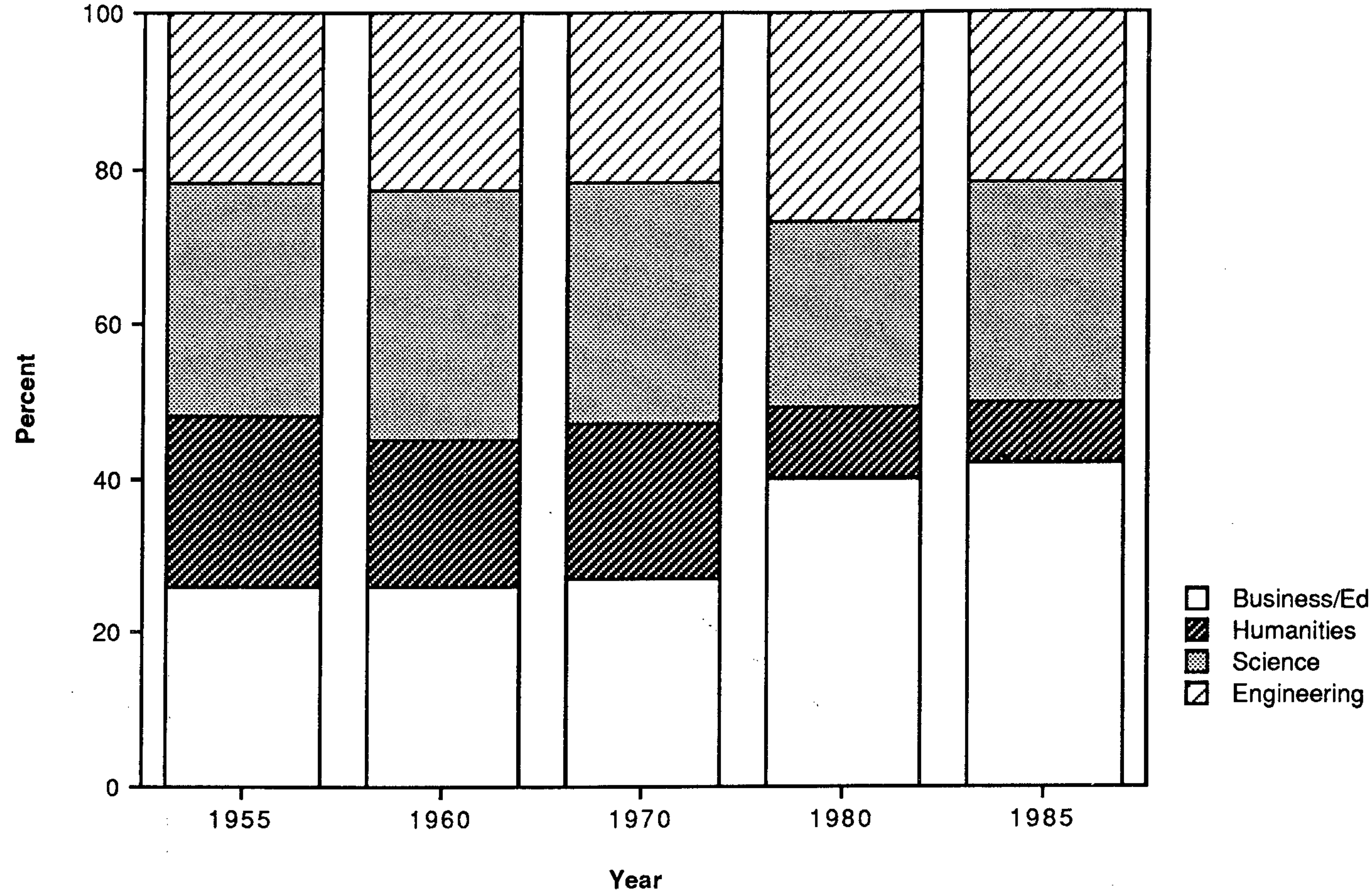
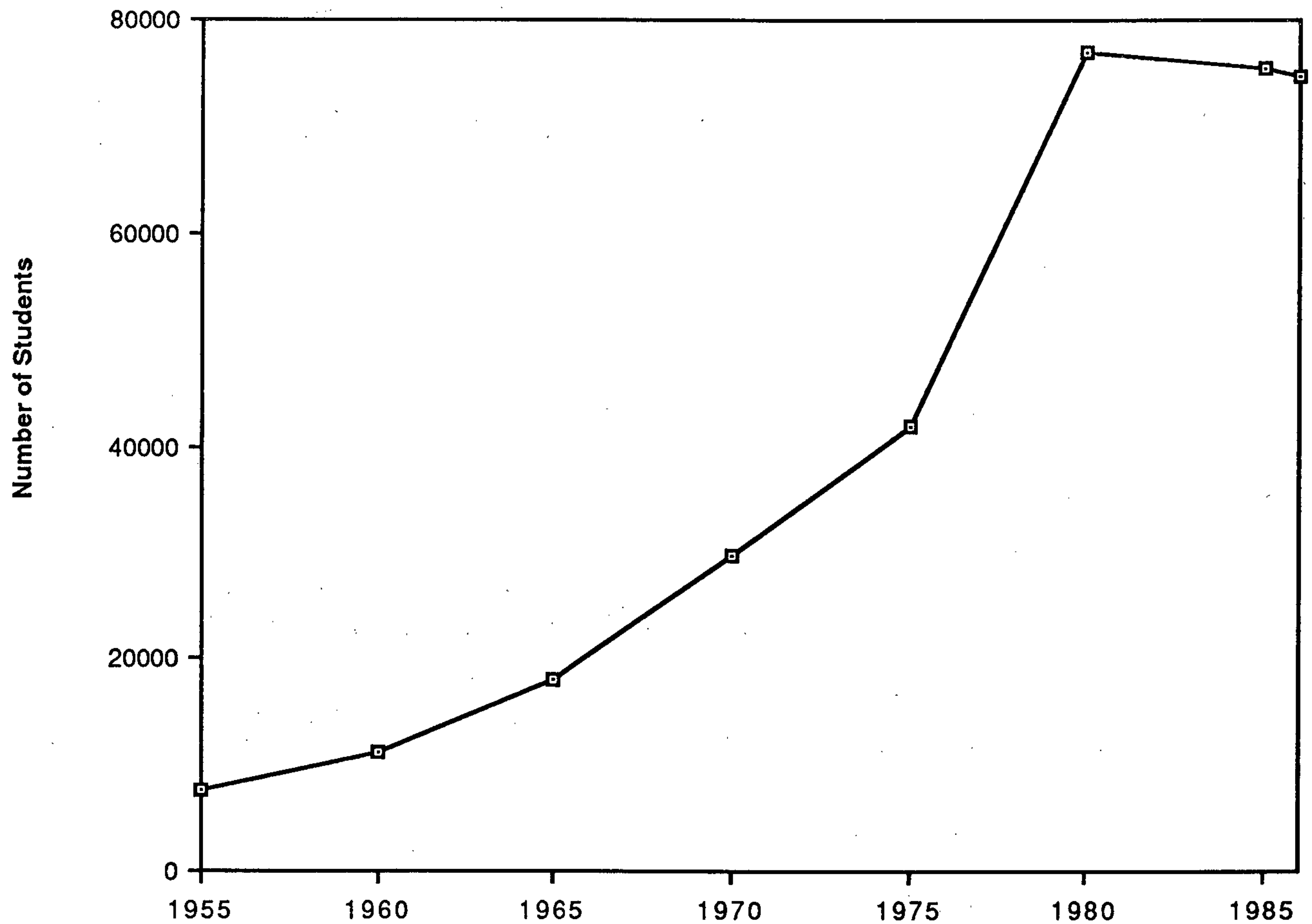


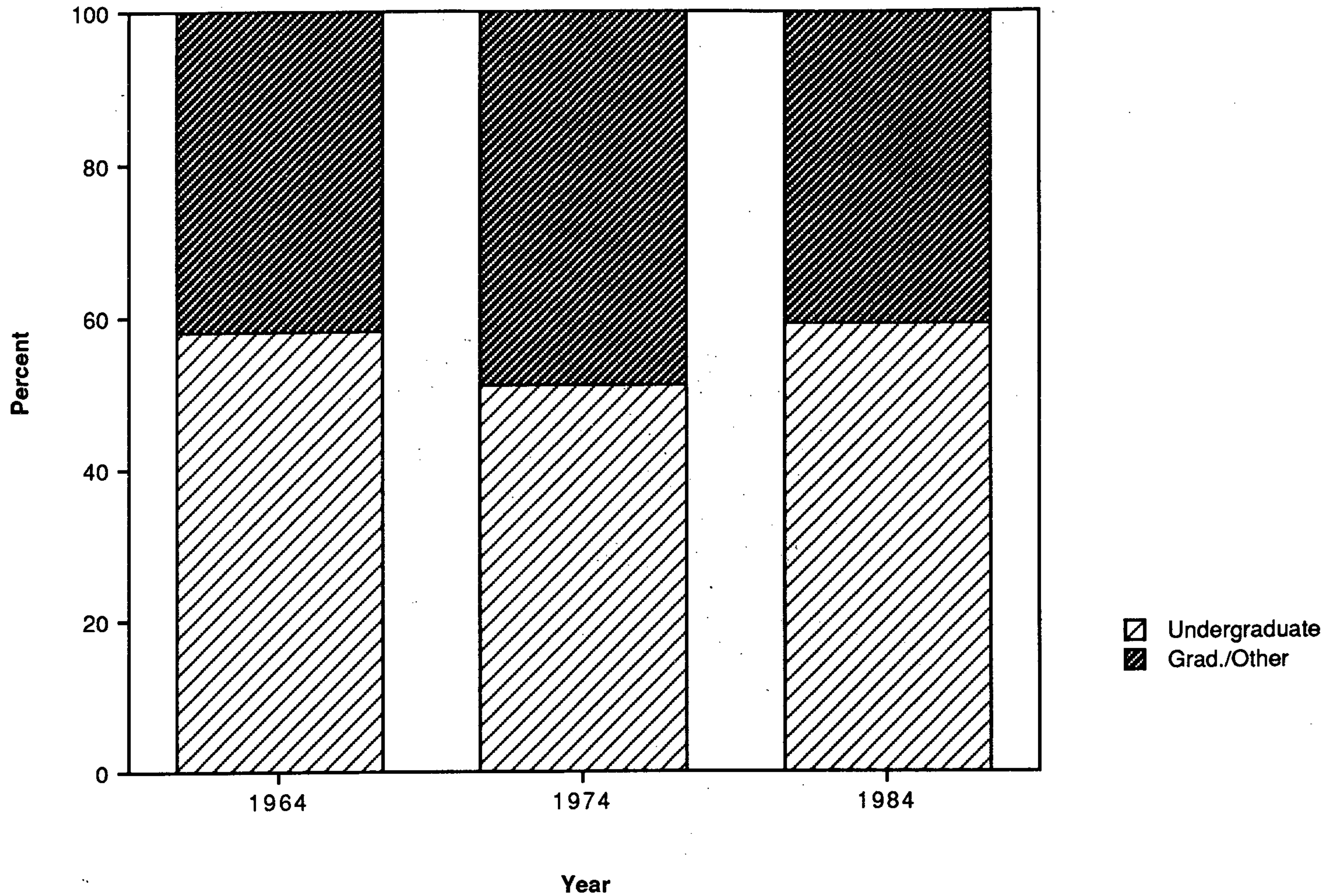
NOTE: See Table A-7.
SOURCE: M. Zikopoulos (ed.), *Open Doors, 1985-86,* New York: Institute of International Education, 1986.

FIGURE A-12 Distribution of foreign students, by field of study, 1955-1985.



NOTE: See Table A-8.
SOURCE: M. Zikopoulos (ed.), *Open Doors, 1986,* New York: Institute of International Education, 1987.

FIGURE A-13 Number of foreign engineering students at all levels, 1955-1986.



NOTE: See Table A-9.
SOURCE: *Profiles, 1983-84,* New York: Institute of International Education, 1985.

FIGURE A-14 Foreign engineering students, by academic level, 1964, 1974, and 1984.

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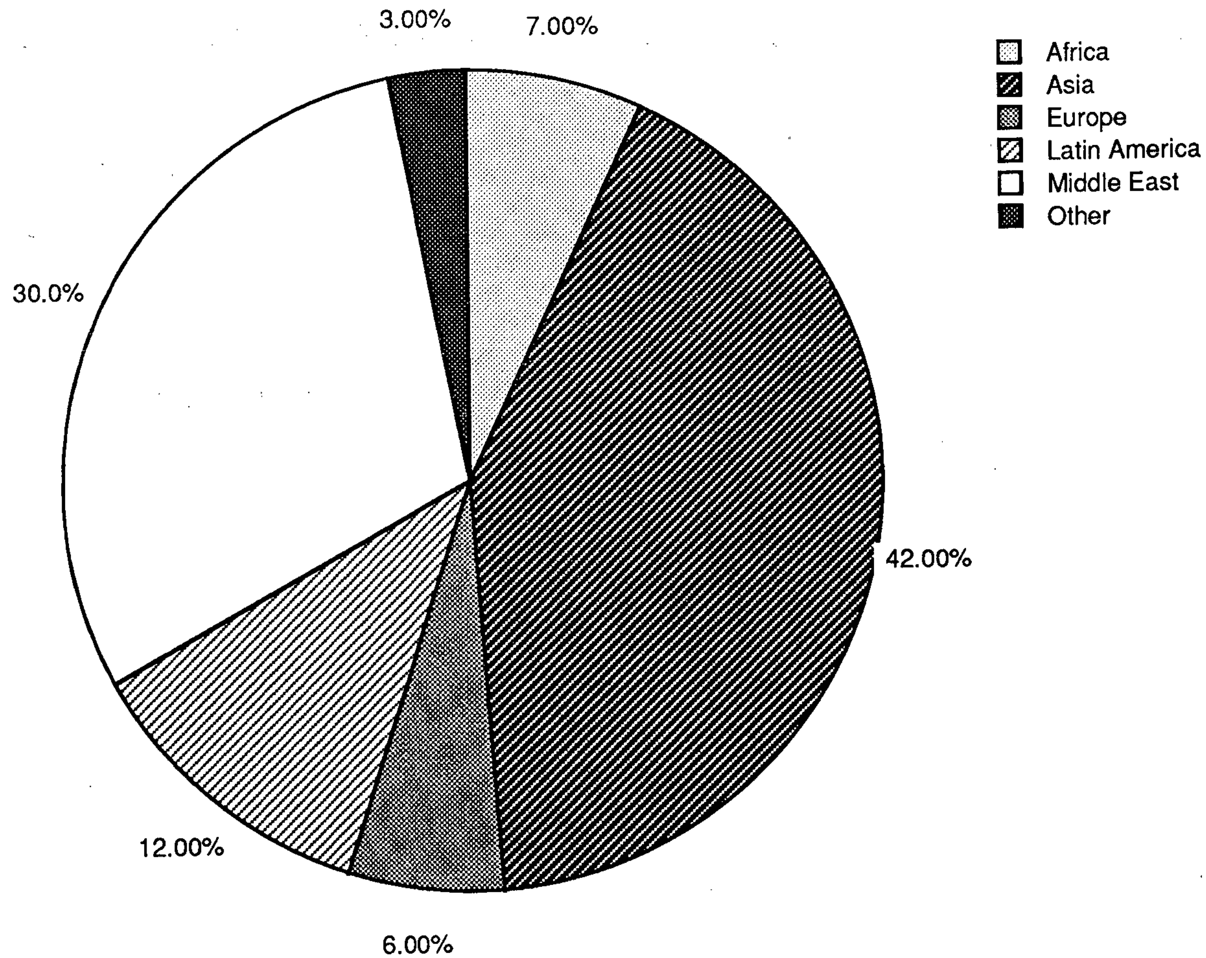

SOURCE: *Profiles, 1983-84,* New York: Institute of International Education, 1985.

FIGURE A-15 Foreign engineering students, by area of origin, 1983-84.

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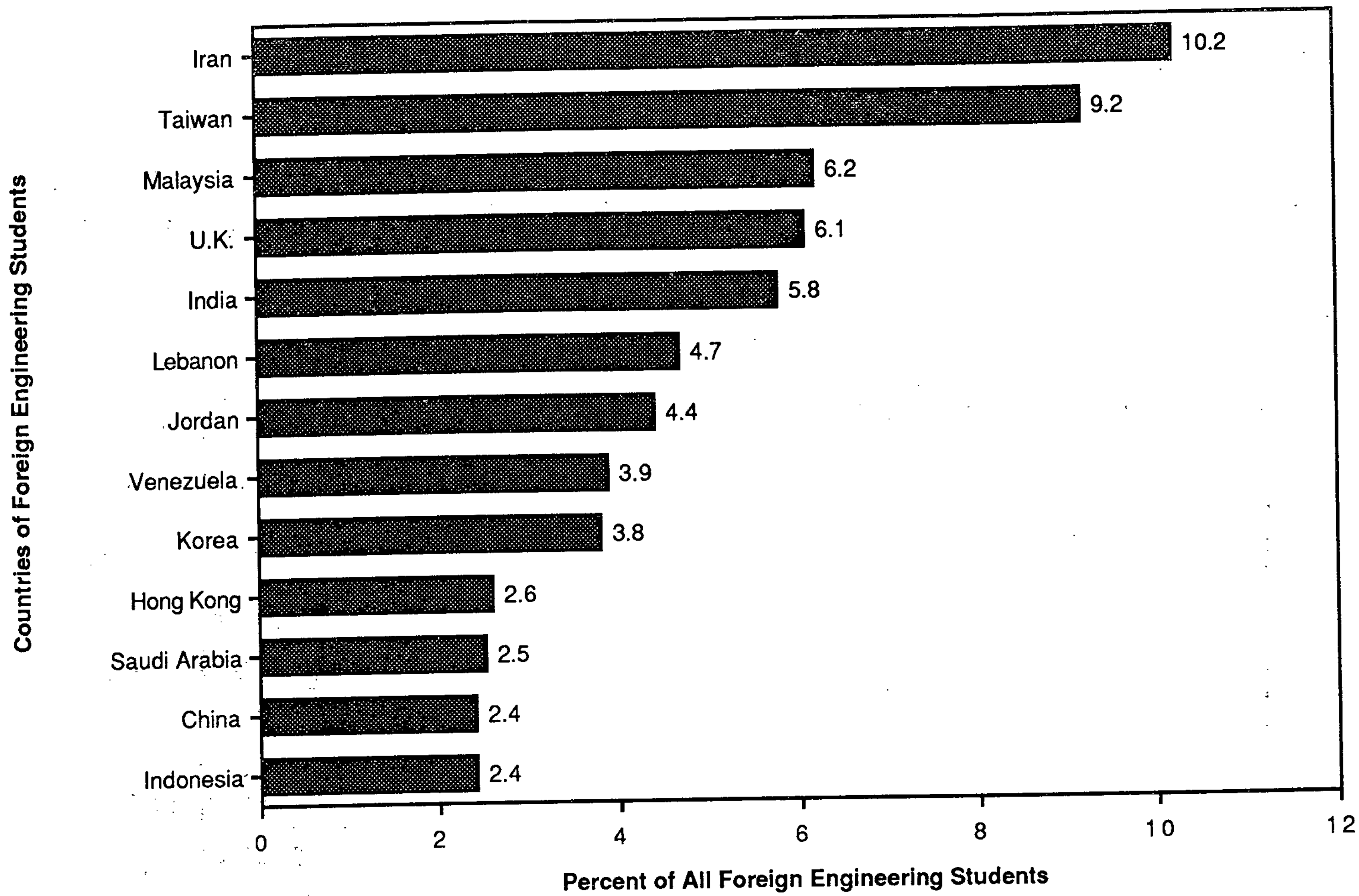

SOURCE: *Profiles, 1983-84,* New York: Institute of International Education, 1985.

FIGURE A-16 Countries that produced the largest number of foreign engineering students, 1983-84.

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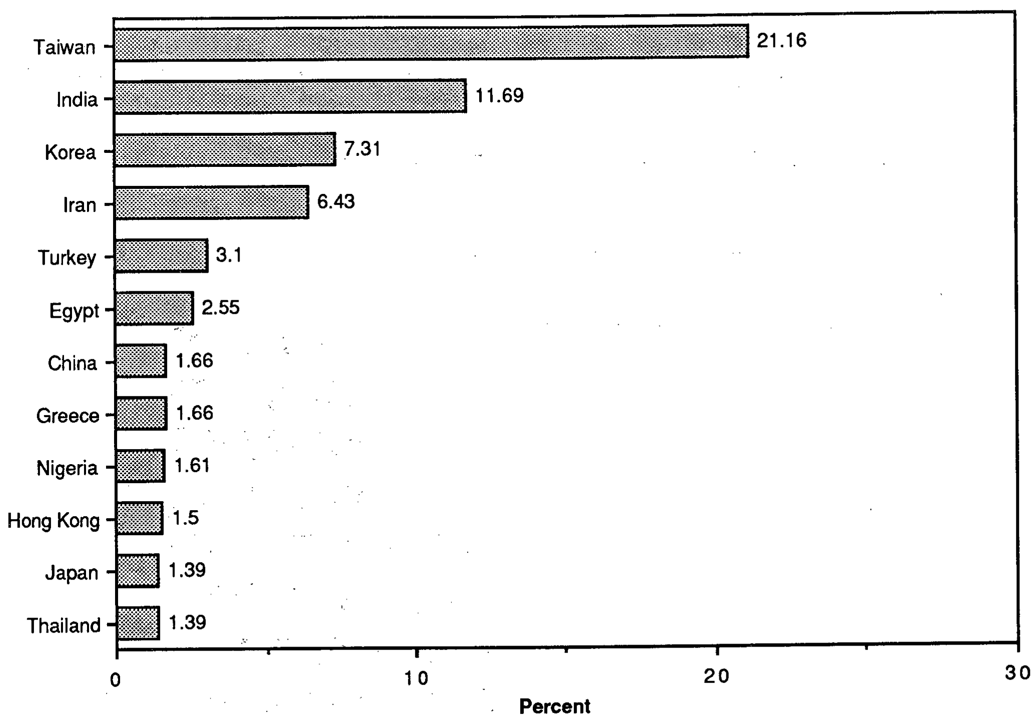
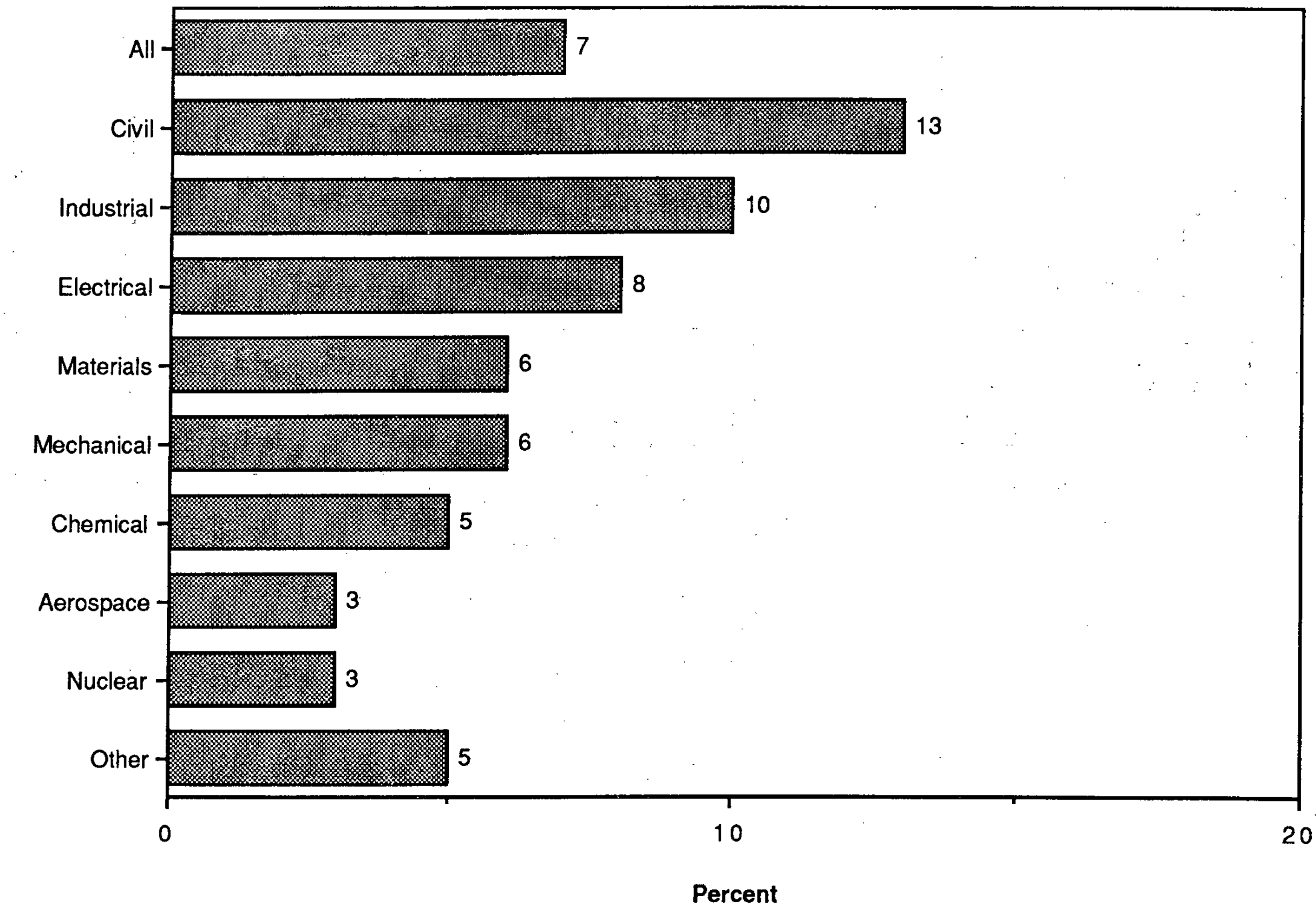


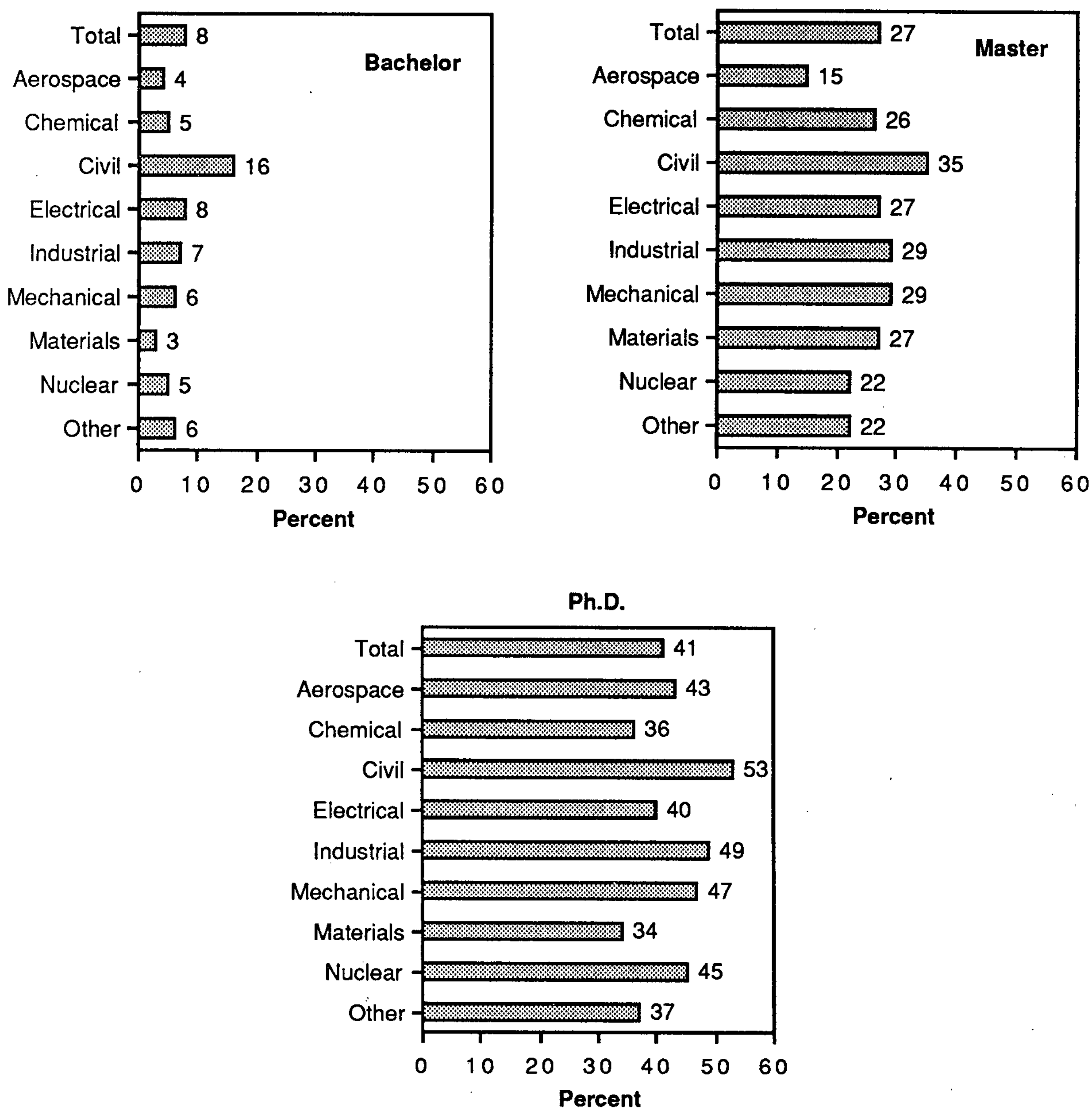
NOTE: See Table A-10.
SOURCES: National Science Foundation, *Science and Engineering Doctorates 1960-85*, Washington, D.C.: U.S. Government Printing Office, 1986; National Research Council's 1985 Survey of Doctorate Recipients.

FIGURE A-17 Leading countries of origin for foreign recipients of doctorates in engineering, 1985.



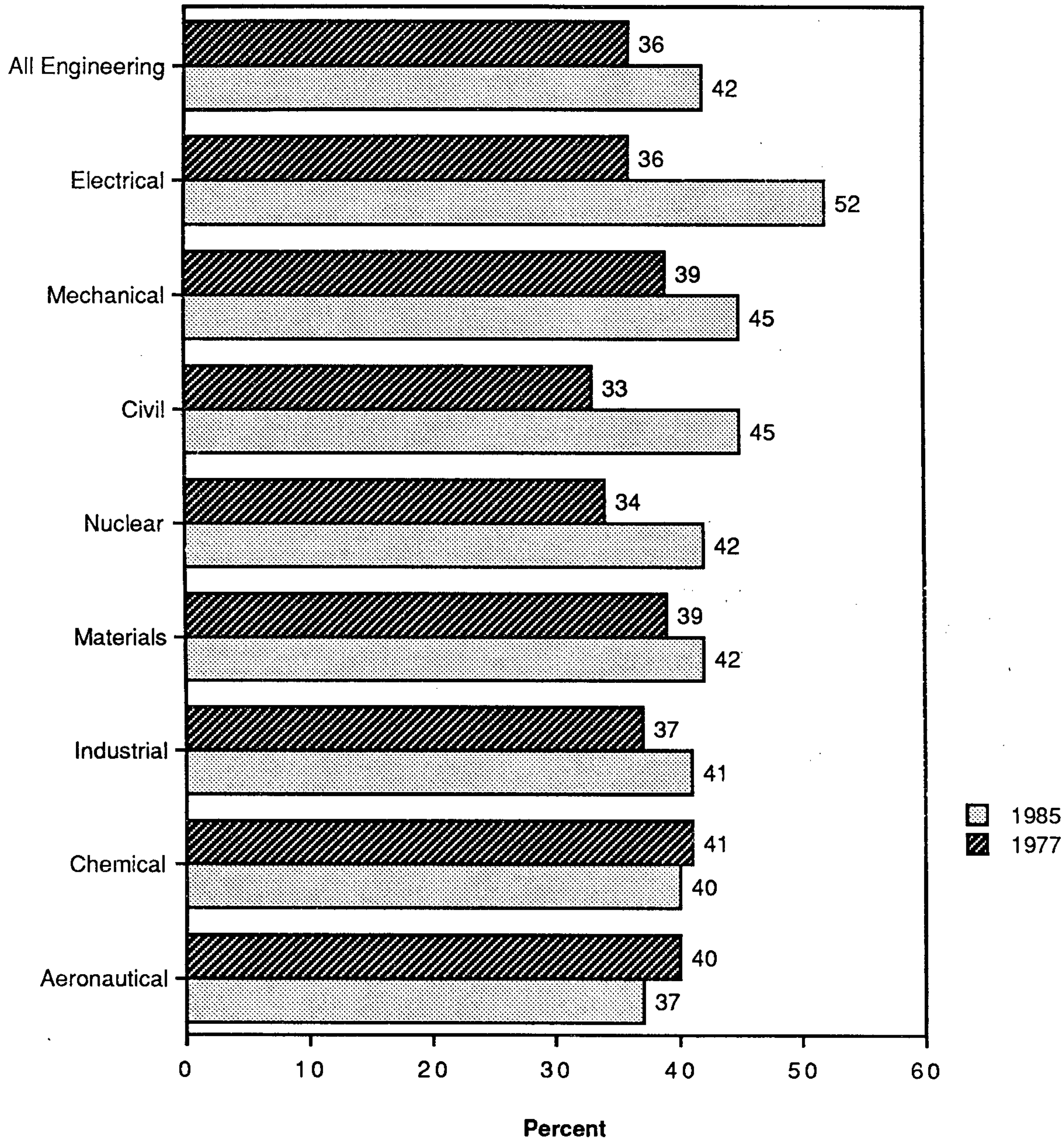
NOTE: See Table A-11.
SOURCE: Unpublished tabulations, American Association of Engineering Societies.

FIGURE A-18 Foreigners as a proportion of all undergraduate engineering students, by subfield, 1985.



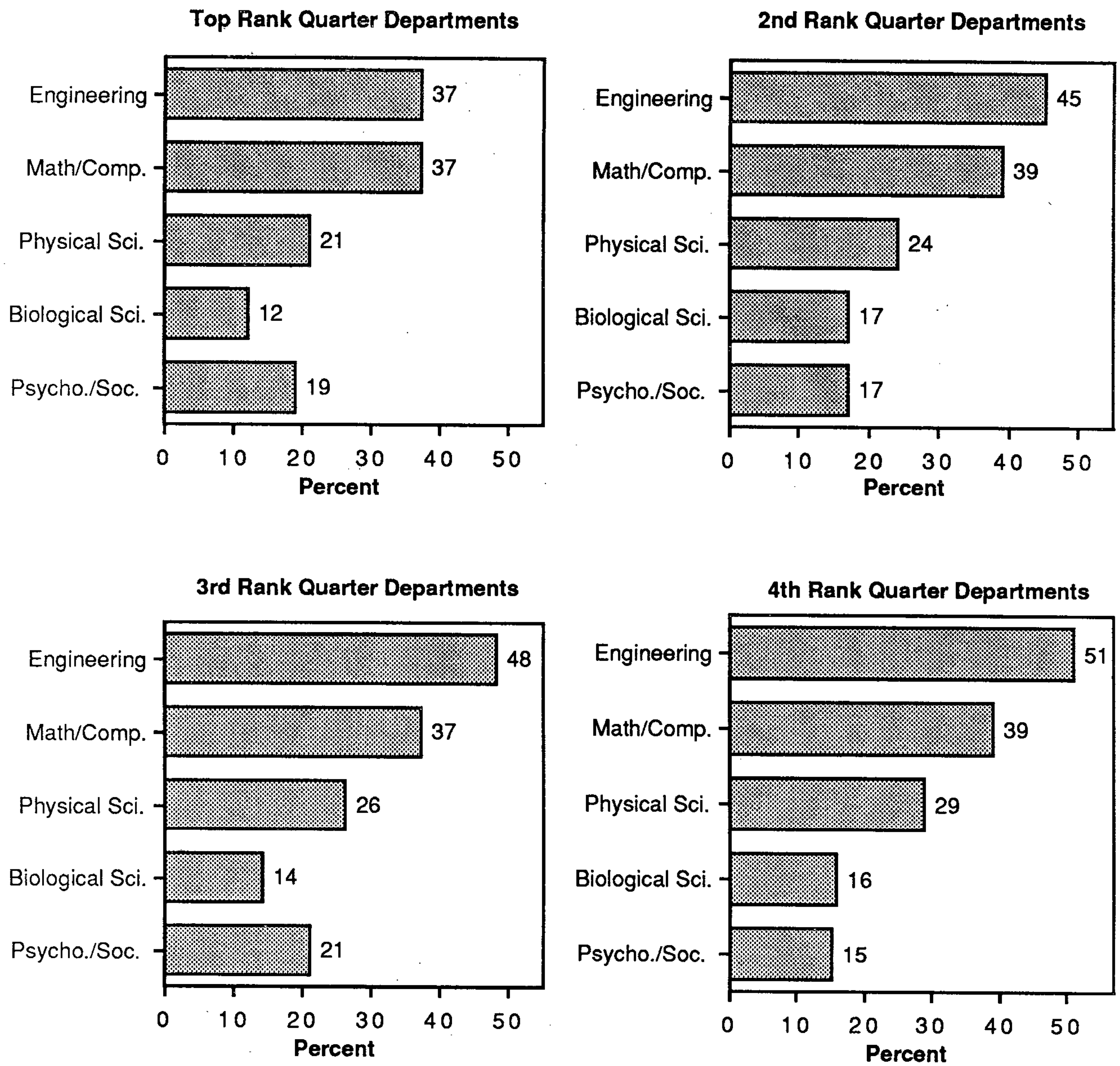
SOURCE: Unpublished tabulations, American Association of Engineering Societies.

FIGURE A-19 Foreigners as a proportion of all engineering degrees, by level and subfield, 1985.



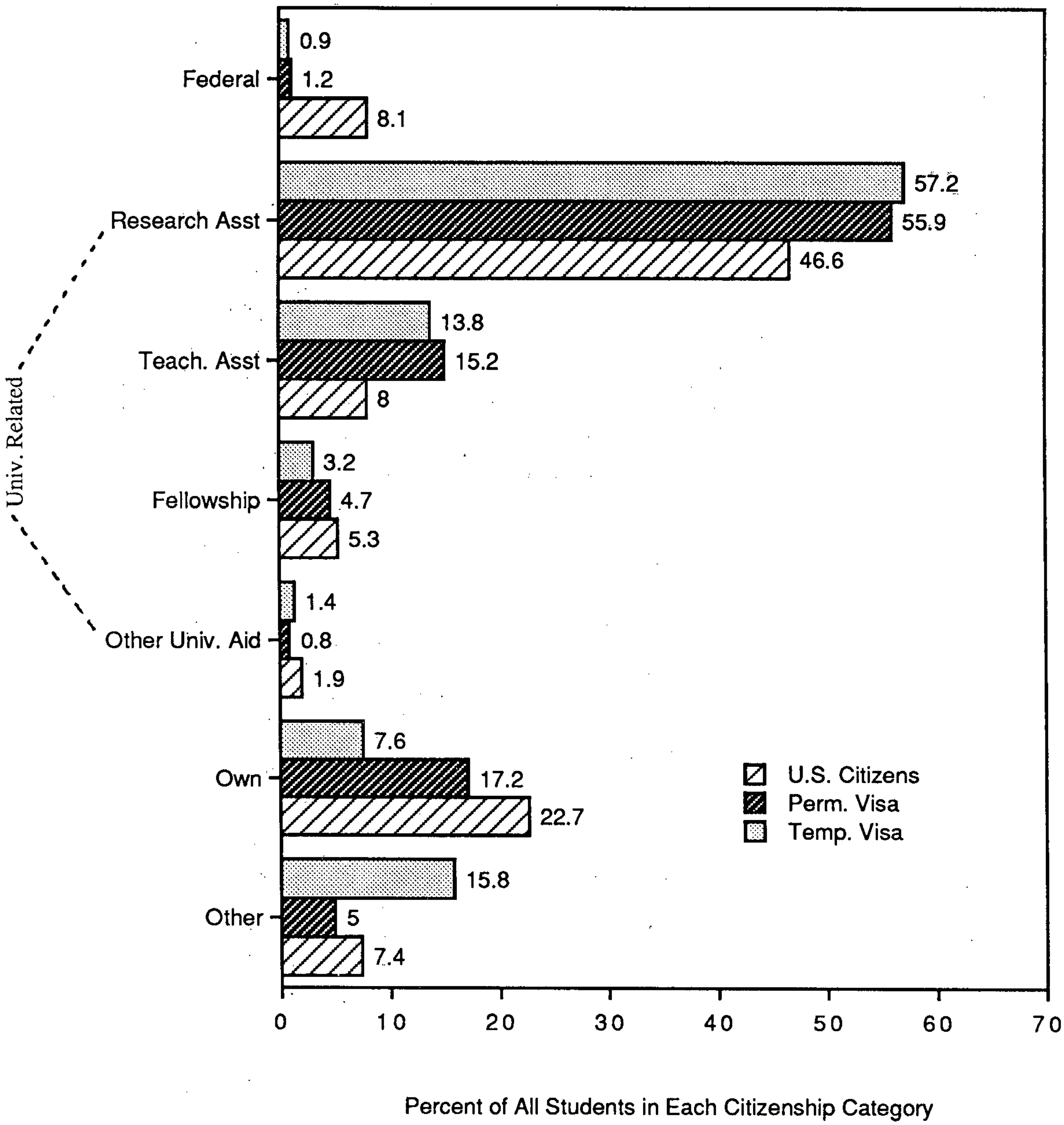
SOURCE: National Science Foundation, *Foreign Citizens in U.S. Science and Engineering: History, Status and Outlook,* Washington, D.C.: U.S. Government Printing Office, 1987.

FIGURE A-20 Foreign students as a percent of full-time graduate enrollment in selected engineering fields at U.S. doctorate-granting institutions, 1977 and 1985.



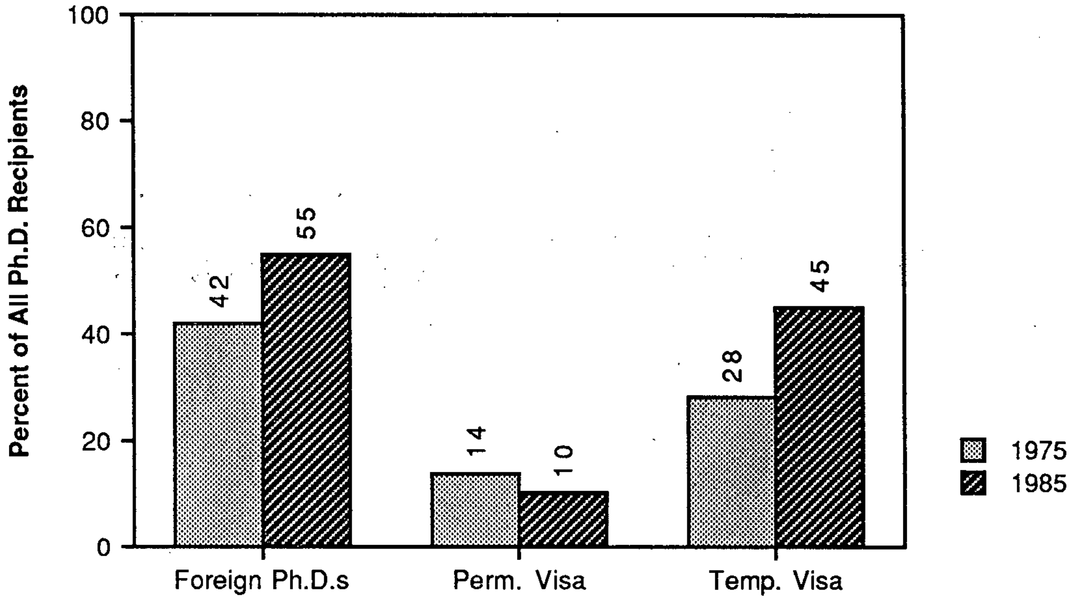
NOTE: The percentage of foreign enrollment in all departments is as follows: engineering, 45; physical science, 25; biological science, 15; math/computer science, 39; and psychology/social science, 17.
SOURCES: Council of Graduate Schools as shown in the National Research Council's Survey of Earned Doctorates; National Science Foundation, *Foreign Citizens in U.S. Science and Engineering: History, Status and outlook* (NSF 86-305), Washington, D.C.: U.S. Government Printing Office, 1987.

FIGURE A-21 Foreigners as a percentage of total graduate student enrollments, by quality of science/engineering department, 1983.

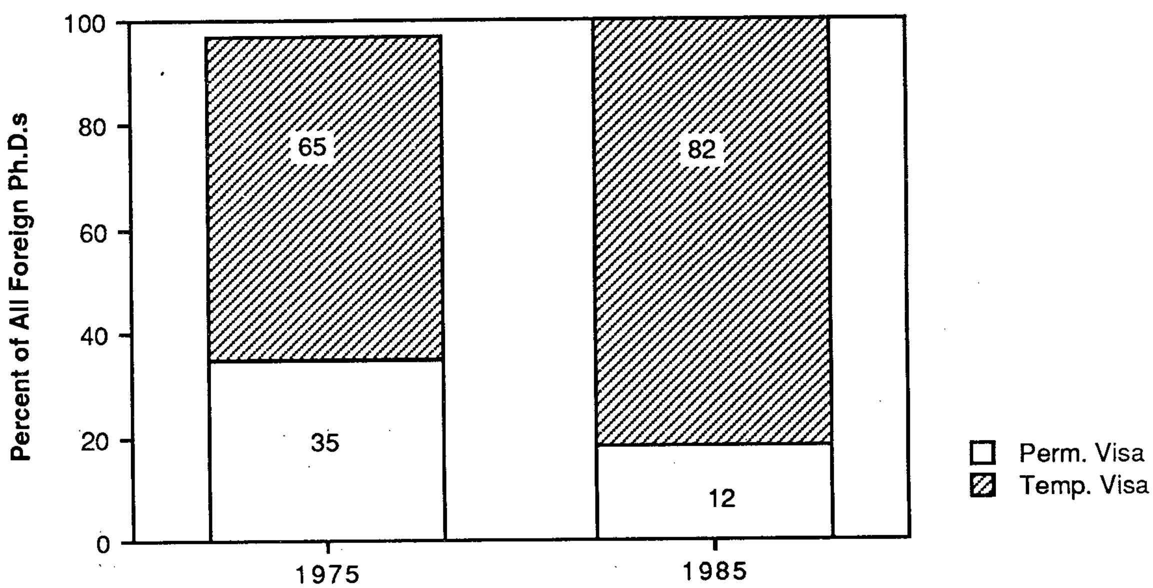


SOURCES: National Research Council's Survey of Earned Doctorates; National Science Foundation, *Foreign Citizens in U.S. Science and Engineering: History, Status and Outlook,* Washington, D.C.: U.S. Government Printing Office, 1987.

FIGURE A-22 Primary source of support in graduate school of doctorate recipients, by citizenship and engineering field, 1985.



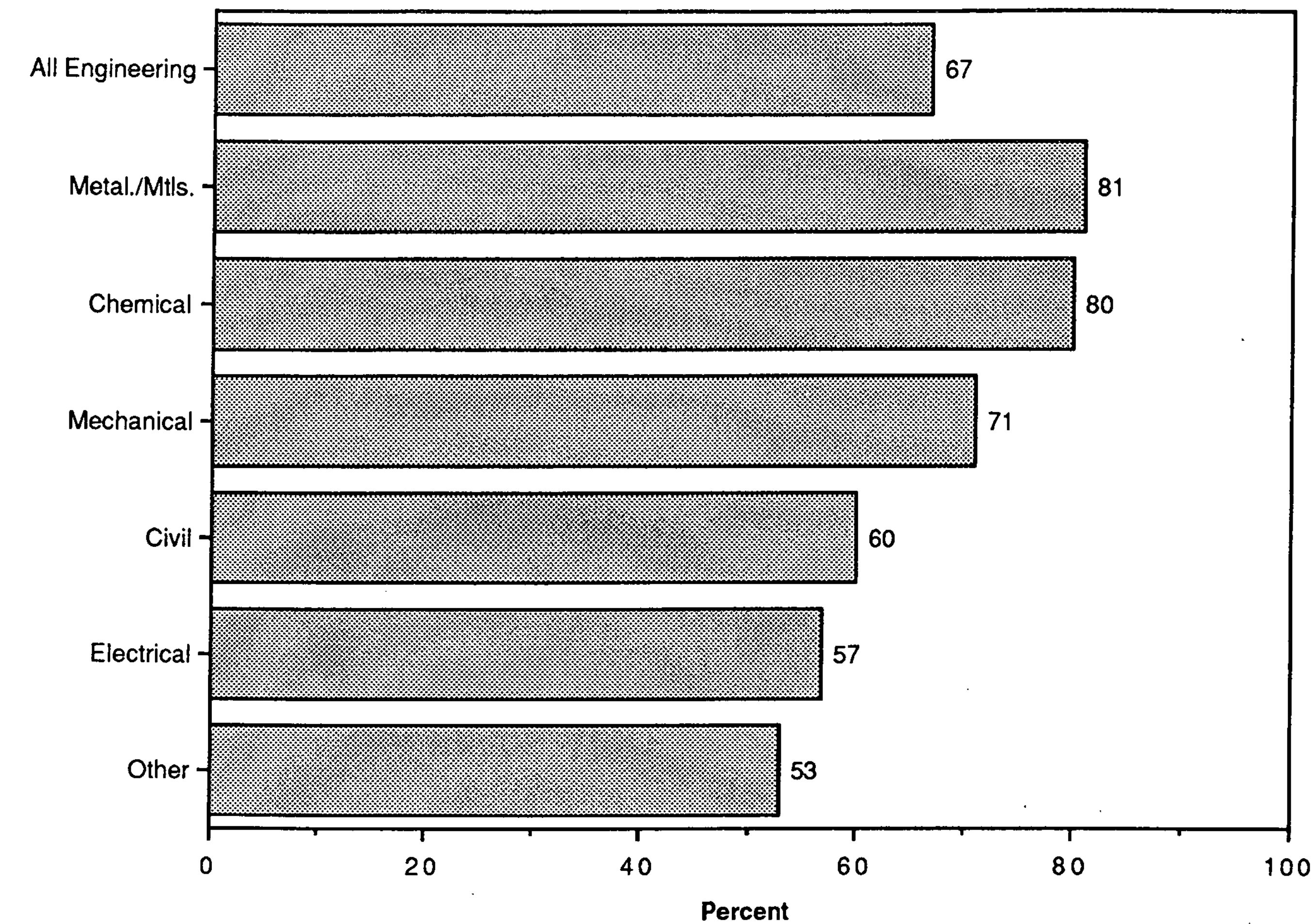
Foreign as Percent of Total Engineering Ph.D. Recipients



Distribution of Type of Visa

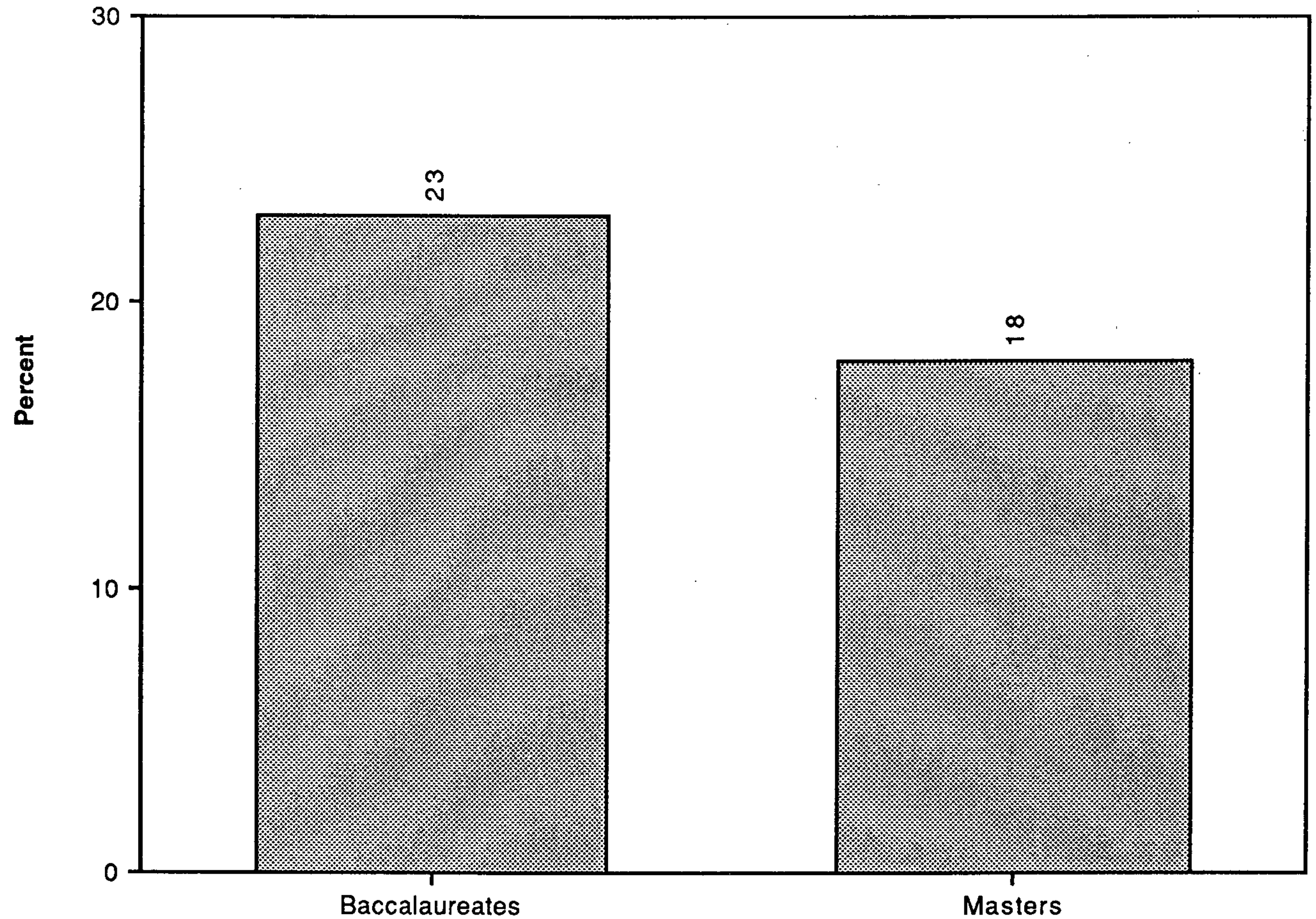
SOURCES: National Research Council's Survey of Earned Doctorates; National Science Foundation, *Foreign Citizens in U.S. Science and Engineering: History, Status and Outlook,* Washington, D.C.: U.S. Government Printing Office, 1987.

FIGURE A-23 Foreign engineering Ph.D. recipients: Percentage of total engineering doctorates and distribution by type of visa, 1975 and 1985.



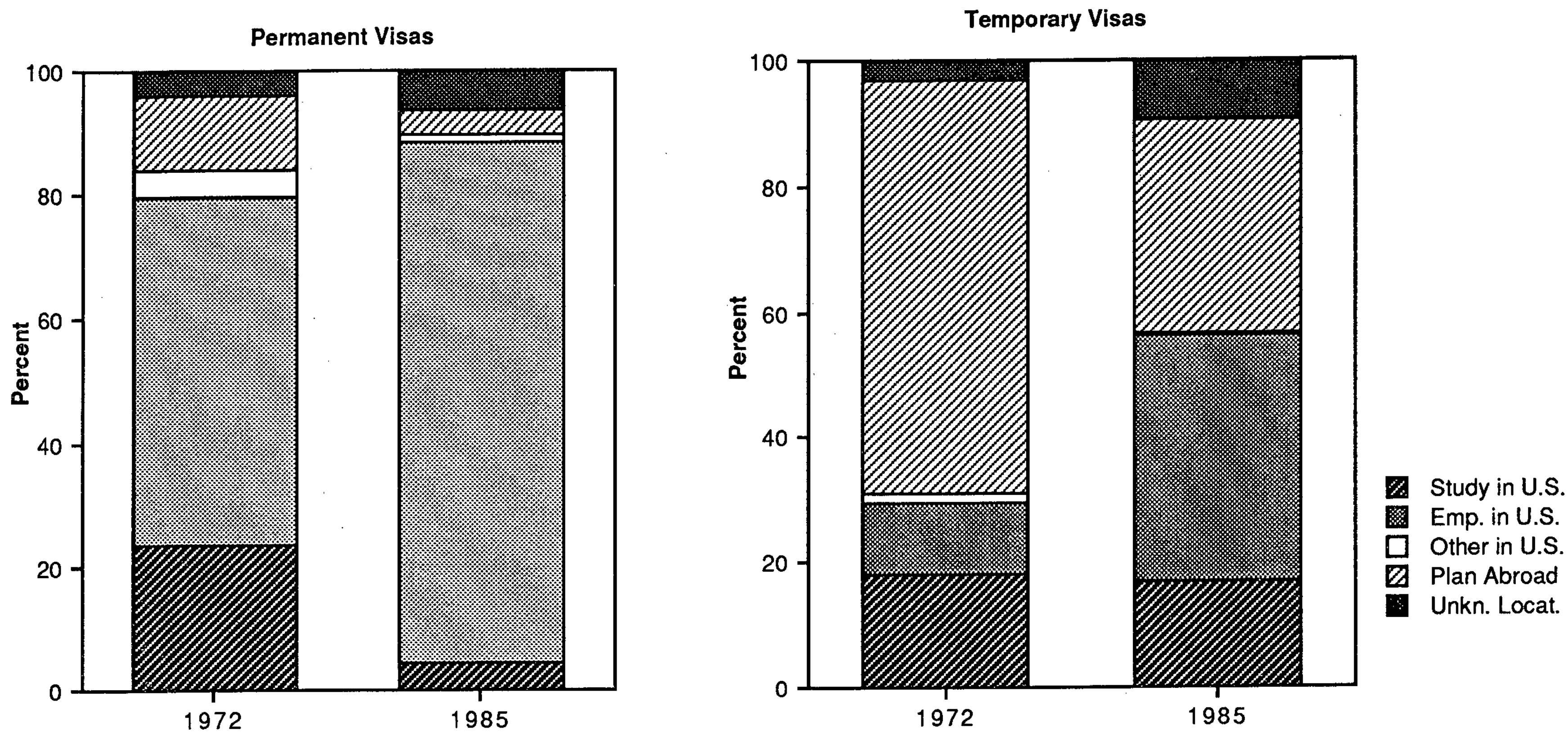
SOURCE: National Science Foundation, *Foreign Citizens in U.S. Science and Engineering: History, Status and Outlook,* Washington, D.C.: U.S. Government Printing Office, 1987.

FIGURE A-24 Foreigners as a proportion of all engineering postdoctorates in doctorate-granting institutions, 1985.



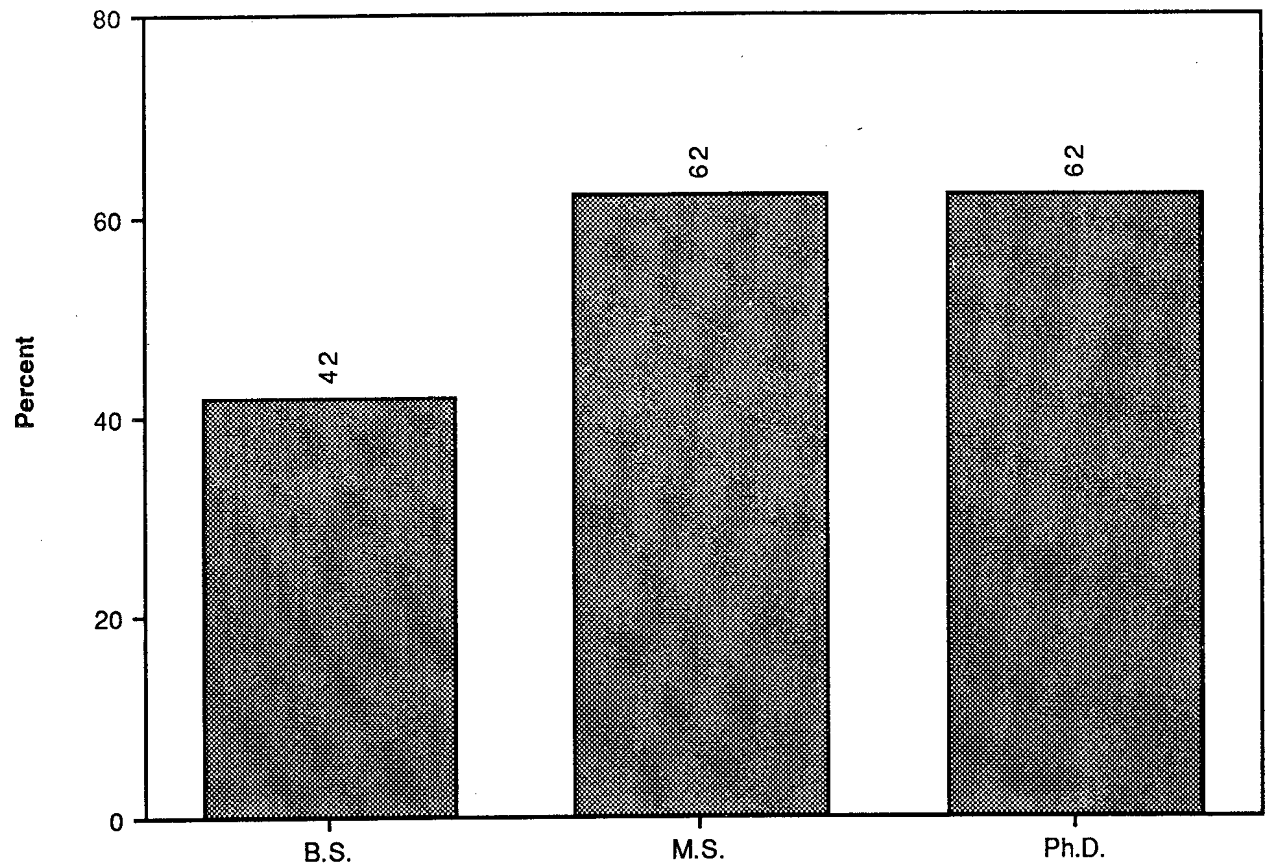
SOURCES: Unpublished tabulations, National Science Foundation and American Association of Engineering Societies.

FIGURE A-25 Proportion of 1982-83 foreign engineering graduates of American universities employed in the United States in 1984.



NOTE: See Table A-12.
SOURCES: National Research Council's Survey of Earned Doctorates; National Science Foundation, *Foreign Citizens in U.S. Science and Engineering: History, Status and Outlook*, Washington, D.C.: U.S. Government Printing Office, 1987.

FIGURE A-26 Postgraduation plans of foreign engineering doctorate recipients (with temporary or permanent visas), 1972 and 1985.



NOTE: Includes only individuals reporting employment in engineering occupations in 1982.
SOURCES: Oak Ridge Associated Universities; National Science Foundation, *Foreign National Scientists and Engineers in the U.S. Labor Force, 1972-1982*, Washington, D.C.: U.S. Government Printing Office, 1986.

FIGURE A-27 Proportion of foreign engineers working in the United States in 1982 (1976-1979 B.S. and M.S. recipients and 1980-81 doctorate recipients).

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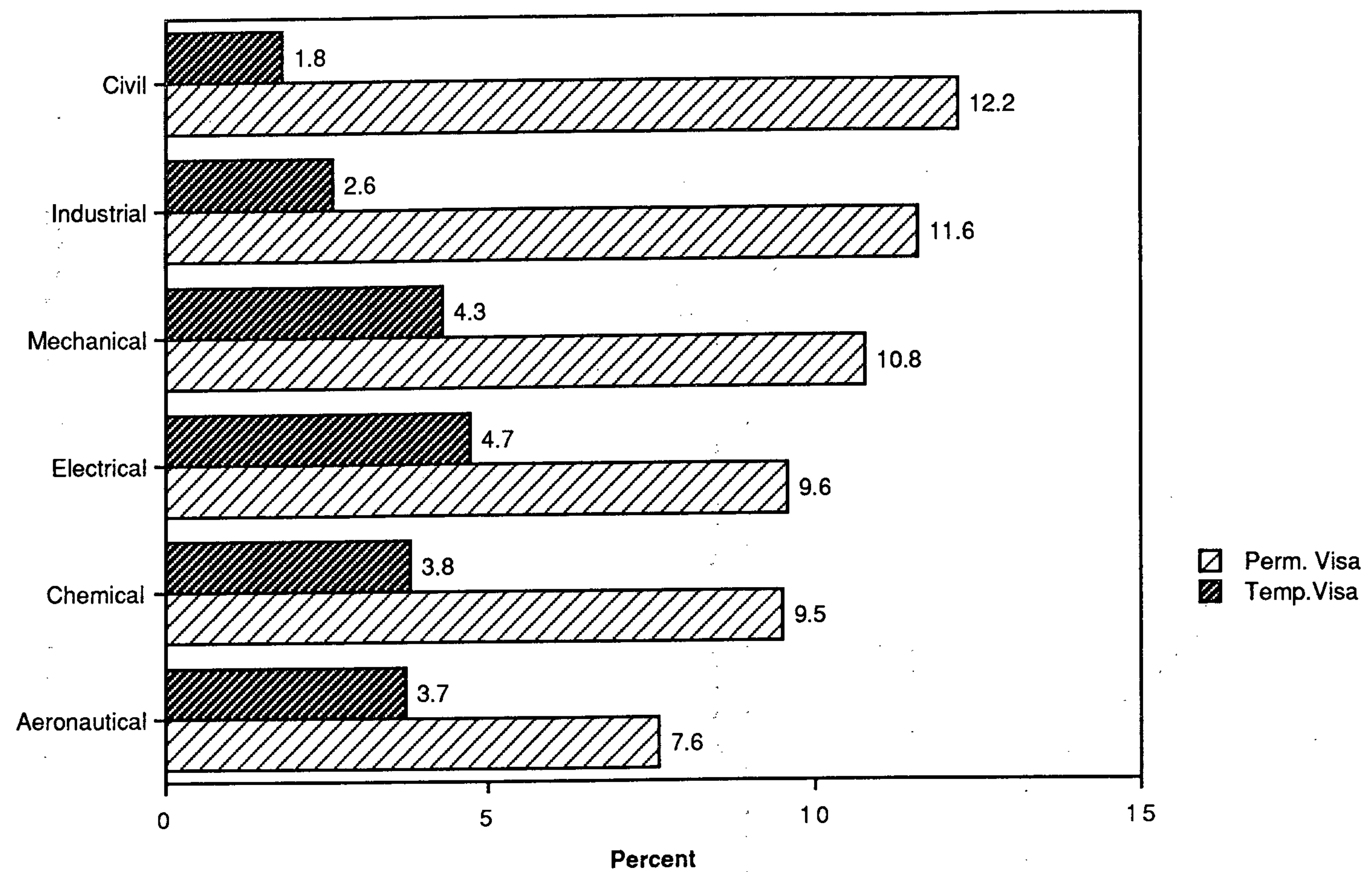

SOURCE: National Science Foundation, *Foreign Citizens in U.S. Science and Engineering: History, Status and Outlook*, Washington, D.C.: U.S. Government Printing Office, 1987.

FIGURE A-28 Foreigners as a proportion of all engineering faculty in doctorate-granting institutions in selected subfields, by type of visa, 1985-86.

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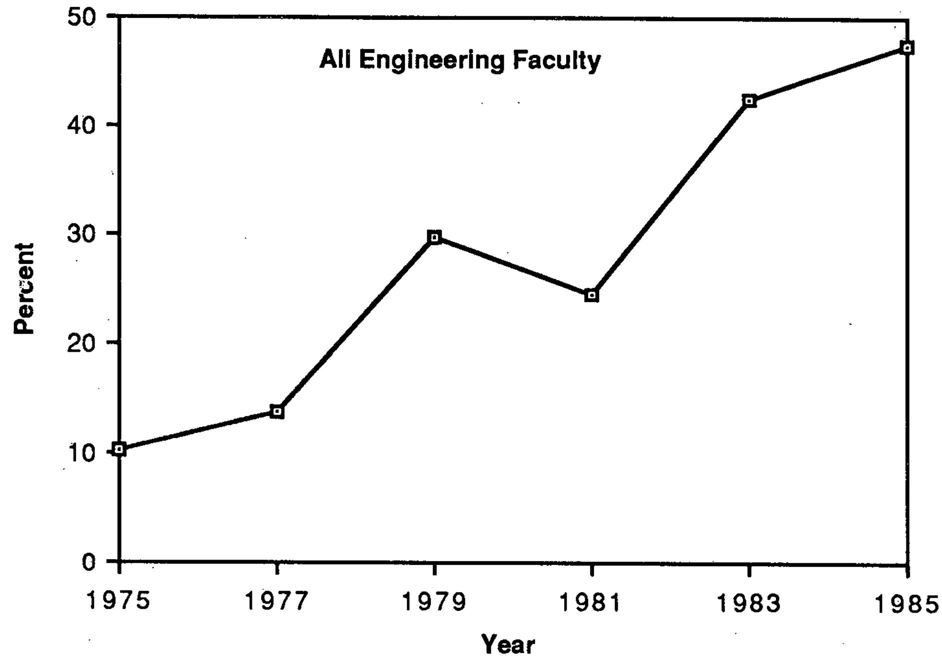

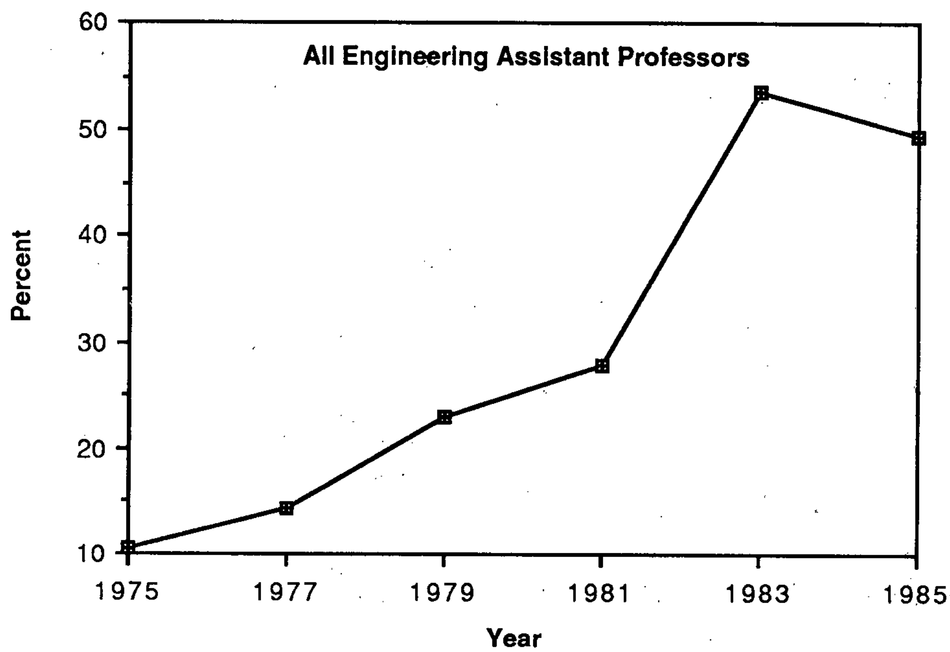

NOTE: See Table A-13.
SOURCE: National Research Council's Survey of Doctorate Recipients.

FIGURE A-29 Foreign as proportions of all engineering faculty and assistant professors, age 35 or less, for selected years, 1975-1985.

TABLE A-1: Employed Engineers, by Field and Citizenship Status, 1982 (percent in parentheses)

Field	Native	Foreign	Naturalized	Total
All Engineers	869,824	36,435	144,346	1,050,605
	(82.8)	(3.5)	(13.7)	(100.0)
Aeronautical	38,660	1,368	5,979	46,007
	(84.0)	(3.0)	(13.0)	(100.0)
Chemical	49,559	2,962	8,688	61,209
	(81.)	(4.8)	(14.2)	(100.0)
Civil	116,951	4,956	24,030	145,937
	(80.1)	(3.4)	(16.5)	(100.0)
Electrical	203,867	8,787	33,073	245,727
	(83.0)	(3.6)	(13.5)	(100.0)
Industrial	58,072	1,778	8,053	67,903
	(85.5)	(2.6)	(11.9)	(100.0)
Materials	18,514	1,522	2,849	22,885
	(80.9)	(6.7)	(12.4)	(100.0)
Mechanical	168,204	7,768	30,971	206,943
	(81.3)	(3.8)	(15.0)	(100.0)
Nuclear	8,138	321	1,165	9,624
	(84.6)	(3.3)	(12.1)	(100.0)
Other	207,860	6,971	29,538	244,369
	(85.1)	(2.9)	(12.1)	(100.0)

NOTES: Includes only individuals reporting employment in engineering occupations in 1972 and 1982.
SOURCES: Special tabulations from Oak Ridge Associated Universities, based on National Science Foundation's 1972 and 1982 Postcensal Surveys.

TABLE A-2: Foreign Engineers in the U.S. Labor Force, by Degree Level, 1982 (in percent)

Degree	U.S. Citizens	Foreign	Naturalized
Bachelor's	85.5	2.4	12.1
Master's	77.7	6.4	15.9
Doctorate	64.3	12.0	23.8

NOTE: Includes only individuals reporting employment in engineering occupations in 1982.
SOURCES: Special tabulations from Oak Ridge Associated Universities, based on National Science Foundation's 1982 Postcensal Survey.

TABLE A-3: Foreign Engineers, by Sector of Employment and Field, 1982 (in percent)

Field	Business/ Industry	Education Institution	Government	Other
ALL FIELDS	82	8	4	6
Aeronautical	85	9	3	3
Chemical	85	9	1	5
Civil	71	10	11	8
Electrical	87	2	4	7
Industrial	82	2	0	16
Materials	58	40	0	2
Mechanical	86	7	1	6
Nuclear	81	0	3	16
Other	82	8	5	5

NOTE: Includes only individuals reporting employment in engineering occupations in 1982.
SOURCES: Special tabulations from Oak Ridge Associated Universities, based on National Science Foundation's 1982 Postcensal Survey.

TABLE A-4: Foreign Engineers, by Primary Work Activity and Field, 1982 (in percent)

Field	R&D/R&D Management	Other*	Design	Non-R&D Management
ALL FOREIGN	36	33	18	13
Aeronautical	64	18	13	5
Chemical	46	17	22	15
Civil	19	49	22	10
Electrical	46	26	20	8
Industrial	21	49	1	29
Materials	57	29	2	12
Mechanical	28	29	29	14
Nuclear	52	26	16	6
Other	32	43	8	17

* Includes teaching and operations.
NOTE: Includes only individuals reporting employment in engineering occupations in 1982.
SOURCES: Special tabulations from Oak Ridge Associated Universities, based on National Science Foundation's 1982 Postcensal Survey.

TABLE A-5: Foreign Engineers as a Proportion of All Engineers, by Primary Work Activity and Field, 1982 (in percent)

Field	R&D Mgmt	Non-R&D Mgmt	Teaching	R&D	Design	Operations	Other	Total
ALL FOREIGN	3	2	8	5	4	3	3	3
Aeronautical	3	1	17	4	4	2	2	3
Chemical	6	3	19	7	9	1	4	5
Civil	3	1	9	8	6	2	4	3
Electrical	3	2	2	5	4	4	4	4
Industrial	2	2	3	3	0	2	3	2
Materials	2	4	34	11	8	4	4	7
Mechanical	2	2	6	4	5	4	5	4
Nuclear	1	1	0	7	6	2	3	3
Other	4	2	9	4	3	2	2	3

NOTE: Includes only individuals reporting employment in engineering occupations in 1982.
SOURCES: Special tabulations from Oak Ridge Associated Universities, based on National Science Foundation's 1982 Postcensal Survey.

TABLE A-6: R&D Funded by U.S. Companies and Performed by Foreign Subsidiaries (in percent)

Year	Company-Performed R&D (Total)	Company-Funded R&D (Total)	R&D Performed by Foreign Affiliates	Foreign Affiliates Company-Funded
1975	24.19	15.58	1.45	9.3
1977	29.83	19.34	1.88	9.7
1979	38.23	30.48	2.75	9.0
1981	51.81	35.43	3.39	9.6
1983	63.40	42.86	3.24	7.6
1985	79.93	49.16	3.94	8.0

NOTE: Chemical and allied products, machinery, electrical equipment, and transportation industries comprised 82 percent of R&D carried out by foreign subsidiaries.

SOURCE: National Science Foundation, *Research and Development in Industry, 1985*, Washington, D.C.: U.S. Government Printing Office, 1986.

TABLE A-7: Foreign Students, by Field of Study, in Selected Years, 1955-1985 (in percent)

Field	1955	1960	1970	1980	1985
Engineering	22.0	23.0	22.0	27.0	22.0
Science	30.0	32.0	31.0	24.0	28.0
Humanities	22.0	19.0	20.0	9.0	8.0
Business/Education	26.0	25.0	27.0	40.0	42.0

SOURCE: M. Zikopoulos (ed.), *Open Doors, 1985,* New York: Institute of International Education, 1986.

TABLE A-8: Number of Foreign Engineering Students at All Levels, 1955-1986

Year	Number	Year	Number
1955	7,618	1975	42,000
1960	11,279	1980	76,950
1965	18,084	1985	75,370
1970	29,731	1986	74,580

SOURCE: M. Zikopoulos (ed.), *Open Doors, 1986,* New York: Institute of International Education, 1987.

TABLE A-9: Foreign Science and Engineering Students, by Academic Level, 1964, 1974, and 1984 (in percent)

Level	1964	1974	1984
Graduate	42	49	41
Undergraduate	58	51	59

SOURCE: *Profiles, 1983-84,* New York: Institute of International Education, 1985.

TABLE A-10: Leading Countries of Origin for Foreign Recipients of Doctorates in Engineering, 1985

Country of Citizenship	Number of Doctorates	Percent of Total
Taiwan	382	21.16
India	211	11.69
Korea	132	7.31
Iran	116	6.43
Turkey	56	3.10
Egypt	46	2.55
China	30	1.66
Greece	30	1.66
Nigeria	29	1.61
Hong Kong	27	1.50
Japan	25	1.39
Thailand	25	1.39
TOTAL, leading countries	1,109	61.40
Other countries	527	29.24
Countries not reported	169	9.36
TOTAL, FOREIGN RECIPIENTS	1,805	100.00

SOURCES: National Science Foundation, *Science and Engineering Doctorates 1960-85*, Washington, D.C.: U.S. Government Printing Office, 1986; National Research Council's 1985 Survey of Doctorate Recipients.

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TABLE A-11: Foreigners as a Proportion of All Engineering Undergraduate Students, by Subfield, 1985

Field	Total Number	Total Foreign	Percent Foreign
ALL STUDENTS	384,191	27,055	7
Aerospace	15,699	549	3
Chemical	23,423	1,269	5
Civil	34,547	4,431	13
Electrical	112,205	9,155	8
Industrial	16,434	1,583	10
Materials	3,204	178	6
Mechanical	66,738	3,946	6
Nuclear	1,857	59	3
Other	110,084	5,885	5

SOURCE: Unpublished tabulations, American Association of Engineering Societies.

TABLE A-12: Postgraduation Plans of Foreign Engineering Doctorate Recipients with Permanent or Temporary Visas (in percent)

Plans	Permanent Visa		Temporary Visa	
	1972	1985	1972	1985
Study	23.6	4.4	18.3	17.0
Employment	56.1	84.2	11.4	39.4
Other	4.3	1.1	1.3	0.4
Abroad	12.1	3.8	66.0	33.7
Unknown location	3.9	6.5	3.0	9.5

SOURCES: National Research Council's Survey of Earned Doctorates; National Science Foundation, *Foreign Citizens in U.S. Science and Engineering: History, Status and Outlook*, Washington, D.C.: U.S. Government Printing Office, 1987.

TABLE A-13: U.S. and Foreign Engineering Faculty, age 35 or less, 1975-1985

Year	All Faculty		Assistant Professors	
	U.S.	Foreign	U.S.	Foreign
1975	89.4	10.6	89.4	10.6
1977	85.7	14.3	85.7	14.3
1979	72.9	27.1	77.1	22.9
1981	75.9	24.3	72.1	27.9
1983	54.3	45.7	46.3	53.7
1985	53.4	46.6	50.5	49.5

SOURCE: National Research Council's Survey of Doctorate Recipients.

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APPENDIX B
AGENDA

Workshop on the International Exchange and Movement of Engineers

National Academy of Sciences

July 7, 1987

8:30	Welcome	Alan Fechter, Executive Director Office of Scientific and Engineering Personnel
8:45	Introduction	Stanford S. Penner, Chair University of California, La Jolla
9:00	Summary of the Data	Charles Falk, Consultant
9:15	Foreign Engineers in the U.S. Labor Force	Michael Finn, Oak Ridge Associated Universities
10:00	Foreign Engineers in Industry	Peter Cannon, Rockwell International
10:45	Break	
11:15	Foreign Engineering Students and Faculty in Academia	Daniel C. Drucker, University of Florida
12:00	Lunch	
1:00	Foreign Engineers and Foreign Visitors in Federal Laboratories	Glenn Kuswa, Sandia National Laboratory
1:45	International Flow of Scientific and Engineering Talent	Dorothy S. Zinberg, Harvard University
2:30	Flow of American Engineers to Japan	Charles T. Owens, National Science Foundation
3:00	Break	

3:15 Federal Policy Perspectives

- John Moore, Deputy Director, National Science Foundation
- Sandra O'Leary, Office of Policy Planning Staff, U.S. Department of State
- Ron William, Committee on Science, Space, and Technology, U.S. House of Representatives
- Deborah Wince, Office of Science and Technology Policy

4:00 Open Discussion

4:30 Adjournment

APPENDIX C
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Workshop on the International Exchange and Movement of Engineers

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July 7, 1987

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APPENDIX D
COMMISSIONED PAPERS

FOREIGN ENGINEERS IN THE U.S. LABOR FORCE*

Michael G. Finn
Oak Ridge Associated Universities

INTRODUCTION

~~During the first half of the 1980s, U.S. universities awarded more engineering doctorates to foreign nationals than to U.S. citizens. Most of these foreign nationals entered the U.S. work force, boosting the number of work force entrants with doctorates to a level that was at least 50 percent higher than it would have been if the foreign nationals had all left the United States after graduation.~~ Yet in spite of this very large foreign inflow to the United States labor market, the market for engineering doctorates was still very tight in 1985. They still earn the highest salaries, and the number of doctorates employed as engineers is still about 4 percent higher than the number who earned doctorates in engineering. To me, this illustrates several points about the role of foreign engineers in our labor market:

- We have a strong market for engineering graduates in spite of large foreign inflows.
- We would have a serious shortage if foreign nationals did not enter our work force.
- Although salaries would be even higher without the foreign inflow, engineering salaries are still higher than the salaries paid to college graduates choosing almost any other major.
- It is difficult to discuss the increasing U.S. dependence on foreign engineers without asking why we do not have more U.S.-born students being educated to meet these needs.

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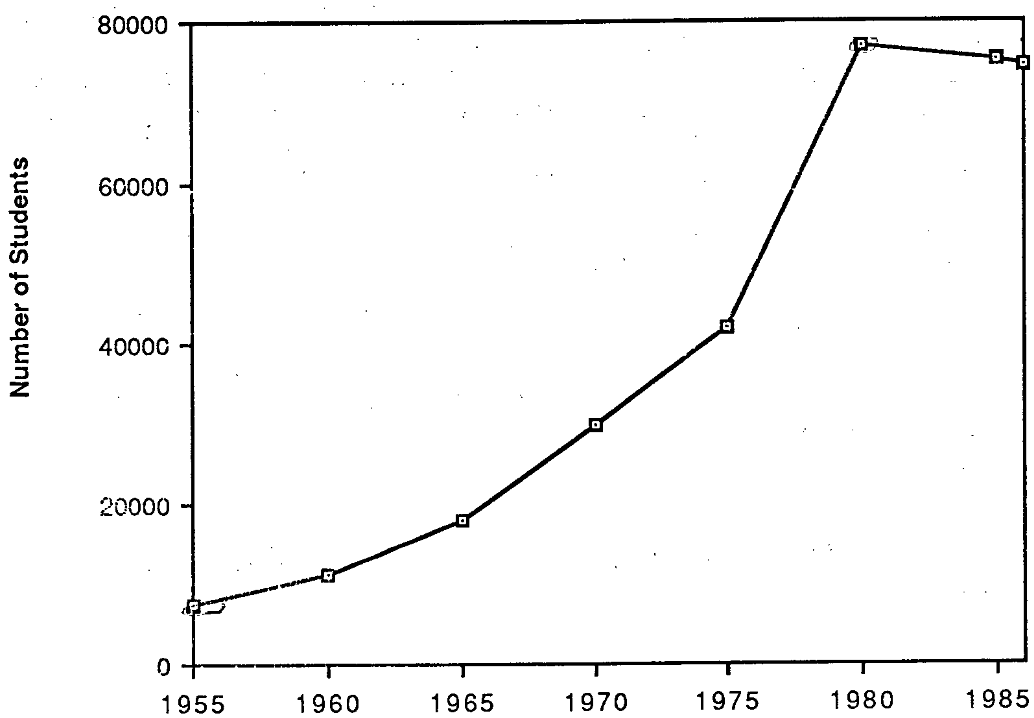
- Employers have few problems with foreign engineers because most of those hired were trained in the United States.

There is widespread agreement on these points when applied to engineering Ph.D.s. The agreement lessens as we move toward the B.S. segment of the engineering market. I discuss these assertions in more detail below. I also deal with related issues such as our ability to retain foreign engineers after they enter the United States work force.

A few definitions are in order first. I use "foreign" to mean all who are not U.S. citizens. There is a much larger group of "foreign-born" engineers because so many become naturalized citizens.

ENROLLMENTS AND DEGREE AWARDS

Figure D-1 shows the steady rise in foreign engineering enrollments. Foreign enrollments have been rising at all levels, but they have been most noticeable at the graduate level, particularly the doctoral level. The 1983 estimates of the Engineering Manpower Commission put foreign enrollments at 7, 33, and 43 percent, respectively, for un-



SOURCE: M. Zikopoulos (ed.), *Open Doors, 1985-86,* New York: Institute of International Education, 1986.

FIGURE D-1 Number of foreign engineering students at all levels, 1955-1986.

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dergraduates, master's candidates, and doctoral candidates, and these would be slightly higher at each level if they included foreigners who are permanent residents of the United States (Ellis, 1985). During the 1960s less than 25 percent of our doctoral engineering degrees were awarded to foreign nationals, but that changed very rapidly during the 1970s. The percentage of doctoral degrees awarded to foreigners passed the 50 percent mark in 1981 and continued to climb to 57 percent in 1985 (NSF, 1983; Coyle, 1986).

Given the strong labor market for engineers over the past decade, it has generally been the case that foreign engineering graduates of U.S. schools have had relatively little difficulty staying in the United States to work, especially if they wanted to stay for graduate work.

What seems to shock people about the rising importance of foreign nationals in U.S. engineering are the statistics at the graduate level. What is going on here? Is there something wrong with U.S. students that we have had such a strong shift to foreign enrollments? I am not the first to ask this question, and I do not claim to have the complete answer. But I would like to offer a couple of observations for your consideration when thinking about this phenomenon.

The percentage of foreign students at the doctoral level has increased mostly because of the decline in U.S. degree awards. We had a record level of degree awards to U.S. citizens from 1969-1975. Unfortunately, that has been the only period since 1950 when real research and development (R&D) growth has been slow in the United States. Also, there was a downturn in undergraduate enrollments during that period. If we acknowledged any planning of these things, we would have to admit to a colossal failure in that we managed to get a record level of supply during the period of weakest demand.

Since 1975 we have had real R&D growth averaging more than 5 percent annually, and this has probably shifted toward the kind of work that employs more graduate engineers (e.g., defense, energy, electronics). Also, we have had a sharp rebound in undergraduate enrollments, though it is unclear how much of this has been translated into effective demand for more teachers, as the faculty/student ratio has been allowed to decline sharply (Coyle, 1986). Altogether, the demand for engineers with graduate degrees is strong. Salaries reported by new engineering doctorates have increased significantly in real terms since 1979 and have increased faster than the average of salaries in science fields. The science fields that look most like engineering in this respect are "math/computer science" and physics, and they too have large and growing foreign enrollments.

One explanation for the inability to attract more U.S. citizens to engineering graduate school is the strong market for baccalaureate engineers. No doubt, this is part of the explanation, though I see little or no increase in the salaries of B.S. engineers relative to those of Ph.D. engineers.

I think we may not have paid enough attention to other possible explanations. One of those we might consider is federal policy on graduate student support. The number of graduate students supported on federal fellowships and traineeships peaked during the late 1960s and

TABLE D-1: Full-Time Engineering Graduate Students in Doctorate-Granting Institutions, by Federal Support Status, 1979 and 1985

Status	1979	1985
Total, full-time students	39,344	55,997
Total federally supported students	10,757	11,226
Federally funded fellowships	659	777
Federally funded traineeships	500	237
Federally funded research assistantships	8,002	8,391
Other federally supported students	1,596	1,821
Federally supported as percentage of total	27.3	20.0

SOURCE: Unpublished data from the National Science Foundation, Survey of Graduate Science and Engineering Students and Postdoctorates.

declined sharply thereafter. There was a definite shift in federal policy away from fellowships to individual students, with the expectation that increasing numbers would be supported as research assistants on projects supported by the federal government. I suggest that one unintended consequence of this shift away from fellowship support is increased federal support for foreign nationals. With few exceptions the federal fellowship programs are restricted to U.S. citizens. In contrast, research assistantships are awarded by universities, and there seems to be little or no discrimination on the basis of citizenship. Universities can defend the practice of awarding federally supported research assistantships to foreign nationals. It is not my aim here to argue that they should discriminate on the basis of nationality. However, it is clear that the federal government would have more influence if it were supporting more graduate students through fellowships, which have more citizenship restrictions, rather than through R&D funding to universities, which generally does not have citizenship restrictions.

This shift in federal policy may be part of the explanation of increasing foreign dominance of doctoral programs, but it is important to recognize that federal influence in this regard would be limited today even if federal fellowships were to grow rapidly from their present level. Federal fellowship support to engineering in 1985 supported fewer than 2 percent of the full-time graduate students in doctorate-granting institutions. Total federal support of all kinds supports only 20 percent of these students (Table D-1). The proportion of engineering graduate students with federal support has fallen since 1979 because student enrollments grew faster than the number of students with federal support.

TABLE D-2: Foreign Nationals as a Percentage of All Ph.D. New Entrants to the U.S. Labor Force, 1980-81

Field	Percent
Engineering and computer science	36.1
Civil engineering	38.7
Chemical engineering	45.9
Electrical engineering	36.6
Mechanical engineering	44.5
Aeronautical/industrial engineering	32.5
Computer engineering/computer science	23.5
All other engineering	34.4
Life sciences	7.5
Social sciences (including psychology)	5.5
Physical science/mathematics	14.9

NOTE: Includes only doctorate recipients from U.S. universities during 1980-81.
SOURCE: Michael G. Finn, *Foreign National Scientists and Engineers in the U.S. Labor Force, 1972-1985,* (ORAU-244), Oak Ridge, Tenn.: Oak Ridge Associated Universities, June 1985.

HAS IMMIGRATION BEEN CONCENTRATED IN "SHORTAGE" AREAS?

The evidence seems clear for recent graduates with U.S. doctorates. We cannot seem to agree on an operational definition of shortage. However, the fields in which employers most frequently report shortages to National Science Foundation (NSF) surveys tend to correlate quite well with the fields with high inflows of foreign nationals (see Table D-2). In particular, the social sciences and most of the life sciences are fields where employers seldom report shortages, where salaries are relatively low, and where the foreign nationals make up a relatively small proportion of the new entrants into our work force each year, when compared with engineering. The exceptions to these generalizations are almost all exceptions that prove the general point; for example, economics is unlike the other social sciences in that it has higher salaries and more foreign students.

Within engineering, however, it is not so clear that immigration has been concentrated in areas of relative shortage. In nearly every field of engineering examined, foreign nationals make up between one-third to one-half of the people entering the U.S. work force with new

Ph.D.s.[1] Where a field lies within that range does not seem to be related to relative degree shortage.

If we look at the data for all scientists and engineers at all degree levels, there is only weak evidence of a correlation between shortages reported by employers and percentage of foreign nationals in the work force (Finn, 1985, p. 3).

A labor certification requirement (that the U.S. Department of Labor certify that an employer has made a good-faith effort to hire a U.S. citizen) applies to many foreign students who wish to stay in the U.S. to work (IEEE, 1984). However, during the early 1980s, the labor certification process showed only a weak correlation between reports of employer shortage and number of labor certifications by field of science or engineering. When the number of employers reporting shortages fell sharply after 1981, the number of labor certifications fell too, but not as sharply. And the number fell entirely because of a fall-off in the number of applications--the turndown rate for individuals stayed below 5 percent in 1982 and 1983. The number of labor certifications seems to contain an element that is not very sensitive to changing labor market conditions. This government mechanism to restrict immigration in "nonshortage" areas seems to have some effect. However, the effect seems to come about because the certification process imposes a significant price on any employer who wants to hire an alien requiring certification. The price is presently in the form of paperwork and delays and is something many employers avoid if they can by hiring someone who is already a permanent resident or U.S. citizen.

ESTIMATES OF IMMIGRATION AND EMIGRATION

We have good estimates of the immigration of foreign engineers into the United States. Statistics from the Immigration and Naturalization Service (INS) indicate immigration of about 7,200 engineers annually from 1982 to 1985 (NSF, 1986). My own research suggests that an estimate of nearly 10,000 foreign national engineers entered the U.S. work force in 1981, though some were working on temporary visas and therefore would not be counted as immigrants by the INS or the U.S. Department of Labor (Finn, 1985). However, we have virtually no data on emigration of scientists and engineers from the U.S. work force. This is needed before we can really assess the role of foreign nationals in the U.S. work force.

Anecdotal reports indicate that some foreign nationals who work in the United States for large U.S.-headquartered, multinational firms will be transferred to foreign sites within the same multinational firm. Firms might, for example, be starting a new laboratory outside the United States and wish to provide training and experience at a similar U.S. facility beforehand. The recent strong growth of Korea in manufacturing has been accompanied by the return of Korean natives who had

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1 This assertion is based on 1982 data (see Finn, 1985) and on an examination of trends in degree awards since 1982.

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worked as engineers in the United States prior to their return. We could compile many bits and pieces of this movement from such anecdotal reports, but this is only enough to suggest that the flow is not trivial. We cannot get a good measurement this way.

I am conducting some research in an attempt to estimate the emigration of foreign-born scientists and engineers from the U.S. work force during the period 1981-1986. While efforts are not complete, I can present some results for doctorate engineers from 1981 to 1985. Using the response rate to the 1981 Survey of Doctorate Recipients (SDR) as a point of departure, I obtained special tabulations of 1981 response rates for those with engineering doctorates. I then examined the 1983 and 1985 response rates for all of the 1981 respondents, calculating response rates separately for those born in the United States, those born abroad but who were U.S. citizens in 1981, foreign nationals on permanent visas in 1981, and foreign nationals with temporary visas in 1981. I hypothesize that emigration would be greater for the foreign-born and, within this group, that emigration would be greatest for those here on temporary visas in 1981. Emigration does not always result in nonresponse to the SDR, so I also recorded responses from abroad and treated an increase in foreign responses the same as an increase in nonresponse.

The estimates in Table D-3 are based on two important assumptions: (1) there is no net emigration by native-born, U.S.-citizen engineering doctorates from 1981 to 1985, and (2) all of the change in nonresponse for others relative to the native-born reference group is the result of emigration. While perhaps not perfectly accurate, I find these to be reasonable assumptions. I am not assuming no difference in response rate behavior for foreign-born individuals living is the United States. That can show up in our 1981 base-year calculation. I am simply assuming that the 1981 to 1985 *increase* in the nonresponse for foreign-born relative to U.S. natives indicates emigration of foreign-born. Given that the foreign-born typically have more opportunities for em-

TABLE D-3: Four-Year Emigration Rate Estimates from Nonresponse to the 1981 and 1985 Surveys of Doctorate Recipients

Status	Percentage
Naturalized U.S. citizen	1.3
Non-U.S. citizens in 1981	
Permanent visas	13.8
Temporary visas	45.0

SOURCE: Calculated by author from special tabulations from the National Research Council's 1981 and 1985 Surveys of Doctorate Recipients.

TABLE D-4: Estimated Emigration Versus Estimated Immigration of Doctorate Engineers, 1981-1985

Classification	Number
Emigration losses	700
"Immigration gains"	
No U.S. degree	800
U.S. degree	3,900
Total immigration	4,700

NOTE: Immigration here includes anyone entering the U.S. work force, even those who are working in the United States on temporary visas. Immigration gains are obtained by estimating a 1-year rate and multiplying this by four. This leads to some overestimation of net immigration during the 4-year period because, due to emigration, the 4-year immigration rate can be expected to be lower than four times the 1-year rate.

ployment abroad and also have more family ties, this seems like a reasonable interpretation. In defense of the reasonableness of this interpretation, I note that the data behave as might be expected in several respects. One, shown in Table D-3, is that our estimates show emigration rates increasing with citizenship status in 1981 in the expected fashion--that is, higher emigration estimates for non-U.S. citizens than for citizens and, among the noncitizens, much higher emigration rates for those who were on temporary visits in 1981.

Also, I examined estimated nonresponse rates by region of birth and obtained what I believe are not surprising results: the highest rate of nonresponse in 1985 was for those engineers who were born in East Asia. Doctorate engineers born in this region are relatively young and have ties to a rapidly industrializing region, so it seems reasonable to interpret their nonresponse as signaling emigration. In contrast, by country of origin, the highest response rate in 1985 was for those born in Western Europe or Canada. These engineering doctorates tend to be relatively older compared with other immigrant engineers, have probably been in the United States for a longer period of time, and thus might be expected to have a lower emigration rate.[2]

Another way to examine the plausibility of the emigration rate estimates shown in Table D-3 is to use them to estimate total emigration during the period. Such estimates are shown in Table D-4, which suggests that emigration of foreign-born doctorates from the U.S. work

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[2] I excluded Ph.D.s over 58 years of age in 1981 altogether because emigration associated with retirement from the labor force is not our primary interest.

force is significant in relation to the number entering the U.S. work force. Over a 4-year period, I estimate that emigration losses amounted to about 15 percent of the number who entered the U.S. work force. To me this is plausible, as my "immigration" estimates include not only legal immigrants but also persons who enter the work force while still on temporary visas. This estimate can be contrasted with estimates that total emigration is about one-third of all immigration (Warren and Kraly, 1985).

A number of issues are worth considering, assuming, as I do, that these numbers are reasonably accurate. First, we need to verify these preliminary estimates; and if confirmed, this means that the Doctorate Records File, based on the annual Survey of Earned Doctorates and maintained by the National Research Council (NRC), needs to be modified. At present, the NRC and the NSF are, I believe, assuming that people I call "emigrants" are nonrespondents. The consequence of this is that they overestimate the number of engineering doctorates in the United States, especially the number of foreign-born engineering doctorates. Second, I believe that, if confirmed, an outflow of foreign-born engineers of this magnitude strengthens the argument for a public policy to encourage greater enrollments of U.S. citizens in graduate schools of engineering.

EARNINGS OF FOREIGN ENGINEERS RELATIVE TO THOSE OF U.S. CITIZENS

I think the evidence is clear that foreign engineers do not work for less than comparable engineers who are U.S. citizens. I have examined this question with two completely different data sets. One was a large representative sample of experienced workers interviewed by the Bureau of the Census for the NSF. In that study I examined the earnings of over 13,000 engineers and controlled for years of work experience, type of employer, degree field, degree level, and several other relevant factors. I found no support at all for the notion that foreign nationals working in the United States without any degrees from U.S. universities might earn less; but this is a small group, and even if we accepted this weak evidence (not significant at the 0.05 level), it pointed to an earnings differential for this subgroup of only 3 percent. I am willing to assume that a small differential such as this might be due to such factors as language ability or school quality, for which we were not able to control (Finn, 1985).

I also analyzed recent science and engineering graduates who earned B.S. or M.S. degrees from U.S. universities during 1982 and 1983. The results are unpublished but support fully my conclusions from analyzing NSF's experienced sample.

I know that there are some engineers who are convinced that foreign engineers do work for less and do depress earnings for those native-born U.S. citizens. The main evidence I have seen offered to prove their point is employment advertisements that offer low wages. I reject these because I know that there is quite a bit of variance in earnings at every experience level. It is not surprising that we should see ads for jobs that pay 30 or 40 percent less than the median wage.

These jobs are at the low end of the pay scale, experience a lot of turnover, and consequently are advertised relatively frequently. I have seen no better evidence offered to support the contention that foreign engineers work for less.

I do, however, concur that foreign engineers probably depress earnings below what they would be in their absence. Based on existing empirical research of the engineering labor market, I think the following is hard to disagree with: if foreign engineers had not been allowed to enter the U.S. labor market over the past decade, we would have seen an increase in engineering salaries above current levels. The increase in salaries would have been greatest for Ph.D.s and would have resulted in an increase in Ph.D. enrollments. However, the increased enrollments would not have been enough to offset completely the loss of the foreign workers, with the result that salaries would remain higher than they are now.

While I can understand why some would prefer higher salaries for engineers, I think it is worth pointing out that engineering salaries are higher than salaries in nearly all other occupations. Further, the legal immigration of engineers is only a small fraction of total legal immigration and, presumably, an even smaller fraction of total immigration, legal and illegal. Engineers account for 1-2 percent of the U.S. work force with the precise percentage in that range depending on whether we use statistics from NSF or the Bureau of Labor Statistics (BLS) on the number of engineers. Engineers account for 1-2 percent of legal immigration as well, and that might fall if we could get a good estimate of illegal immigration. If we restricted entry of engineers without restricting total immigration, we would probably reduce the overall quality of our work force and depress wages in some of the occupations that already offer substantially less than engineering. In short, I do not think it is relevant to consider a scenario where the only thing different is that we have fewer engineering immigrants and higher engineering wages. Restricting immigration generally to lower levels is an issue beyond the scope of this paper. However, I would note that a strong argument has been made that such restrictions would not necessarily raise U.S. wages or would raise wages by a very small amount (Borjas and Tienda, 1987; Johnson and Orr, 1981).

DO FOREIGN ENGINEERS DISPLACE U.S. NATIVES IN ENGINEERING SCHOOLS?

Remarkably little research has been directed to this issue, but I think that the evidence suggests a displacement effect. The more interesting questions are: How great is the displacement effect? and So what? I say this because the evidence from the labor market studies support the view that (1) other things equal, salaries would be higher with fewer graduating engineers, and (2) engineering enrollments are responsive to the economic incentive of higher salaries (Freeman and Breneman, 1974; and Shamia, 1984).

We really do not have the research that we need to estimate the displacement effect. The model that comes closest to what we would need is in Shamia's 1984 Ph.D. dissertation, which builds on earlier work by Hansen, et al. (1980), Freeman and Breneman (1974), and Scott (1979). Shamia's model has four equations--one each for the number of enrollments, number of graduates, salary, and total employment. For the question at hand, two parameters from Shamia's model are especially relevant: the elasticity of engineering enrollments with respect to salaries and the elasticity of salaries with respect to enrollments 5 years earlier. Using his estimates of these parameters over the period 1959-1980, we can obtain an estimate of the effect of increasing foreign enrollments on salaries and thus on domestic enrollments. Assuming that 60 percent of the foreign engineering Ph.D.s stay in the United States to work, a 1.0 percent increase in enrollment by recruiting foreigners can be expected to cause a 0.2 percent drop in salaries and this, in turn, would cause a decline in U.S. citizen enrollments of 0.16. This is the short-run impact. With several years to adjust, Shamia's model produces estimates of enrollment elasticity of 1.28 (instead of 0.81 in the short run), and this can be used to produce an estimate of a longer-run displacement effect of 0.26. Thus, increasing foreign enrollments by 100 increases total enrollments by only 84 (74 in the longer run). If one wants to increase total enrollments by 100 though, foreign enrollments could be increased by 119 (135 in the longer run).

Let me be the first to criticize the estimate just provided. Shamia's estimates of enrollment elasticities were calculated for total enrollments, not U.S.-citizen enrollments. He did not design the model to address this question. It is plausible that the effect for U.S. citizens' response to salary changes is greater, since the total effect reflects some averaging of the response to salary changes in the U.S. market by foreign and U.S.-citizen students. If this is so, we would expect the displacement effect to be somewhat larger than estimated here. Perhaps more important, I would argue that Shamia's results may not be robust. Would we get the same results with a different time period, with a slightly different model specification, with salary data other than the salary offer data reported by the College Placement Council? We do not know. We do know, however, that his parameter estimates are not out of line with other estimates of the market for Ph.D.s.[3] If there is a more appropriate model of the engineering Ph.D. labor market, I am not aware of it.

Suppose we accept that there is a displacement effect. Let us, for the purpose of discussion, even say it is around 0.25--that if foreign enrollments go up by 100, then U.S. enrollments will fall by 25. So what? What difference does it make? Would it affect our view of the desirability of foreign engineers in the U.S. labor market?

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[3] Enrollment elasticities measure the percentage change in enrollments in response to a 1 percent change in salaries. Shamia (1984) estimated enrollment elasticities of 0.81 (short term) and 1.28 (longer term). This is somewhat lower than the 2.0 that Freeman and Breneman (1974) assert to have been the case in the physical sciences, but close to what Scott (1979) found for Ph.D. economists (0.89).

I think there is a need for more engineers in the United States. I think we should encourage more young people to go into science and engineering. If we are successful, employers will be hiring fewer foreign engineers. We should do this because our young people want the kinds of jobs engineers get, but many who want those jobs are not preparing themselves properly and cannot get in or cannot stay in engineering school.

We would have a difficult choice if estimates of displacement were so high that the admission of foreign engineering students could be expected to reduce the size of our total engineering work force in subsequent years. Consider the arithmetic for Ph.D. engineers. Suppose that admission of 100 foreign students does displace 25 U.S. students on the margin. Suppose that 62 percent of the foreign nationals who get doctorates stay here to work, then (assuming U.S. natives all work here) our work force would have a net gain of 62 - 25 = 37. What about emigration? If some of the foreign nationals emigrate, would that reduce the net gains to the United States from admitting foreign students? Yes, but to the extent that they emigrate, the displacement effect is smaller (they are not here having a depressing effect on salaries). I have examined different stay rates and emigration rates applied to those who do stay, and I cannot find any combination where the total Ph.D. engineering work force is smaller because of foreign students. Unless we come up with some estimates of displacement effects that are very different from those produced using Shamia's dissertation, I can imagine only one scenario where foreign enrollments reduce total supply: we could get a temporary decrease in supply if the stay rate for foreigners declined sharply. It might take several years before the graduate schools could recruit and graduate more U.S. students, and in the meantime total Ph.D. supply would probably be less than it would have been if a smaller number of foreign students had been admitted in the first place.

NET BENEFITS OF FOREIGN ENGINEERS

The emigration of foreign-born engineers may be a problem for the United States if these engineers transfer technology to our military or commercial adversaries. The displacement of U.S.-native engineering students is a problem too. But both of these can be exaggerated. The cost of technology transfer is difficult to measure, and the steps that are sometimes used to reduce the flow have, it has been argued, often been more costly to us than the problem that they are intended to cure. It is not even clear what we might accomplish in this regard if the number of foreign graduate students in engineering were limited to some arbitrary but positive percentage of the total student body. Would technology transfer be reduced if the number of foreign students were cut in half? I doubt it.

On the other hand, there are some very real benefits to the U.S. economy from the foreign engineers who do stay here. Scholars who have looked at the total immigration picture are not in complete agreement but tend to conclude that immigration on balance benefits the U.S. economy (Johnson and Orr, 1981). These conclusions are generally based on benefits other than productivity increase because immigration tends to increase productivity only if the average immigrant is more highly skilled than the average worker in the U.S. labor force. Borjas' studies indicate that, at least in recent years, immigration on the whole appears not to be increasing the average skill level of the labor force because so many immigrants are low-skilled (Borjas and Tienda, 1987). The immigration of engineers and scientists is an important element of immigration, tending to offset the lower productivity of low-skilled immigrants. To see the benefit of foreign engineers, consider what would happen if the entry of foreign engineers were restricted. The total immigration quota would almost certainly be filled, but the average skill level of immigrants would decline. To the extent that immigrants do depress wages, this would probably still happen; but it would happen more in other (already lower-paid) occupations. The U.S. economy would almost certainly be worse off.

On a final note, let me add to the evidence indicating that foreign-born scientists and engineers are enriching the quality of our work force. Lerner and Roy (1984) documented that foreign-born engineers and scientists are overrepresented among the memberships of the National Academy of Engineering and the National Academy of Sciences and also among U.S. winners of the Nobel prize. I believe that our science and engineering immigrants are also contributing to the quality of our work force through the achievements of their children. I inquired of the Westinghouse Science Search Organization and found that nearly one-third (13) of the 40 high school seniors that it honored this year were the children of immigrants, mostly Asian Americans. I did not get data on their parents' occupations, but it seems a safe bet that most of their parents are among the small minority of immigrants who were themselves trained as scientists and engineers.

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FOREIGN ENGINEERS IN U.S. INDUSTRY: AN EXPLORATORY ASSESSMENT*

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INTRODUCTION

The following, an exploratory paper that attempts to identify and validate issues related to the presence of foreign engineers in U.S. industry, is largely based on surveys of and discussions with top-level managers in the industrial research and development (R&D) community. Inasmuch as recent data from the National Science Foundation (NSF) show that the predominant work activities of foreign engineers were in R&D--encompassing some 36 percent of all foreign engineers--the sample of views surveyed is thought to be representative of the prevalent views within those segments of U.S. industry that most frequently confront issues related to foreign engineers. By comparison, 24 percent of U.S. citizen engineers are engaged in R&D activities.

NSF quantitative data recording the participation of foreign engineers in the U.S. labor market was extensively used as a secondary source for the background of this study. The study, however, is qualitative in nature inasmuch as it aims to get a handle on such nonquantifiable issues as the advantages and disadvantages of employing foreign engineers, the role of the immigrant engineer in U.S. industry, and the effect of language and cultural differences on the interactions of foreign engineers with their American peers. Thus, except when the data clearly reflect the validity of an issue--as in the case of the "dependency" of U.S. industry upon foreign talent--it is of secondary interest to this study.

Several other issues raised by survey respondents and in conversations were checked against relevant secondary data. The existence of barriers to the hiring of foreign engineers is raised as an issue, and such barriers are extensively described in the study. The chances for growth in the number of foreign scientists moving into upper management is an issue that arose not only in conversation with members of the R&D community, but also from the sheer demographics of a situation in which there is a decreasing number of native-born Americans--in absolute and proportional terms--entering the scientific and technical disciplines while an increasing number of foreign engineers are choosing to work in

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* The views and opinions expressed herein do not necessarily state or reflect those of the Rockwell International Corporation.

technical fields in the United States either temporarily or permanently. In no instance was purely anecdotal evidence relied on in the treatment of a topic. The field is ripe for further research of both a descriptive and causal nature in all the issue areas raised by this paper. Whether such research would prove useful is an issue in itself that this study raises.

For purposes of this paper (except where noted otherwise), "foreign national" refers to all persons not citizens of, nationals of, or immigrant aliens to the United States. An "immigrant alien" is any person who is lawfully admitted into the United States under an immigration visa for permanent residence. An "immigrant" is any person who was not born in but has become a citizen of the United States.

SURVEY QUESTIONNAIRE

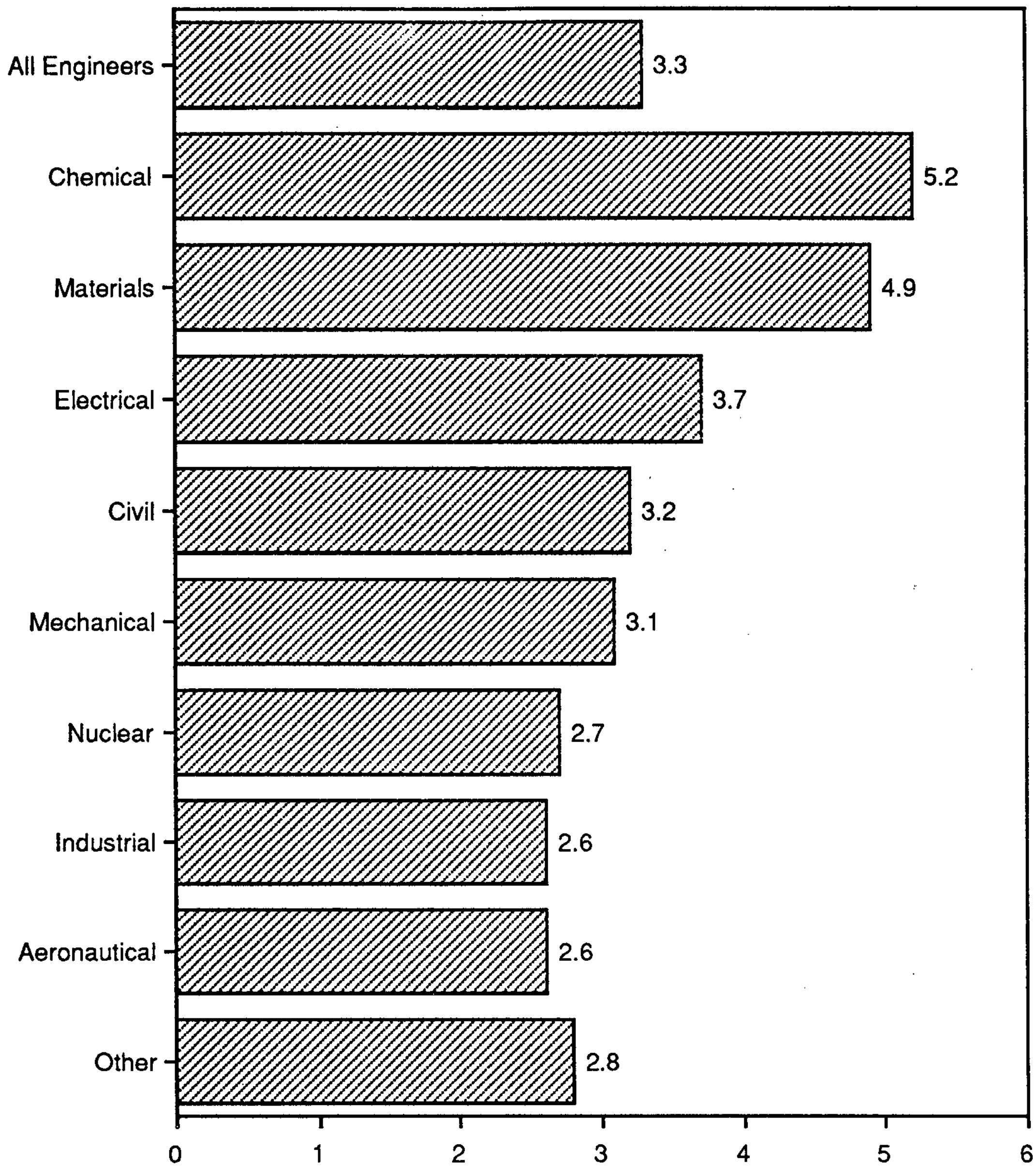
A written survey questionnaire (see Appendix I) was developed after discussion with appropriate professionals in personnel and R&D management and distributed to 20 members of the Industrial Research Institute (IRI) who had previously expressed an interest in public policy issues. The questionnaire was designed to identify issues related to the presence of foreign engineers in U.S. industry and to establish the parameters of concern in respect to each issue. More specifically, the questionnaire attempted to

- Establish the dependency (if any) of U.S. industry on foreign engineers;
- Determine the preparation, skill, and professionalism of the foreign engineer in comparison to his/her American counterpart;
- Identify and describe barriers to the hiring of foreign engineers;
- Determine the prospects for growth of the foreign engineer into upper-level management and the role (if any) that cultural and language differences play in the conduct of business and the calculus of growth;
- Determine the level of interest in the subject of foreign engineers in U.S. industry itself and the extent to which it is thought to warrant further study; and
- Identify any other concerns of the respondents not raised in the questionnaire.

THE ISSUE OF INDUSTRIAL DEPENDENCY UPON FOREIGN ENGINEERS

Given the limited time and resources for preparation of this paper, the question of just what constitutes "dependency" could not be determined through quantitative measures, though some valid inferences can be drawn from existing data.

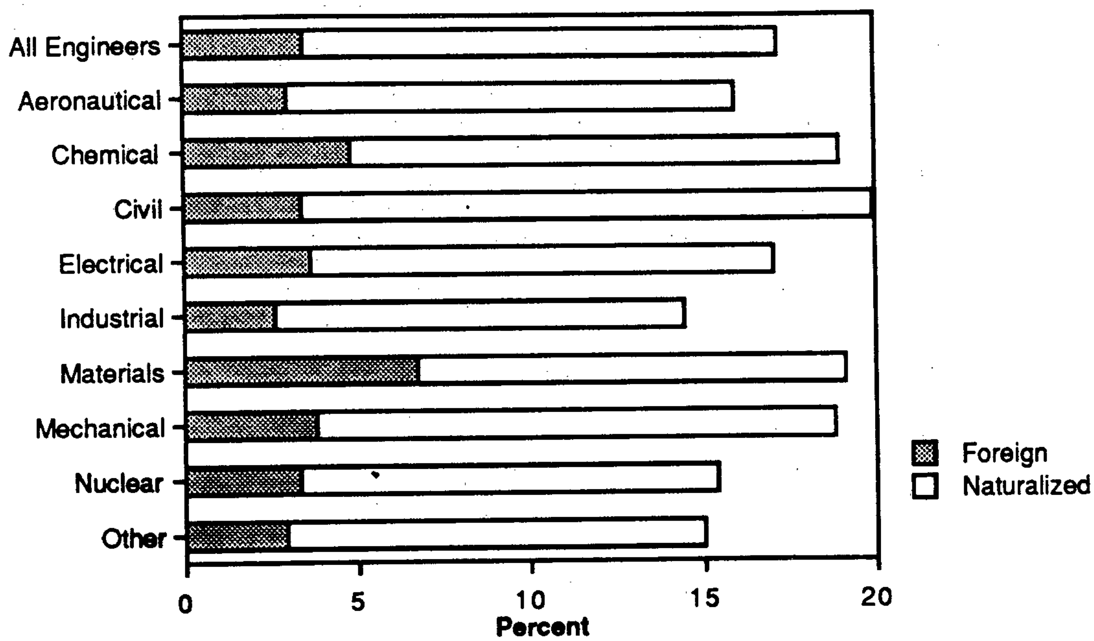
According to NSF reports (the most recent data available), only 3.5 percent of all engineers employed in the United States in 1982 and



NOTE: Includes all individuals reporting employment in 1982.
SOURCE: National Science Foundation, *U.S. Scientists and Engineers: 1984*, Washington, D.C.: U.S. Government Printing Office, 1985.

FIGURE D-2 Proportion of foreign engineers in the U.S. engineering labor force.

1984 were foreign nationals (including both those with temporary visas and those with permanent visas). This proportion varied from a high of about 5.2 percent in chemical engineering to a low of about 2.7 percent in industrial and aeronautical engineering (Figure D-2). However, about 15 percent of all employed engineers were naturalized citizens with the proportions varying from a low of about 9 percent for petroleum engineers to a high of 17 percent for civil engineers (Figure D-3). Thus, at a minimum, 18.5 percent or nearly one in five of the engineers employed in the United States in 1982 were either foreign

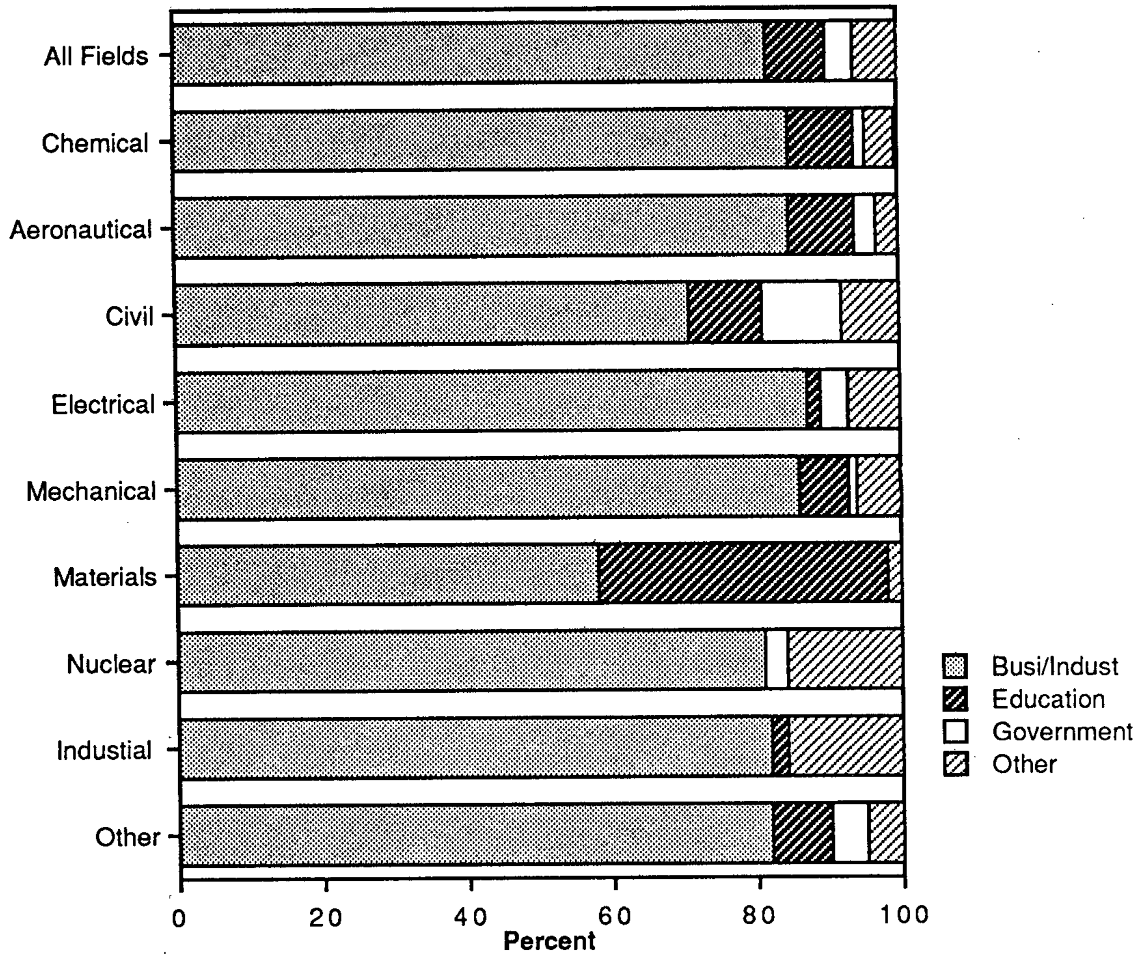


NOTE: Includes only individuals reporting employment in engineering occupations in 1982.
SOURCE: Special tabulations of Oak Ridge Associated Universities, based on the National Science Foundation's 1982 Postcensal Survey.

FIGURE D-3 Employed engineers, by field and citizenship status, 1982.

nationals holding temporary or permanent visas or naturalized citizens. Of this 18.5 percent, the greatest concentration, in absolute terms, was in industry which in 1982 employed 80 percent of all foreign engineers (Figure D-4).

Current data do not exist to confirm the claim, but there are valid reasons to believe that the percentage of foreign engineers in the population of all engineers in the United States is greater than 18.5 percent. This is because the number obtained in 1982 has been shown to be part of a rising trend. Michael Finn, a senior economist at Oak Ridge Associated Universities, compared data from NSF's 1982 Postcensal Survey with a similar one conducted in 1972 to see how immigration has changed over time (Finn, 1986). Finn found that the percentage of immigrant engineers increased some 9.1 percent over the decade, from 9.4 percent in 1972 to the 18.5 percent level of 1982. These trends are likely to continue. When the educational trend lines in engineering are considered, it is found that, inter alia, (a) demand for scientific and engineering personnel in academia and industry is rising, (b) the college-age population is shrinking and fewer Americans are pursuing engineering studies after the undergraduate years, and (c) more than half of all new engineering Ph.D.s entering the work force are foreign nationals. Can we infer "dependency" from such



NOTE: Includes only individuals reporting employment in engineering occupations in 1982.
SOURCE: Special tabulations of Oak Ridge Associated Universities, based on the National Science Foundation's 1982 Postcensal Survey.

FIGURE D-4 Distribution of foreign engineers, by sector of employment, 1982.

trends? Would the United States suffer if it lost nearly one-fifth of its engineering work force? Can it remain competitive with only half as many engineering Ph.D.s?

At the very least, such numbers indicate that foreign talent comprises a significant and growing segment of the engineering work force in U.S. industry. The R&D executives who responded to our survey went further, as the majority concluded from experience that their particular industries are, in fact, dependent upon foreign talent and that such dependency is growing. It should be noted that the respondents from industries that engage in defense-related work also asserted that dependency exists, but in their case the definition of "foreign talent" entailed only naturalized citizens, owing to the existence of legal and regulatory barriers. The survey revealed that foreign engineers and scientists are being heavily relied on in areas of high scientific concentration. In several responses, foreign talent was said to be a "critical" element of the firm's operations. Almost every respondent said that such dependency is increasing. Only two people said that their business was "slightly" or not dependent upon foreign talent. Asked if their business would "thrive" or "progress" without foreign engineers, most respondents said that they could continue but would have to curtail certain areas of work or staff them with lower-degreed or less optimally degreed people (e.g., chemist as opposed to biochemist). Other respondents noted that foreign engineers are making significant contributions to the technical quality of American industry. It appears that the words "thrive" and "progress" were probably too leading and/or amorphous to elicit further explication on what is meant by "dependency."

THE FOREIGN ENGINEER IN COMPARISON TO THE NATIVE AMERICAN ENGINEER

When asked to compare foreign engineers to American engineers in terms of preparation, skill, and professionalism, the uniformity of responses that was elicited by the dependency question did not arise. No respondent said that foreign engineers were much better or much worse than Americans in the above terms. "Equal to" or "on average, better than" Americans were typical responses. Some respondents--seemingly anticipating the next question--mentioned comparatively poor communication skills as a big drawback of foreign engineers.

The Language Factor

Almost every survey respondent believed that language differences present difficulties in the operation of their business. Respondents from consumer-oriented businesses said that communication difficulties arising from language differences were real problems. In a later question concerned with the prospects for growth of the foreign engineer into upper management, language difficulties were repeatedly mentioned as factors.

Barriers to the Hiring of Foreign Engineers

A general policy at the companies of the survey respondents seems to be not to hire engineers who do not have "green cards" or permanent visas. The paperwork and litigation necessary to clear those without such papers were mentioned as too time-consuming and expensive. Respondents mentioned security considerations and government-imposed regulations as the principal barriers to the hiring of foreign engineers. Included below is a brief description of those regulations. As noted earlier, there is a marked difference between defense-oriented industries and commercial industries with regard to the definition of a foreign engineer. For the past 5 years, defense-oriented industries have had to wade through a host of complex procedures and legal thickets just to speak with a foreign national; consideration of hiring an immigrant with a temporary or even a permanent visa has been almost as difficult for both defense and commercial industries. As far as foreign nationals are concerned, the Immigration and Nationality Act provides that a foreign national (already in the United States) who seeks immigrant status for the purpose of employment is ineligible to receive such a visa and is then excluded from admission into the United States at this time.

Relevant government regulations are numerous. Companies conducting defense-related work are covered by International Traffic and Arms Regulations (ITAR) promulgated by the U.S. Department of State. ITAR limits military exports including material products and even information itself (State, 1987b). Further, Department of Defense regulations (a) prevent the disclosure of unpublished technical information to a foreign national, (b) prevent two-way technical interchanges, (c) insist that a foreign national be escorted at all times when in a defense-related industry, and (d) prevent a foreign national from being processed for a security clearance (Defense, 1986). Only in rare circumstances can defense companies obtain clearance for an immigrant alien at the secret or confidential level: the U.S. government must determine that such a clearance is in the national interest, and the company must then obtain a personnel clearance letter from the Defense Industrial Clearance Office. Finally, there is also a required procedure to be followed in requesting a foreign student for practical training in U.S. industry. Companies not engaged in defense-related work are subject to a host of Export Administration Regulations (EAR) overseen by the Department of Commerce. EAR limits the export of "non-military items and information" (State, 1987a) using very broad definitions that have been the subject of much recent controversy and of a National Academy of Science sponsored study (Committee on Science, Engineering, and Public Policy, 1987).

The penalties for companies violating such regulations are severe, including the loss of security facility clearances and an end to payment on current contracts, as well as a $100,000 fine and 10 years' imprisonment for individuals who engage in the violations.

Aside from U.S. government rules, industry often must deal with various state regulations regarding the employment of foreigners. For example, in California, employers must coordinate their plans with the State Employment Development Department prior to contacting any foreign national.

For obvious reasons, many companies simply do not hire foreigners until they are well on their way to becoming American citizens.

Discussions

Here it is appropriate to introduce the observations that arose in the course of the author's discussions with engineers and R&D personnel from industry and universities, for the observations bear directly on the issues addressed above. The discussions were unstructured and contained no direct questions as in the survey questionnaire. Perhaps the most interesting observation the author brought away from these discussions was the relative noninterest in the "issue" of foreign talent in U.S. industry. As will be seen later in this paper, this observation correlates with the responses to two of the final three survey questions.

The conversations revealed that companies that operate worldwide, even those that are principally U.S.-owned and U.S.-domiciled, tend to employ indigenous nationals in their global product-markets. The universe of such firms tends to be led by those domiciled in the trading and mercantile nations, like the Netherlands, United Kingdom, Switzerland, and Japan, rather than in the United States. Examination of the Fortune 500, roughly equating to a scale of $7 billion and up, reveals no company that has exclusively domestic markets (Anonymous, 1987a). While several such firms are not transparently multinational (e.g., several are defense contractors), over half are known to conduct operations outside the United States, and several, according to the Industrial Research Institute (IRI) handbook, operate R&D facilities outside the United States also (IRI, 1985).

For both multinationals and very large domestic corporations with international reach (henceforth, "international corporations"), the issue of national origin and for that matter the country of training becomes less relevant than an assessment of ability, training, and proficiency in the skills of importance. In fact, the very existence of the question that is the theme of this report appears to be thought irrelevant in such companies as Shell, Nestle, Mitsubishi, and Imperial Chemicals, except to the extent that the prospects for advancement into the policy-determining governance of the company continue to be seen in cultural terms instead of purely technical excellence.

No matter the nationality or the country of training, "foreign" men and women are in the mainstream of technical-management work in U.S.-owned multinational and international corporations, and their status is assured by their ongoing performance. (Still, as will be shown shortly, foreigners are not breaking into the ranks of upper-level management or into corporate board rooms in any of the world's corporations.) The only outstanding foreign engineer "issue" that seemed to be on the minds of those with whom the author spoke concerned whether such personnel would be allowed to become naturalized citizens and remain in the United States after a term of employment. Interestingly, a further search of the IRI membership handbook reveals that at least 12 percent of the senior R&D managers from the Fortune 500 were foreign born or foreign-trained--an observation that brings us back to my survey and into a discussion of group behavior within upper levels of business organizations.

PROSPECTS FOR GROWTH INTO UPPER MANAGEMENT

This survey revealed that within the R&D organization, the prospects for growth of the foreign engineer into upper management positions is excellent. Indeed, within technical management areas, the prospects for growth appear to hinge upon individual capability and professionalism. Put another way, the "melting pot" is at work within R&D. These survey results reinforce the observations gleaned from the discussions. However, the majority of respondents noted that the chances of rising into upper-level management outside technical areas —for example, corporate director level—are slim to none. Language and cultural differences were most often cited as factors in limiting growth. The discussions, however, revealed that another somewhat more parochial factor may be at work.

To a remarkable extent, it appears that the personality and values of the owner or chief executive of companies of all sizes still exercise an enormous influence over the behavior of their corporate organization. Chief executive officers (CEOs), discussants asserted, project a company's value system (Stieglitz, 1985). Thus, if the chief executive is inward-looking, the company will reinforce those attitudes, and the foreign scientist or engineer could stand to suffer. Several of the discussants are convinced that foreign engineers are not breaking into upper corporate management because their company CEOs' value systems project provincial attitudes that are keeping the doors closed. Without equating intellectual provincialism with life-style, it is interesting to note that a recent *Wall Street Journal* article found that many Fortune 500 CEOs live life-styles more in tune with the 1950s than the 1980s (Anonymous, 1987b).

Admittedly, these are extremely subjective notions, but they are notions voiced by persons with long experience and a high regard for the scientific method. In any case, without inferring linkage, there is hard evidence that corporate board rooms in the world's largest corporations remain closed to persons whose origins are from a nation other than the home country of the company. *The Economist* magazine found that in 1986 only 21 companies out of the world's 100 largest corporations (ranked by dollar sales) had foreigners on their boards (Table D-5). Only nine of those had more than one foreign representative on their boards. What is most remarkable about the results is what is missing—namely, Mobil, IBM, Ford, and General Motors, respectively, the sixth, fifth, fourth, and first largest corporations in the world—each of which derives billions of dollars of its total income outside the United States. At present, IBM is the only one of these four giant multinationals with a non-American director on its board.

THE ISSUE AS ISSUE

The last questions on the survey were "Does the subject of the increasing presence of foreign engineers in U.S. industry merit the concern of American business and political leaders? Is it a subject worthy of an in-depth private or government study? Why or why not?"

To these questions, the majority of the respondents answered in the negative. The reason most often given was that it was not even an issue; thus, the respondents underscored the observation that arose in

TABLE D-5: Foreigners on the Boards of the World's 100 Largest Companies

Company	Rank by $ Sales	No. of Foreign Directors
Royal Dutch/Shell	2	2
Exxon	3	2
Texaco	11	1
Unilver	17	3
Philip Morris	19	1
Philips	26	1
Nestle	30	1
United Technologies	35	2
Bayer	36	1
BASF	39	1
Tenneco	41	1
Hoechst	42	1
Fiat	43	4
ICI	49	3
Dow Chemical	66	3
Canadian Pacific	67	1
Goodyear	70	1
Volvo	72	1
Xerox	78	3
Sara Lee	92	2
Ruhrkohle	96	1

SOURCE: *The Economist,* April 24, 1987.

the discussions that the issue was irrelevant. The only problem pointed to by survey respondents was the same as that pointed to in discussion--namely, the problem that would arise should a significantly greater proportion of foreign engineers choose to return to their native countries. The author could find no data that would either confirm or deny that such a situation was actually taking place or on the horizon, although it should be noted that Michael Finn, using National Research Council (NRC) data, found that 62 percent of all noncitizen graduates in science and engineering in 1982 remained in the United States (Finn, 1986). Moreover, in a recent speech Erich Bloch, director of the NSF, indicated that this finding is part of a trend that is weighted toward staying in the United States after graduation; he stated that in the years 1972-1985, the proportion of foreign engineering Ph.D. recipients on temporary visas reporting plans to remain in this country increased some 30 percent (Bloch, 1986).

THE "OTHER" MAJOR ISSUE

When asked to discuss any other relevant concerns not raised in the questionnaire, respondents raised one of two concerns only--either the need for reform of federal government regulations vis-a-vis the employment of non-U.S. citizens or the need to understand why Americans, particularly American males, are not choosing to enter science and engineering fields. Respondents overwhelmingly expressed the opinion that the reason lies in the weakness of America's primary and secondary educational system. Rather than a study concerned with reasons that foreign engineers wish to work in the United States or the implications therein, the majority of respondents asserted that a study that lays out an agenda for the major reform and strengthening of the American education system from kindergarten through grade 12 is what is called for. Bearing in mind that another report commissioned by the study committee of the NRC will explore the subject, a short brief on the education issue is in order.

As one may validly infer from Finn's study, the employment of foreign nationals in America's corporations is directly linked to the presence of foreign students in American colleges. This is an unsurprising conclusion in itself. However, in 1985, a record 342,113 foreign students were enrolled in U.S. colleges and universities (McCormack, 1987). California alone attracted 47,318 of these foreign students. Engineering continued to be the leading field of study for foreigners; it attracted 75,370 students. But, again, over the decade of the 1980s, this latter number has represented a constant average (Figure D-5).[4] Further, 75,000 foreign engineering students computes to 22 percent of all engineering students--a proportion that has not significantly changed over the last 30 years (Figure D-6). So, wherein resides the significance of the foreign student-American industry linkage?

The answer to our question is to be found when it is noted that at a time of increasing demand for scientists and engineers in the labor market, the pool of American college-age students is shrinking (Figure D-7). Erich Bloch notes that even if the United States could con-tinue to attract students at the 1983 rate, it would still train 700,000 fewer graduates in science and engineering fields over the next 20 years (Figure D-8) (Bloch, 1986). In addition to these demographic factors, there are choice factors that are combining in an explosive manner. In short, the proportion of today's college-age cohort choosing science and engineering degrees is smaller than the appropriate cohort from the 1970s (Figure D-9). Given the demographic trends and the career choice trends of American students, it is obvious that foreign science and engineering students are filling an important need in the U.S. engineering market. As Erich Bloch observes, "With fewer

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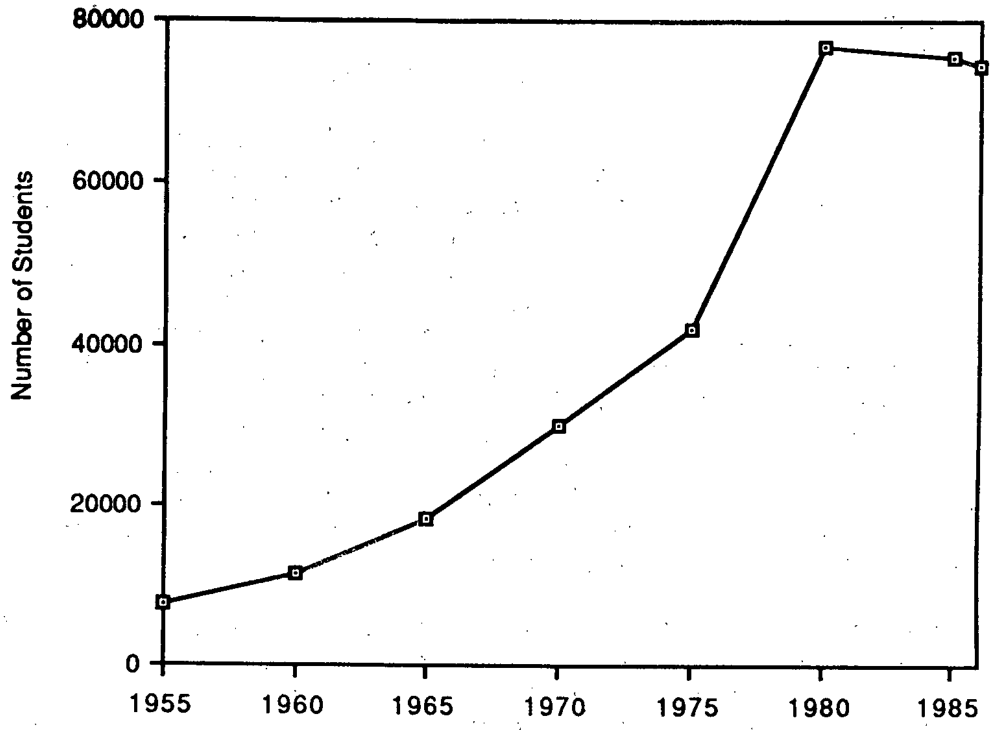
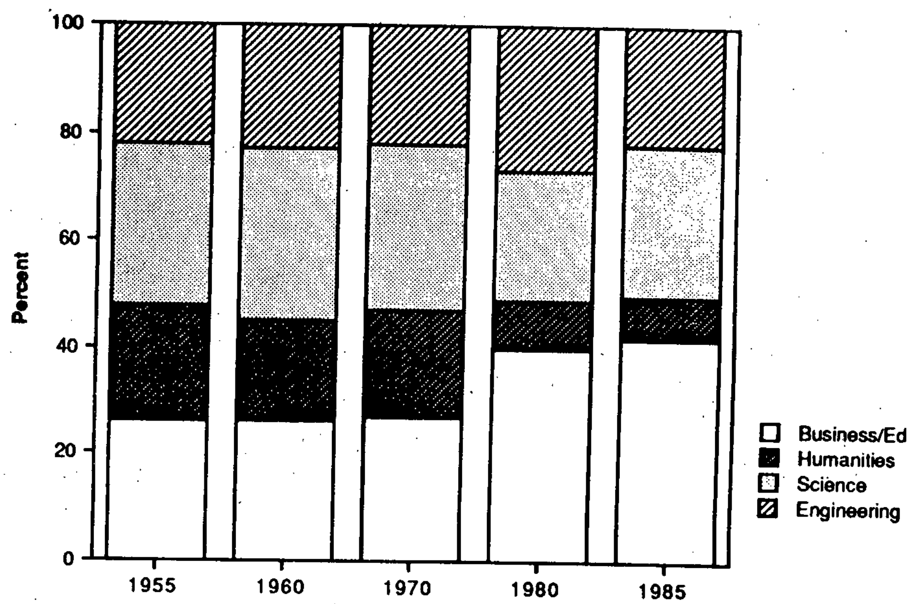
[4] Figures D-4, D-6, D-7 & D-8 are taken from Bloch's presentation of September 29, 1986, cited earlier.



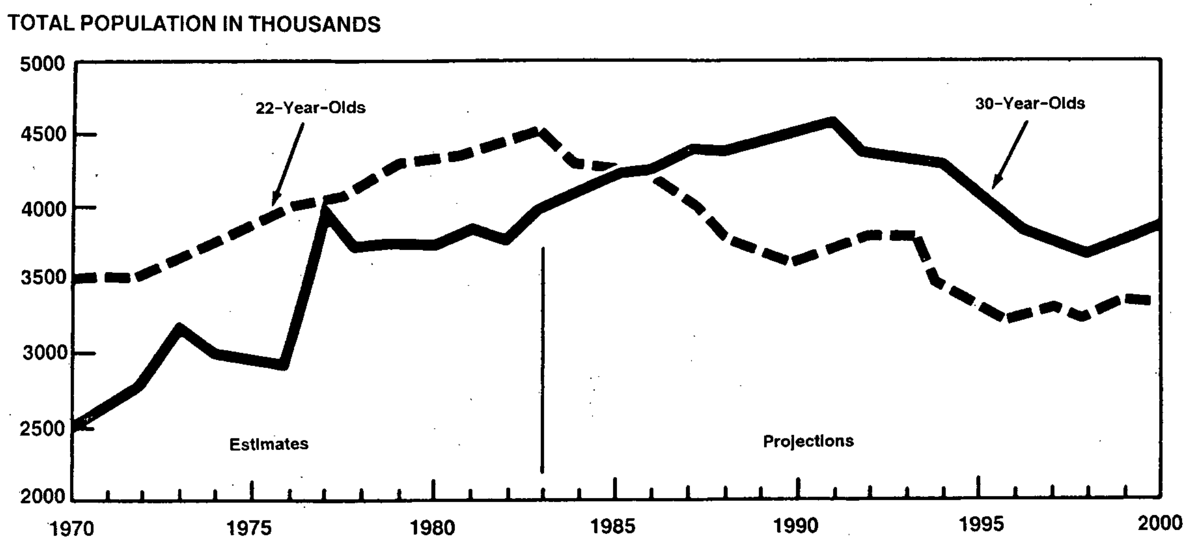
SOURCE: M. Zikopoulos (ed.)., *Open Doors, 1985-86,* New York: Institute of International Education, 1986.

FIGURE D-5 Number of foreign engineering students at all levels, 1955-1986.



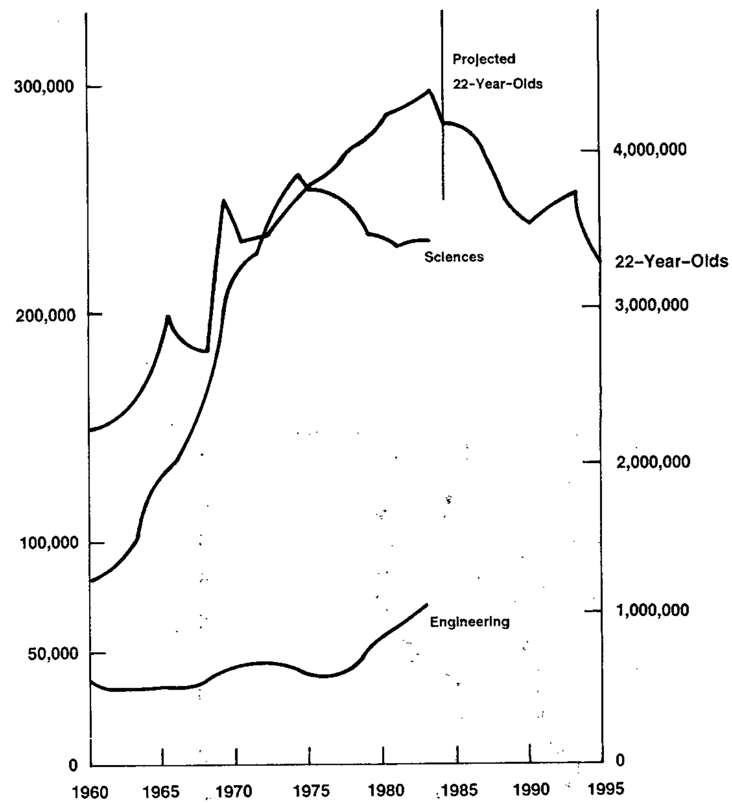
SOURCE: See Figure D-4.

FIGURE D-6 Distribution of foreign students, by field of study, 1955-1985.



SOURCE: U.S. Bureau of the Census.

FIGURE D-7 Projections of 22- and 30-year-olds in the U.S. population.



SOURCES: National Center for Education Statistics and U.S. Bureau of the Census.

FIGURE D-8 Science/engineering bachelor's degrees and 22-year-old population.

Americans choosing careers in the sciences and engineering, we are increasingly dependent on foreign nationals in some of the most important specialties" (Bloch, 1986).

The respondents' concern with understanding the reasons underlying Americans' decreasing interest in science and engineering thus appears valid. Further, a number of recent reports trace this disinterest to poor and demotivating preparation in the primary and secondary years of schooling.[5] The decreptitude of the educational system is well docu-

5 See, for instance, William Bennett, *First Lessons: A Report on Elementary Education in America,* Washington, D.C.: U.S. Department of Education, 1986; Carnegie Forum on Education and the Economy, *A Nation Prepared: Teachers for the 21st Century,* Washington, D.C.: The Forum, May 1986; U.S. Study of Education in Japan, *Japanese Education Today,* Washington, D.C.: U.S. Department of Education, January 1987.

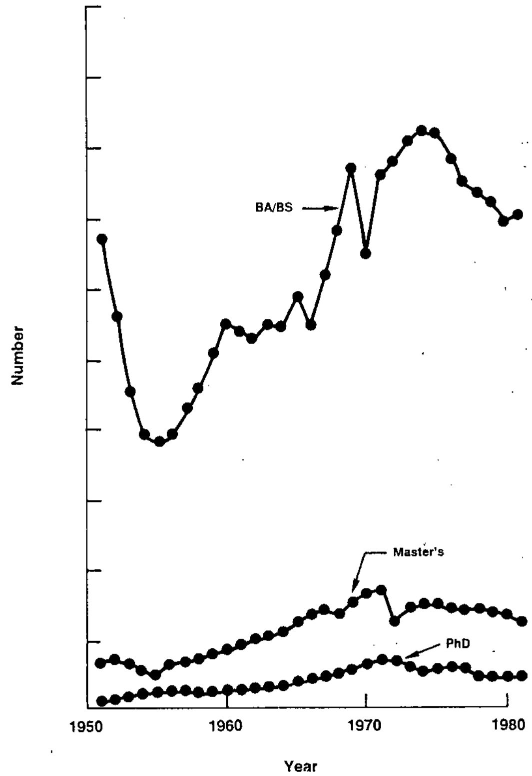


FIGURE D-9 Science/engineering degrees per thousand in appropriate age cohort, 1950-1981.

mented. What remains to be done, in the eyes of the respondents, is the completion of a study that specifically establishes the implied linkage between poor preparation and the nonchoice of science and engineering and that then goes one step further and posits an agenda for pro-active reform.

CONCLUSIONS

It is important to reflect on the value of a full-trained immigrant engineer. He/She is one who represents a net inflow of knowledge capital, with an approximate standing invested value of $100,000 and with a prospective return of at least 500 percent per year on that standing investment. Should such a person prove to be an inventor, or gifted with disciplinary insights of significance, the return is much higher.

Thus, investment in the education and recruitment of trained intellects is collectively and individually rewarding in the extreme. Subject only to some broad supply-demand concerns that should cause a prospective incentivization of allocation of resource, a plurally driven, free-market response in the schools is beneficial to the economy and its participants. The artificial barriers to entry must be lowered. There is an urgent demographic and market need to simplify current regulations so as to make it easier for American industry to employ foreign-born graduate students.

What we must assure is that a free-market flow of trained people from whatever source does not cut off or discourage the training initiatives that are needed domestically.

A study of the causes of Americans' decreasing choice of scientific and engineering fields is warranted, and a major agenda for strengthening the educational system at all levels is imperative.

As far as foreign engineers themselves are concerned, the leadership for altering and extending the value screen to enable the proper use of the large number of foreign graduate students presently in America's technical schools properly rests with the present and next generation of America's industrial research managers, a group that, as we have seen, contains a remarkable representation of the foreign-born themselves. They can provide a proper transition culture for the 10,000 and more young men and women that might be expected to graduate each year with M.S. or Ph.D. degrees--students, who might otherwise simply re-export the standing investment in knowledge capital that has been partly funded by the American taxpayer. By and large, this group wants nothing more than a fair chance at hiring the students presently in graduate schools, or an easier route to hiring those who wish to immigrate to the United States to practice their professions. What stands in the way?

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APPENDIX I

Survey Questionnaire

On behalf of the National Research Council, I am conducting an exploratory study designed to identify and validate issues related to the presence of foreign engineers in U.S. industry.

About 30 minutes of your time would help me immensely. Please read the introductory paragraphs below and respond to the questions that follow. If you cannot respond today, please take the questionnaire back to your offices and return it to me as soon as you can at the following address:

Dr. Peter Cannon
Vice President-Research & Chief Scientist
Rockwell International Corporation
1049 Camino Dos Rios
Thousand Oaks, CA 91360

Introduction

There is growing concern that U.S. industry is becoming "over-reliant" on foreign talent to meet its manpower needs in the fields of science and engineering. Some figures set the issue in perspective:

- While only 3.5 percent of engineers employed in the United States in 1982 and 1984 were foreign nationals, some 36 percent of those worked in research and development.
- In 1982 the representation of foreign nationals among employed doctorate and masters engineers stood at 12 and 6.5 percent, respectively. These numbers will probably go up as today more than half of all engineering Ph.D.s in the United States are awarded to foreign nationals.
- Charts 1-1a through 1-6 attached provide other data that you may wish to review.

With fewer Americans choosing careers in the sciences and engineering, we are increasingly dependent on foreign nationals in some of the most important specialties. What are the implications? What issues arise from the increased presence of foreign nationals within U.S. industry? The questions below, though nonquantitative, attempt to identify related issues and the respective parameters of concern. They ask for your informed opinion, not your further research. For purposes of this questionnaire, "foreign" refers to those with temporary visas, those with permanent visas, and immigrants (foreign-born Americans); American engineers are those born and educated in the United States.

Questions

1. a. Is your particular industry today dependent on foreign talent?
   b. If so, is this dependency increasing or decreasing?

c. Could your business or research thrive or progress without the foreign engineer? (For example, the assertion has been made that the field of optics would not exist in the United States were it not for foreign talent.)

2. In terms of preparation, skill, professionalism (perhaps measured in productivity), how do foreign engineers compare to American engineers?

3. Do language differences present difficulties?

4. What barriers to the hiring of foreign engineers exist? Should these barriers be strengthened or relaxed?

5. What are the prospects for growth into upper management for the foreign engineer? What role do cultural differences, language differences, etc., play in the calculus of career growth? Is the "melting pot" at work in your industry?

6. Does the subject of the increasing presence of foreign engineers in U.S. industry merit the concern of American business and political leaders? Is it a subject worthy of an in-depth private or government study? Why or why not?

7. Please discuss any other concerns that you believe should be raised with regard to this subject.

THE JOB MARKET FOR HOLDERS OF BACCALAUREATE DEGREES IN ENGINEERING

Charles E. Falk

The nature of the job market is alleged to be a major factor in engineering baccalaureates' decisions regarding entry into graduate school. Consequently, considerations of incentives to attract more American engineering students into graduate study must take into account the status of both current and near-future job markets. To assist in such evaluations, information about the current job market for engineers is presented.

A variety of organizations were contacted to extract data on the current situation. If such hard information was not available, anecdotal information was sought. These organizations included the American Association of Engineering Societies, the American Association for Engineering Education, the Engineering Division and the Division of Science Resource Studies of the National Science Foundation (NSF), the College Placement Council, the Commission for Professionals in Science and Technology, Purdue University, and Massachusetts Institute of Technology. The following picture emerged.

The only data on professional activities of new engineering baccalaureates in the year following graduation are developed by the NSF from the Survey of New Graduates. The most current data cover the March 1986 activities of the class of 1985. Preliminary tabulations show that 11 percent of the graduates were in full-time graduate study and that 86 percent of the rest were in science/engineering jobs with 78 percent in engineering and 4 percent in computer sciences. In other words, the job market was very good.

However, discussions with the other organizations mentioned above indicate a belief by some that there has been an erosion of the job market for engineers since 1986 and that even now the market is still in a transitional phase. This was confirmed by data on job offers received by new graduates. The most comprehensive, that collected by the College Placement Council, is representative of the total academic sector. Preliminary 1987 data seem to indicate that the numbers of job offers to new electrical and mechanical engineering baccalaureates are about 30 percent smaller than they were in 1985. The job offer trend was also confirmed by the Purdue University Placement Office, which indicated that job offers reported to it by Purdue engineering bachelor's graduates had held steady between 1985 and 1986 but had declined by about a factor of two between 1986 and 1987. While these data certainly indicate an erosion of the job market, the numbers cannot be interpreted to indicate necessarily a corresponding decrease in engineering jobs for new graduates. Firms make multiple offers for a single job, and baccalaureates can receive multiple offers. While these practices counteract each other, it is not known whether one dominates. For example, a 1986 National Research Council report, *The Impact of Defense Spending on Nondefense Engineering Labor Markets,* stated, "Placement offers from about a dozen academic institutions indicated that currently the demand for graduates roughly matches supply. . . ." However, this labor market has, as shown above, deteriorated further.

ON FOREIGN ENGINEERS IN ACADEME

Daniel C. Drucker
University of Florida

INTRODUCTION

The purpose of this paper is to raise a wide variety of significant intellectual and other issues for consideration. Some factual background information is provided. In addition, a number of strong and often divergent views, including an assortment of those I hold, are presented to stimulate discussion and to encourage the expression of as many alternate points of view as possible. An effort is made to cover the broad spectrum of important topics related to foreign engineers in academe, from undergraduate students to professorial staff. Among these are the questions raised by those who observe the increasing fraction of the foreign-born among the professoriate and the current dominance at the entry level of foreign-born assistant professors who received their undergraduate engineering education in developing countries. Both hopes and concerns are expressed about the likely effects on the teaching of engineering undergraduates and graduate students, the setting of the curricula, the setting of the research agendas and the modes of engineering research, and the many changes in the attitudes and actions of academic institutions that are made over time as the scope and character of engineering alter. Attention also is devoted to the specific issues identified earlier by the Committee on the International Exchange and Movement of Engineers. Long-time trends, the present situation, and the likely future are presented briefly. However, most of the detailed listing and analysis of the important numbers involved is left to other documents.[6]

IMPLICIT ASSUMPTIONS REQUIRING DISCUSSION

A number of implicit assumptions about commonly shared views underlie much of the presentation that follows. An attempt is made here to list the major ones explicitly to be certain that they are indeed shared, at least within the context of academe. If they are not, atten-

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6 See, for instance, Charles E. Falk, "Foreign Engineers and Engineering Students in the United States" (Appendix A of this report).

tion should be devoted first to any of prime significance that prove controversial. Of equal or greater importance is the identification of all other key agreed-upon assumptions that should be listed.

- First and foremost is that in this nation of immigrants there have been and will continue to be enormous contributions to engineering, as well as to all fields of knowledge and activity, from those who come to this country for a short time or a lifetime.
- Considerable diversity in educational and cultural background and experience of students and of faculty adds greatly to the educational experience of all and to the research effectiveness and productivity of the academic institution.
- Many of our foremost academics (as well as leading people in industry, government, and research institutes) are foreign visitors or immigrants.
- Many of our very best engineering graduate students come from abroad.
- At most of our research universities, the proportion of foreign graduate students in almost all of the engineering departments has exceeded a level that raises questions and concerns among many constituencies in both the public and the private sector.
- Similar concerns exist for most engineering departments about the growing and now dominant fraction of new assistant professors who received their undergraduate engineering degrees from abroad, mostly from schools in developing countries. This fraction is especially high at research universities not in the top echelons. However, it is uncomfortably high in electrical and computer engineering and in many other areas at the most prestigious of research universities as well as at schools that do not offer the Ph.D. degrees.
- Appropriate measures of quality of the individual, not the country of origin, should govern additions to the professorial staff in engineering and decisions on tenure and promotion.
- All students, undergraduate and graduate, should be held to acceptably high standards of quality of performance.
- A proper engineering education at each degree level is a key element in the maintenance of our defense capability and the needed improvement of our economic competitiveness in today's world.
- The fundamental engineering research output of our academic institutions, which provides an essential basis for the viability of our society, must be and is now in the process of being appreciably enhanced in a variety of directions and modes.

A PERSPECTIVE ON CHANGES OVER TIME

This is an interesting, important, and probably crucial time to consider the questions posed by the changing demography of undergraduate students, graduate students, and professorial staff in engineering.

Even a casual look at our universities, industries, governmental and research institute laboratories, and consulting firms discloses a healthy and very strong participation by many who are not native-born and whose formal education took place partly or totally in other countries. Those who came in appreciable numbers from Europe in the 1930s and 1940s are well represented at the highest levels or were so positioned prior to their retirement. Those who came after them from the developing countries of Asia and the Middle East are emerging rapidly, and many now occupy key positions. All can rejoice in this strong evidence of the attraction and the effectiveness of the American system of opportunity. Perhaps the telling of their success will help solve our own internal problem of ensuring that black, Hispanic, and Native American minorities take advantage of these same opportunities now open to them. As the fraction of Hispanics alone will exceed 50 percent of the K-12 school population in a number of states in the not too distant future, the new composition of the graduate student and younger faculty populations in engineering may prove inspirational.

There have been very many changes in attitudes and activities in engineering education from the almost totally current-practice-oriented pre-World War II days to the present time. Prior to World War II, only a few engineering schools devoted appreciable effort to fundamental engineering research. Most of those that did did so through Engineering Experiment Stations or their equivalent. They tended to separate the research and teaching functions almost completely. With some notable exceptions, there were just a few professors of engineering, labeled as "research professors," who concentrated exclusively on research; the other engineering professors taught and did consulting work but no research. Ph.D. output per year averaged under 100 for all the engineering fields combined; the number was negligible in most branches of engineering. The continental European tradition of engineering science was just beginning to be transplanted here in the 1930s through such people as von Karman and Timoshenko. For the most part, however, it was considered irrelevant to engineering and ignored. A few forward-looking professorial or prospective professorial people went abroad to study under world-recognized masters. However, even in science, "foreign" was not a prestige word. A distinguished foreign scientist or mathematician often had great difficulty in obtaining any academic post in this country. Those on the engineering side had fewer opportunities still.

The pace of Ph.D. production in engineering began to pick up following World War II but did not reach 500 per year until the mid-1950s. During that transition period, there were only a very few places like Brown University with its large number of foreign visitors in applied mechanics and, for the times, a great many foreign-born and foreign-educated members of staff. Such groups were viewed by most of the professoriate at most of the schools of engineering as not in the mainstream of engineering. Many thought of them as a "foreign influence" in all the then-negative connotations of that term. Yet, in fact, despite the broad international leadership and the intensive international outreach, the great majority of the staff and the graduate student body at Brown and similar places were born in this country. The foreign contingent was very visible and remarkably large for those days but modest in size by today's standards. Also, most of the many foreign students and visitors who came in the late 1940s and early 1950s planned to and did return to their homeland in Europe.

From the mid-1950s on, the educational and research activities of many U.S. universities in almost all the fields of engineering gained enormously as graduate students and faculties became more diverse and as contacts with a variety of engineering activities in other countries were greatly expanded. No longer was there excessive narrowness of experience and viewpoint produced by a graduate school population and professorial staff conditioned solely by what had become an overly isolated U.S. culture.

In the past 15 years, however, the pendulum has been swinging ever closer to the opposite extreme in many departments of many schools of engineering. At the Ph.D. level of engineering graduate study, students who were born and educated in the United States are in the minority. In some instances that minority is so small as to be overwhelmed by foreigners, as foreigners once were overwhelmed by the native-born. The same is true in very many departments for the young assistant professors of engineering.

Is there cause for concern, or instead will the immigrant group and the visitors, both coming primarily from the developing countries rather than from the developed, lend new vitality to engineering education and research?

UNDERGRADUATE ENGINEERING STUDENTS

Under 10 percent of all undergraduate degrees in engineering are awarded to foreigners. The percentage has remained fairly steady at between 7 and 9 percent for quite a long time. There has been a shift in the developing countries from which most of these undergraduates come, but each school seems to have reached its own accommodation without much obvious turmoil. A number of major state universities have limited undergraduate engineering enrollment drastically, as admission pressure mounted enormously in the dramatic shift toward engineering by so many of the best U.S. high school students. Most of them admit very few foreign undergraduates today: unable to accept bright and capable students from their own state, they understandably feel constrained to accept few from outside. There is more than a little feeling of conflict with the land-grant tradition of world service and a sincere willingness to help educate students of the developing world. At the other extreme, in the rather recent past, some of the developing universities in this country did turn to foreign engineering students in very large numbers to swell their undergraduate ranks as they began to establish a more secure place for themselves in the hierarchy.

It is interesting and perhaps important to speculate on what might happen if the present great attractiveness of B.S. engineering degrees to our high school graduates were to decrease significantly as the number of 18-year-olds in the population continues on its sharp downward trend in almost all states:

- Would the fraction of foreign undergraduates in engineering then increase?
- Is there a desirable or an optimum proportion of foreign engineering undergraduates? If so, what is the appropriate range from the viewpoint of the education of our own undergraduates?
- Should foreign undergraduates be expected to pay the full cost of their tuition, rather than the subsidized amount paid by domestic students?
- Is it our obligation as a nation to help the (friendly?) developing countries by educating some of their students at our engineering schools? If so, how many and at what cost to whom?
- As a result of the changed composition of the body of our engineering graduate students and faculty, should changes be made in our present affirmative action approach to our domestic minorities, an approach aimed at encouraging and facilitating entrance to an engineering career?

These certainly are interesting questions that do arise and are being addressed at individual schools. Should we refine and study them, recommend that others do so, or simply propose to leave their resolution to the discretion of each school of engineering that now is facing or will face such issues in the future?

GRADUATE STUDENTS AND ASSISTANT PROFESSORS

It is primarily at the graduate student level and the professorial staff level in engineering schools that major policy questions about foreigners have arisen over the past decade and now are raised with increasing frequency. Such expressions of concern are likely to become more strident in the near future. They will be augmented and confused by what appear to be primarily emotional rather than intellectual responses to similar but less extreme trends in the sciences and mathematics.

Engineering Ph.D. degrees over the past 15 or so years have been awarded to noncitizens in ever-increasing percentages, still moving up through the neighborhood of 60 percent. Young assistant professors of engineering added in recent years are increasingly foreign in origin and undergraduate education. These additions from abroad currently run in excess of 75 percent of all those being recruited at the assistant professor level in such major fields as electrical and computer engineering. It should be emphasized that these additions to the professorial staff have been selected by the existing staff, which is still dominantly native-born in almost all departments of all engineering schools. The choices reflect the traditional and yet continually evolving judgments of relative quality among all those available for academic positions.

Experience over the past decade indicates that, in engineering, every American Ph.D. who wishes to join the academic world will be offered several assistant professor positions. Minimum qualifications do vary from school to school and usually from department to department within each school. However, the door is open somewhere in engineering academe to just about all such candidates. Despite this significant preference for domestic prospects, the selection made is most often, and increasingly so, of a foreign-born and primarily foreign-educated person with a U.S. Ph.D. degree in an engineering or engineering-related field, again leading to several questions:

- Should this be a concern? If so, what should be done to alter the situation?
- Is the problem one of too many foreigners or instead that not enough first-rate domestic undergraduates go on for the Ph.D. degree, and of those that do, too few opt for an academic career?
- Is there a justified worry that, if nothing more is done, in time the faculties of departments of engineering will become dominantly foreign-born at all levels and then increasingly so?
- In the process of faculty educating students in their own image, traditional at all levels but especially at the Ph.D. level, what will that image be?
- Will the perception within academe of the role of engineering in this country then no longer reflect adequately the concerns of the average informed citizen?
- Will there be a further decrease in attention to laboratory experience and to experimental research because working with one's hands is viewed as demeaning in most of the upper-class cultures from which most of our foreign contingent now comes?
- Will future undergraduate curricula take on still more of a backward look than today? In most instances the undergraduate engineering education given to our new assistant professors in their home country was a copy or reflection of U.S. or European engineering programs in vogue a decade or two earlier than when they were in school.
- What will be the effect on cross-disciplinary fundamental engineering research efforts, the success of Engineering Research Centers, and other efforts designed to produce significant change in our engineering educational and research patterns to aid in restoring the international competitiveness of industry in this country?
- Is it realistic to expect incisive contributions to such highlighted and targeted areas as integrated manufacturing systems from many of this group of people, who although very talented have, on average, almost no modern industrial experience?
- Will academic engineers and the enormously larger number of engineers in industry, government, and private practice then become so disparate in background and attitude that constructive dialogue and interchange become almost impossible?
- Are special faculty development programs during the summer or the academic year desirable or necessary to provide an adequate

understanding and knowledge of the U.S. scene and its culture, along with its problems and opportunities in the industrial and service sectors?

QUESTIONS POSED BY THE STUDY COMMITTEE

The issues and questions raised by the Committee on the International Exchange and Movement of Engineers about engineering students, graduates, and postdocs in the call for the workshop are important ones:

- What are the trends in the numbers enrolled and receiving degrees in engineering programs: by field? by degree level? by country of origin? What are the trends in the percent of the enrollees and degree recipients who are foreigners?
- How does the quality of these foreign engineering students compare with that of American engineering students?
- Are these foreign engineering students replacing American students at the undergraduate level? At the graduate level?
- How many receive support as teaching assistants? Research assistants? Postdocs? What other form of support or subsidization is given to foreign engineering students? Does financial assistance and enrollment of foreign students come at the expense of financial assistance and enrollment of American students? To what extent does engineering research in academe depend on foreign postdoctorates? What is the cost to the American taxpayer?
- How effective are those who receive support as teaching and research assistants in these roles?
- How many return to their countries of origin? Does the likelihood of returning vary by field, degree level, country of origin?
- How effectively is the training received by these graduates utilized in their countries of origin?
- Do those who return exert a positive influence on their country's relationship with the United States?
- Among those who return, how many become employed by American firms in their home countries? How many ultimately come back to the United States?
- How are graduate engineering curricula, design, and pace of instruction changing to meet the needs of foreign students?

With appropriate substitution for the words "engineer" and "engineering," several are clearly the most important ones for the sciences and mathematics. There is, however, no distinction in subject matter to be made between U.S. basic science or mathematics and foreign basic science or mathematics. Even if the foreign graduate students and new assistant professors were to become a majority in these fields, provided the quality standards were maintained, few intellectual problems of teaching and research would arise other than the degree of emphasis on experimental work in the natural sciences.

Engineering like medicine, law, and other professions is often highly country-specific in many of the aspects of practice and consequently in appropriate education and research. The issues of foreign students and professors, therefore, take on very different dimensions for engineering in academe than for science or mathematics. Intellectual issues are far more important than questions of cost. A dominance of foreign student or staff raises basic questions about the future centrality and societal effectiveness of our entire engineering education and academic research establishment, questions that for the most part do not arise in science and mathematics education and research. Here I do not quite share the comforting conclusion that all is well, reached by Elinor G. Barber and Robert P. Morgan on the basis of the satisfaction with graduate students expressed by faculty and chairpersons.[7]

There are many significant and interesting differences in detail as well that distinguish engineering from science and mathematics in academe. For example, the pattern of progression from graduate student to professor is quite different. Academic postdoctoral appointments, which are virtually a necessity in the sciences and mathematics for aspirants to a successful academic career, are a rarity among native-born engineering students. The supply of native-born Ph.D.s is so short and the demand is so high that assistant professorships are available immediately to all who are interested and at least marginally qualified. Foreign graduate students may go the postdoctoral route as a holding pattern prior to return to their own country or, more often these days, to await permission to remain in this country as immigrants.

An analogous situation exists for admission to graduate study. Native-born engineering undergraduates who meet minimum standards and wish to go on to graduate study at the M.S. level can do so without impediment at a research university or elsewhere. Those who are successful and then wish to continue on to the Ph.D. level also will have that opportunity. They are cherished because their numbers are so small. There is such a shortage of promising domestic graduate students aiming for an engineering Ph.D. degree that they are not and will not be displaced by foreign applicants, although a superb foreign graduate student may be given a higher priority than an ordinary domestic one.

The engineering professoriate shares at least one attitude with their colleagues in the sciences and mathematics. Any domestic or foreign graduate student, even one marginally qualified or less by the standards of earlier years, is viewed as far better than none. Gone is the feeling, once rather widespread, that a first-rate graduate assistant is a help in teaching and research, but a mediocre student is a

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7 Elinor G. Barber and Robert P. Morgan, "The Impact of Foreign Graduate Students on U.S. Engineering Education," *Science* 236:33-37, April 3, 1987.

drag, and a marginal student an enormous detriment. Gone also are almost all vestiges of the view that, because failure would be so devastating to them, foreign graduate-student applicants should be taken on only if their record indicated such high quality that successful completion of the Ph.D. degree in time seemed assured. Lower standards for admission of domestic applicants were and remain appropriate, in engineering at least, because so many perfectly acceptable alternate paths to a successful career are open to them.

I can attest to the strength of this professorial attitude of viewing even a marginally qualified graduate student as better than none over the last 10 years of my tenure as dean of the College of Engineering of the University of Illinois at Urbana-Champaign, a college that included physics and computer science. In arguing against an explicit and strong college budget policy that in effect established a high standard of admission for foreign graduate students, the statement was made over and over, often by one or another very distinguished member of the staff, that the teaching and research enterprise would suffer irreparably if we did not admit some additional number of possibly marginal students to assist in computation, taking of experimental data, mathematical analysis (but not theory), and grading. That this attitude is the mode among both professorial staff and departmental administrators in engineering across the country is clear from the survey reported by Barber and Morgan. My own view that a mediocre student increases the load on a faculty member because everything done must be checked with care, and that a marginal student is far worse, clearly is not shared by the majority of professors.

As a consequence, it seems clear to me that the average quality of foreign graduate students in engineering has declined appreciably over the past 15 or so years. So also has the average quality of domestic students, primarily because of a great decrease in the fraction of the best of the engineering undergraduates who elect to go on to the Ph.D. level. Furthermore, the available and qualified engineering pool (upper 20 percent of Ph.D.s) interested in an academic career has contained and still contains far too few to fill the many available assistant professor positions in engineering. As noted earlier, recruits from the sciences and mathematics are no longer a sufficiently large alternative source of supply.

The crippling blow of both immediate and long-term devastating consequences to academe is the small fraction of the qualified engineering Ph.D.s who choose to enter the academic world either immediately or reasonably early in their career. Yet many positions are filled each year because there are so many excellent students to be taught, and in a relatively short time, tenure is granted to a sizable fraction of those in the pipeline.

APPENDIXES ADDRESS SOME OF THE QUESTIONS

Perspectives on several of these and allied questions are extracted from other documents and included as appendixes. Among the major relevant and possibly controversial points made in them are the following:

- The demands for both a more incisive and a higher level of performance by engineers in government, industry, private practice, and academe everywhere always increase with time. The intellectually driving forces are the rapidly increasing volume of useful knowledge and the continually increasing level of knowledge required to make significant engineering contributions.
- For us in the United States, there is the added factor of the increasingly successful competitive pressure from many parts of the developed world whose average level of education still is increasing while ours appears close to saturation. Joining vigorously in this competitive pressure are the developing nations of the world, whose population, as well as level of education, is rising rapidly while ours is in the process of leveling off.
- Our severe crisis in engineering education has been ameliorated somewhat by a number of important measures taken by the universities, government, and industry. However, for the great majority of schools, it remains as a debilitating chronic sickness with strong adverse effects on the present quality of engineering education, along with a severe shortage of people available to provide a more effective and a higher level of education in the future.
- The total yearly U.S. output of engineering Ph.D.s, quite independent of country of origin, has been and remains too low to provide an adequate pool of people just to meet the need of academe for highly qualified researcher-educators (defined here as those in the upper 20 percent of Ph.D.s, but upper 10 percent would be a far more appropriate echelon for an educator of highly qualified future generations of researcher-educators).
- Worse still, those available are only a small fraction of this inadequate pool. Some of the foreign students return to their homeland, but the major reason for the drastic reduction is the purposeful choice of a nonacademic career by so large a fraction of the very best Ph.D.s.
- The average quality of engineering graduate students, foreign and domestic, has decreased appreciably for several reasons. Despite the great increase in the number of B.S. engineering degrees awarded each year, and the remarkable concurrent great increase in the average ability of domestic undergraduate engineering students as measured by high school rank and test scores, far too few of the best domestic students opt to go on to the Ph.D. level. Many of the foreign graduate students are far from the superb absorbers of classroom-imparted knowledge to whom we had become accustomed in earlier years. At least one of the countries from which we obtained large numbers of well-educated undergraduates is no longer such a source. Other developing countries are building their own graduate schools in engineering and keeping a sizable fraction of their best undergraduates at home. The United States is no longer the uniquely

suitable place for a graduate education in engineering that it once was.

- Nevertheless, it is true in most doctorate-offering departments of most schools of engineering that the foreign Ph.D. students are better, on average, than the domestic.
- The continual and still accelerating increase in the scope and scale of effort required in the practice of engineering at the advanced level demands an increasing number of new people properly qualified. This excess of demand over the engineering output can no longer be met adequately, as it has in the past, by a sufficient number of entrants to the field from the natural sciences and mathematics. The physical sciences and mathematics, in comparison with engineering, no longer do or can educate the relatively large number of people at the advanced level that they did when engineering output was so much smaller. Also, they too now suffer from a significant and worrisome decrease in highly qualified domestic students.

APPENDIX I

*1986 Thurston Lecture**

. . . In all the excitement generated by new directions and new opportunities, it cannot be forgotten that the crisis in engineering education has become a chronic debilitating sickness that remains with us. This was a crisis of quality, exacerbated by the great influx of students into engineering curricula over the past decade. Student-teacher ratios became and remain enormous at most engineering schools. Far too few of the brightest of our undergraduates went on to graduate study or now do, and far too few of those that did then opted for an academic career. As a consequence, there are very many unfilled assistant professor positions in engineering today. Because the increase in financial support of schools of engineering has lagged far behind the increase in student demand, there are many, many more professorial positions needed but unfunded. Worse still, the long period of shortage has inevitably led to compromises on standards of quality for appointment, promotion, and tenure at far too many institutions. Such compromises are natural, and likely as unnoticed, as are gradual changes in the absolute standard for the grades given to students as the quality of the student body changes appreciably up or down over the years. Of course, each school has chosen the best faculty members available to it within its financial resources; each has made the best selection from among those on the tenure track, compatible with its ability to cope with student demand. . . .

Quality of Engineering Students Versus Quality of Their Education

Present-day engineering undergraduate students are the best engineering students ever, superior in their verbal ability to most students on campus and vastly superior in their mathematical ability. Their quality has obscured the lessening of the quality in their education. Bright to start, they are bright when they finish. Yes, there are complaints from employers about our graduates' ability to communicate. Such complaints have been voiced from the beginning of time. The fact is that engineers today are far more articulate, on average, than ever before. Surely they could be and should be better communicators; they suffer from the same well-documented inadequacies of elementary and secondary school education as do all of their age group.

However, it is in their areas of greatest potential strength that there is weakness far more difficult to overcome in later years. Despite the statements from employers that our students are well-grounded in the fundamentals, the chronic illness that has followed the crisis in engineering education has taken and still is taking its toll in the

* Excerpts from Daniel C. Drucker, speech at American Society of Mechanical Engineers (ASME), as modified for a joint Johns Hopkins University-ASME seminar, March 19, 1987.

very best of schools. We are not serving our country well because we are not serving our students properly. . . .

The great overload of the engineering faculty, over so many years, in combination with the shortage of adequate laboratory equipment has led to many retrograde steps in individual courses and in curricula. This negative progress continues to occur because the sad situation in engineering education has only been partially ameliorated at most schools. The critical shortage of funds for equipment, faculty, and a competitive faculty salary-scale persists, despite the welcome increase in support from industry, because industrial support is but a small fraction of the total. Even for those with appreciable additions to their university budget, the funds available have been insufficient to accommodate both the needed competitive salary-scale and the needed number of faculty. . . .

Retrogression has taken place instead of the significant continual advances needed in the level of the curriculum to keep pace with the continual advances in the level of engineering practice. I emphasize <u>level</u> rather than the more rapidly expanding breadth and complexity with which no single curriculum can ever keep up. . . .

. . . Clearly, a large number of drastic improvements are needed in engineering education just to bring it in line with the demands of today. Much more is required to make it commensurate with the nature of the demands that we can foresee our students will have to meet in their working years ahead if our country is to maintain a leadership position in a world of intense competition. . . .

We must develop a far more effective approach to convey the essentials of a much broader spectrum of modern engineering sciences to students at the much higher level needed today than when the name was invented. We must fill in many glaring gaps in our understanding of the people-made world. For example, we somehow must learn first to build and then to teach an as "yet nonexistent" engineering science base for an integrated design-manufacturing or construction systems approach.

The computer revolution in industry and education provides strong evidence that the principle we agreed upon in engineering education three decades ago remains valid today. At that time, we abandoned the earlier mode of engineering education with its strong emphasis on current practice and its absence of research orientation. That then-obsolete mode had served well for a century of accelerating but still relatively slow change. By World War II, the pace of change had become so rapid that an elementary understanding of the fundamentals clearly was far more useful than a complete knowledge of current practice when meeting substantially new engineering challenges. In response, after much delay, engineering education moved away from educating highly knowledgeable apprentices to educating prospective engineers able to contribute effectively in directions totally new to them. The many engineers who played so strong a role in the development of modern computer systems and the modes of their use demonstrated the effectiveness of their education. Until very recently, of course, none were educated as computer engineers. . . .

It is natural, in times of bewildering change, that many engineering educators, as well as the majority of people and their political leaders, may want to pause for breath, or even to retreat to the more comfortable pattern of a distant past in the name of progress. Yet if we simply pause, we move backward, in effect, because genuine progress sweeps over us while we stand still.

Research Is the Answer

How do those of us in universities accommodate to a rapidly changing technological world? How do we lead our students into the future rather than follow them? Research is the answer, provided the research is of high quality and the faculty has the time for that research, the time for the contemplative activity of curriculum design and rebuilding, and then the time for the teaching itself. That is another reason I am such an enthusiast for cooperative research within disciplines and for cross-disciplinary research as appropriate. Individual researchers of genius can and do make giant strides rapidly on their own, but such individuals are rare indeed. Unfortunately, if my assessment of our current faculty situation is valid, they will be proportionately rarer still in the future. Important fundamental questions can be tackled incisively by people of adequate quality when they work together with people of high quality in appropriately sized groups. When each works separately, the total output of all but those of the highest quality will have negligible impact. . . .

Participation in cross-disciplinary research activities of the high intellectual character visualized in the guidelines for Engineering Research Centers would provide an extremely valuable component of engineering education for undergraduate as well as graduate students.

APPENDIX II

*Engineering Education: A Key to Industrial Leadership**

Abstract

Industrial competitiveness in world markets and defense capability are critically dependent upon engineers able to utilize a very rapidly increasing body of knowledge at a level that also increases significantly with time. We in this country are a small minority in the world with which we interact. For almost three centuries we were underpopulated and benefitted enormously from the substantial immigration of many diverse, able, and energetic people. An increasing level of education for more and more of our people enabled us to achieve world leadership. Now our working population is leveling out as is our average level of education. Worse yet, for 15 years our output of M.S. degrees in engineering has remained almost constant while the number of Ph.D.s dropped. Furthermore, the severe shortage of available faculty of appropriate quality has degraded the average quality of engineering education in this country over the past 10 years. This "crisis in engineering education" is exacerbated by the great increase in the number of undergraduate engineering students, students of the highest quality ever, but would persist were the numbers to be cut in half. Pervasive curricular changes reflecting tomorrow's world, following a national Goals of Engineering Education study, are long overdue.

Historic View

Take a historic look at the U.S and the world over the past few centuries. The U.S. kept up with the quantity and level of knowledge in use through a greatly increased population and a rising level of education for more and more people, along with enough properly educated engineers to do the job well. We were able to work increasingly harder and smarter. It is not by chance that I chose a representation with numbers of engineers well above the knowledge-in-use curve from 1950 to 1970 (Figure D-10). It also is not an accident that Japan with its recently developed large and able cadre of respected engineers is more than competitive with us in many areas. . . .

. . . The increasing population and level of education in the world will drive both the quantity and level of knowledge up along the present growth curves or higher. How will we in the U.S. keep up? . . . To keep up with the world, the level of education achieved upon leaving the university should go up with time, perhaps by 1 year every 30 or 40 years as indicated schematically in Figure D-11. Engineering education did keep up through the early 1970s by the large but infrequent jumps in level shown. In 1940 the conceptual or intellectual level of the B.S. engineering degree was about the equivalent of our

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* Excerpts from an article of the same title by Daniel C. Drucker, *Hi-Tech Review* 16:74-85, 1984.

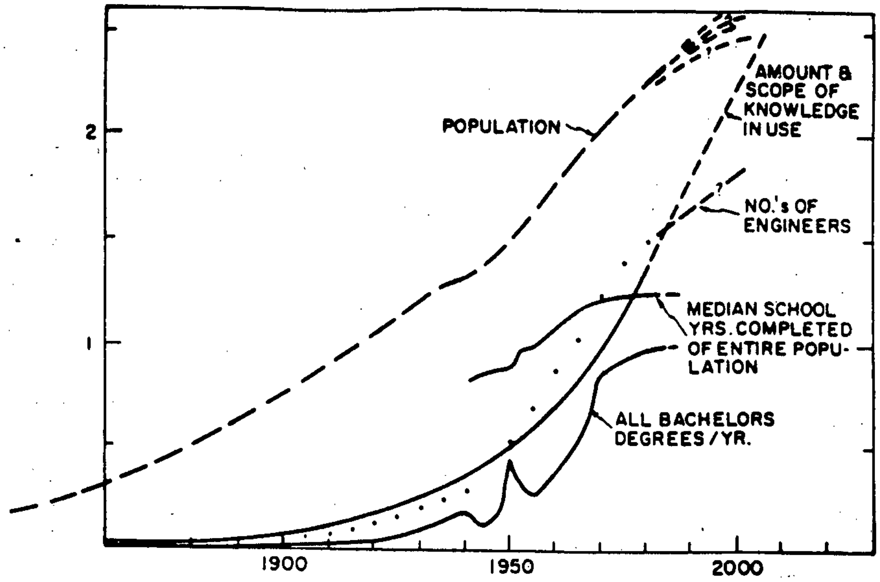

FIGURE D-10 U.S. population (in hundreds of millions), number of self-identified engineers (in millions), total B.S. per year (in millions), median school years completed (divided by 10).

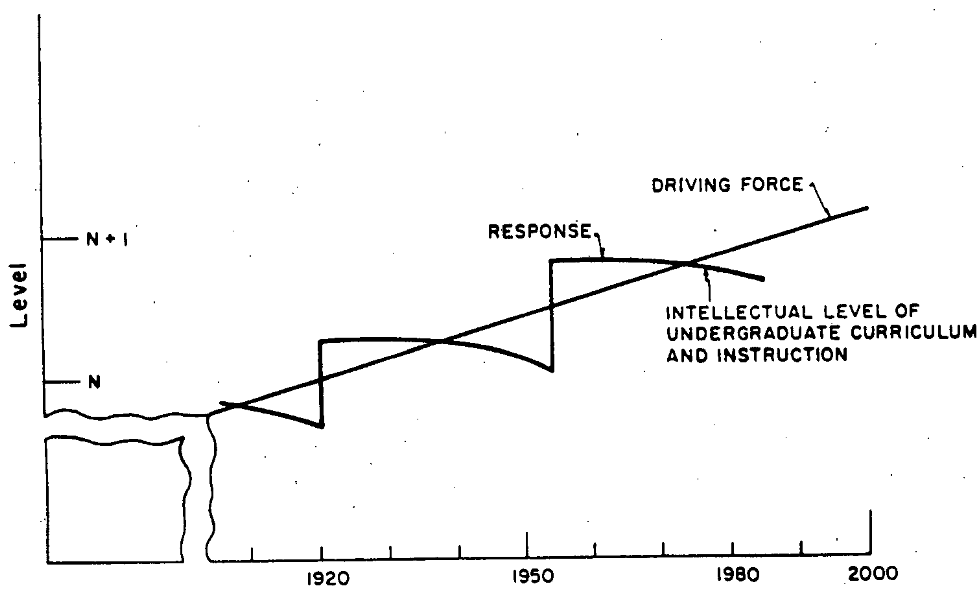

FIGURE D-11 Level of engineering knowledge, understanding, and information measured schematically in equivalent years of university education today.

present end of the junior year. In 1900 that level was about the present end of our sophomore year. Another jump in level of instruction is urgently needed. Also, in order to keep in the lead, over the next decades an increasing proportion of students must go on to the M.S. level and to the Ph.D. level. Yet, in the past decade, the trend has been down, not up. The answer is not to spend more time on undergraduate education. You never can keep up with the flood of useful knowledge through years in school. Each year more useful information is generated in each engineering field than can be taught in one year.

. . . Engineering numbers, quality, and level must keep up with the curves of knowledge in use and the level of that knowledge. Historically, we have done so until recently and so were able to become the industrial leader of the world. . . .

Only a small fraction of what is known can be taught; only a small fraction of what is taught can be required in any one curriculum. Excellent curricula can be devised to meet today's needs but obviously should not be taught because they would guarantee obsolescence on graduation. An acceptable curriculum for the future demands continual incisive thought and experimentation on everyone's part. Appreciable faculty time is required. Excellent teaching in the broadest sense is the primary obligation of the universities. The continuing and most difficult intellectual problem faced by each group is what to teach.

APPENDIX III

*The Severe Past and Present Shortage of Engineering Ph.D.s Qualified for Academic Careers and Available**

A very crude model is good enough to exhibit the extreme severity of the shortage and consequent negative effect on the average quality of the engineering faculty. For simplicity, the need to add to the staff to catch up with the expanded engineering student enrollment will be set to one side.

Consider a nationwide steady-state picture with about 15,000 to 20,000 tenured engineering professors. About 600 per year, on average, would retire or die and have to be replaced. Suppose, as appears to be true, that those who have tenure and leave academe for positions elsewhere are replaced by an equal number of experienced recruits from industry, government, and private practice. The promotion to tenure route for assistant professors then would have to supply the 600 per year lost through retirement and death.

As a bare minimum, then, 1,000 new assistant professors would have to be added each year to produce the 600. Many who enter upon an academic career, as any career, find they prefer another activity. Unfortunately, also, for a variety of reasons a significant fraction of the most interested and promising recruits will not perform well enough to meet the standards for tenure and promotion.

At present, the combined total of foreign and domestic engineering Ph.D.s turned out each year, who would like to remain in this country, is about 3,000. The number was appreciably less for most of the past dozen years. Suppose that visa problems can be resolved and all 3,000 are available for work in industry, government, private practice, and academe.

Of the 3,000, about 20 percent, or 600, are suitable for academe on the assumption that those who teach should be intrinsically more able than 80 percent of their students. Fewer would be considered suitable if the goal were set at 90 percent. Even if an academic career was chosen by every one of the top Ph.D.s, the numbers still would not balance because of the attrition from entrance to tenure. However, the tradition in engineering is very different from that in science and mathematics. In the past, about two-thirds of all engineering Ph.D.s have opted for nonacademic careers. In recent years the number of high-paying and otherwise very attractive positions in industry and private practice has grown enormously. That two-thirds fraction has become larger still across the entire ability spectrum.

Therefore, by the reasonable criterion of the upper 20 percent, only 200 or so foreign and domestic engineering Ph.D.s would be both suitable and interested in the 1,000 positions that would be open every year once the current shortfall is made up. That factor of five represents the severe shortage in a projected steady-state of lower demand than that of the present and the recent past.

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* From a speech by Daniel C. Drucker to the American Association of Engineering Societies, Port St. Lucie, Florida, May 6, 1982.

In the more distant past of the 1950s and early 1960s, when engineering Ph.D. output was much lower and the demand for research-oriented faculty was much smaller, the situation was quite different. A larger fraction of the best engineering undergraduates went on to the Ph.D. A larger fraction of the best engineering Ph.D.s, as judged by academic standards, opted for an academic career. Also, a considerable fraction of the new entrants to engineering academe came from the ranks of bright and able Ph.D.s in science and mathematics whose interest turned to modern engineering. The roster of the NAE [National Academy of Engineering] and those honored by the engineering societies bear ample witness to the ability and success of this component of the professorial staff as well as those earlier engineering Ph.D.s.

At the much larger numbers required today, although entrants from the sciences and mathematics continue, they necessarily constitute a much smaller fraction of all new assistant professors as well as tenured professorial staff. Furthermore, almost all those who now choose the path of a science or mathematics Ph.D. do so out of considered preference and with much greater knowledge of the engineering Ph.D. alternative.

The numbers are far from precise, but the conclusion is clear. Regardless of rank in an academic hierarchy of excellence, just about every engineering Ph.D. of the past decade (foreign and domestic) who elected to join academe could and probably did, provided any visa or communication problem could be resolved.

EFFECT OF FOREIGN NATIONALS ON FEDERALLY SUPPORTED LABORATORIES

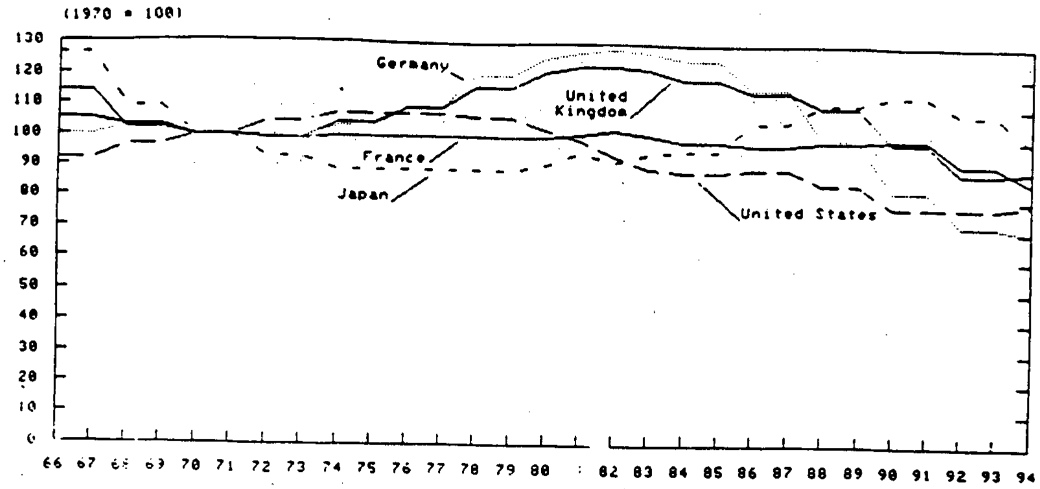
Glenn W. Kuswa
Sandia National Laboratories

SUMMARY

The United States has a conflicting set of goals surrounding its policies for international technical exchanges. We seek worldwide affinities for democracies in general and friendships toward us in particular. We also seek new markets for our goods. Students who are trained in the United States and return abroad presumably help attain these goals. However, these goals may not coincide with our desires for improved commercial competitiveness with friend and potential foe alike. We seek greater relevance and vitality in our technological development by promoting closer relationships between universities and research laboratories in government and industry, but we also want to maintain academic freedom in our universities and in the broader scientific and engineering community. At the same time, we are attempting to restrict certain militarily and commercially useful data and goods from reaching various foreign destinations. Finally, our nation needs a steady supply of the finest technical talent, but we are mindful that U.S. citizens should not find opportunities denied in favor of foreign nationals. This final point has special interest to those who seek additional opportunities for U.S. minorities.

Opinions vary on how to best resolve some of the questions that arise concerning foreign nationals. In this contribution we focus on concerns associated with foreign nationals and naturalized citizens interacting with or employed by the federally funded laboratories. Specifically, we explore the effects on federally supported laboratories of foreign visitors and foreign-origin engineering and science employees. We also seek some estimates on whether the pool of scientific and engineering talent available to these laboratories can meet present and future needs, and we address the need for having foreign students and faculty to interact with federally funded laboratories on research efforts.

The primary conclusions are that foreigners contribute to the U.S. technical development as individuals, but their presence in our universities sometimes inhibits cooperative research programs with government and industry. Foreigners are not generally denying opportunities for U.S. citizens, but we may find it advantageous to place more incentives for citizens to follow advanced technical careers. In some cases the pool of U.S. citizens with advanced technical degrees is small



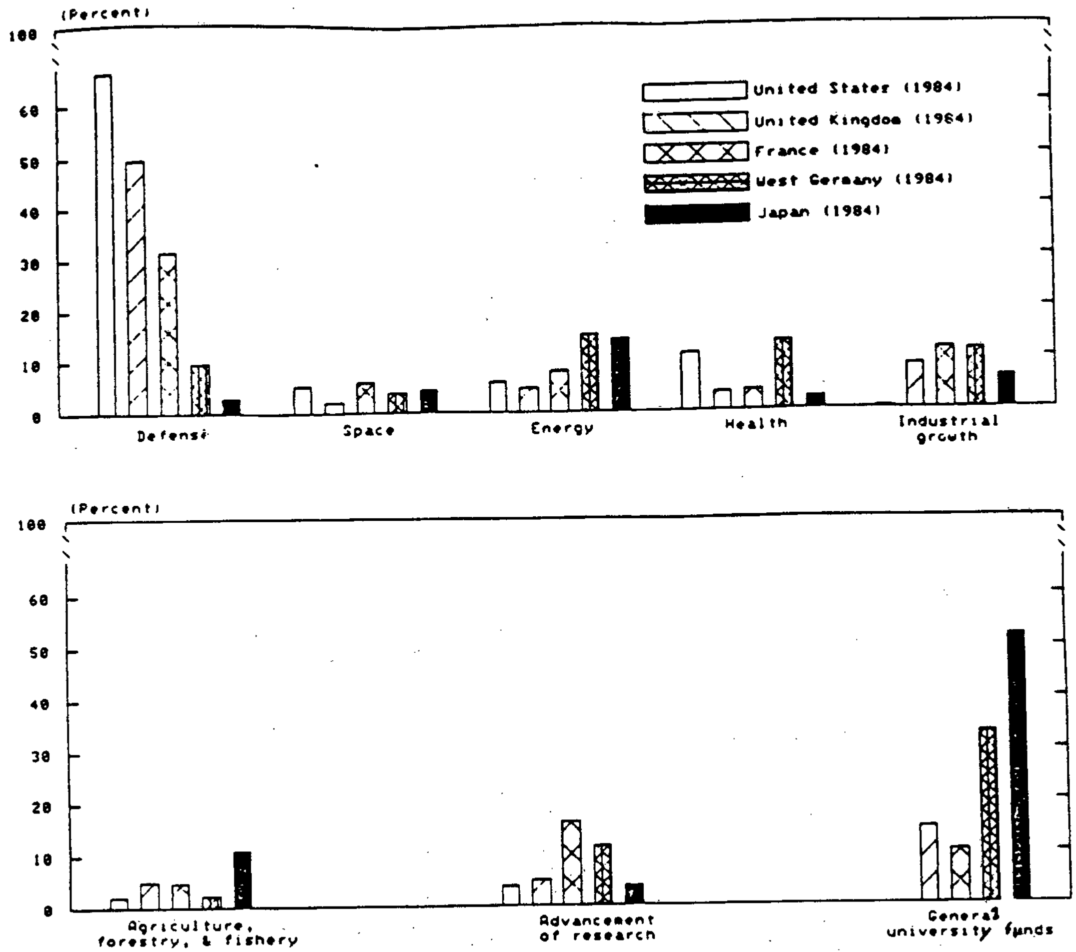
NOTE: Although the United States experienced a peak during the mid-1970s in the number of young people available to enter the science and engineering pipeline, other countries are experiencing the same phenomenon. Many European countries are experiencing a peak in the 16- to 18-year-old population during the mid-1980s. The peak for Japan should occur later--about 1990.
SOURCE: National Science Foundation, *International Science and Technology Data Update* (NSF 86-307), Washington, D.C.: U.S. Government Printing Office, 1986, p. 33.

FIGURE D-12 Indexes of 16- to 18-year-old populations for selected countries.

enough that our laboratories must seek foreign talent when citizens would be preferable.

BACKGROUND

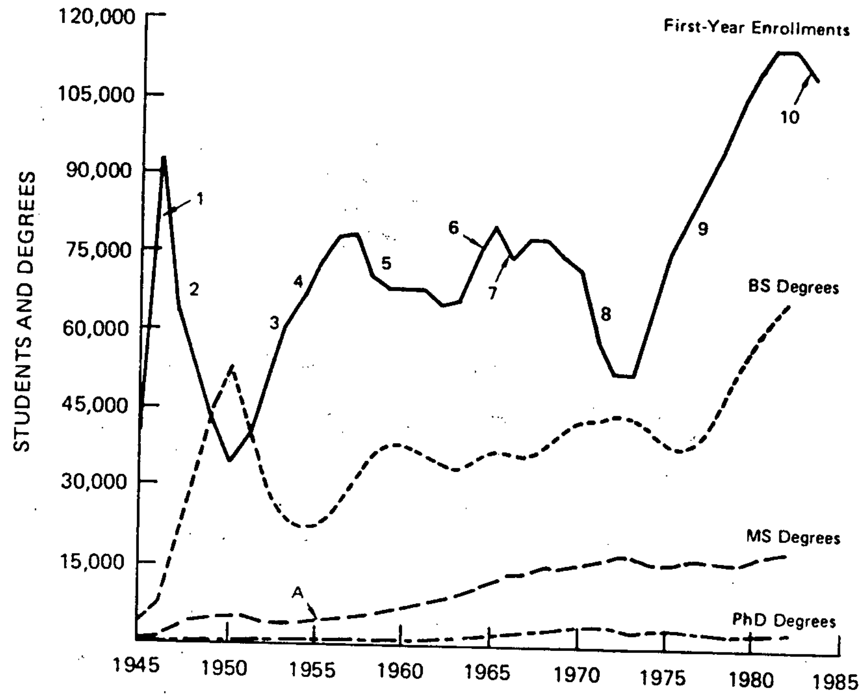
Economists cite three nearly equal factors in economic growth: new technology introduction, new markets, and capital formation. We depend on foreign involvement in all three areas. Owing to a large percentage of foreign students in technical programs in U.S. institutions, particularly at the graduate level, and owing to a large foreign interest in exploiting technical developments from this country, it is important to assess the effect of foreign nationals in our laboratories on our economic competitiveness and on our military security. The federally funded laboratories produce a large fraction of the research and development (R&D) for economic well-being, health, and national defense; these institutions spend approximately $18 billion on R&D of the $60 billion spent by the federal government annually. This paper focuses on how persons of foreign origin affect federally funded laboratories.



NOTE: Most of the U.S. research and development funds, compared with less than 10 percent in West Germany and Japan, are spent on defense. West Germany and Japan have high concentrations of R&D funds in general university and energy areas. About 11 percent of Japan's R&D funds were in food industries. In the 1960s and 1970s, the United States spent a much greater share of R&D funds in space, but by 1984 space received a smaller share in all of these countries.
SOURCE: National Science Foundation, *International Science and Technology Data Update* (NSF 86-307), Washington, D.C.: U.S. Government Printing Office, 1986, p. 7.

FIGURE D-13 Distribution of government R&D expenditures among selected objectives, by country, 1984.

Projections on the future demand for advanced technical degrees will be very uncertain, but several factors deserve attention. A National Research Council study in 1985 pointed out that "40 percent of the anticipated new Ph.D. graduates will be foreign students on temporary visas and thus probably will be unavailable" (Committee on the Education and Utilization of the Engineer, 1985). Note that availability is not an absolute; potential employers can certify a need and



1 Returning World War II veterans
2 Diminishing veteran pool and expected surplus of engineers
3 Korean War and increasing R&D expenditures
4 Returning Korean War veterans
5 Aerospace program cutbacks and economic recession
6 Vietnam War and greater space expenditures
7 Increased student interest in social-program careers
8 Adverse student attitudes toward engineering, decreased space and defense expenditures, and lowered college attendance
9 Improved engineering job market, positive student attitudes toward engineering, and entry of nontraditional students (women, minorities, and foreign nationals)
10 Diminishing 18-year-old pool

SOURCE: Committee on Engineering Education and Utilization, Commission on Engineering and Technical Systems, National Research Council, *Engineering Education and Practice in the United States,* Washington, D.C.: National Academy Press, 1985.

FIGURE D-14 Engineering degrees and first-year enrollments: Historical factors influencing changes in engineering enrollments.

thereby convert student visas to resident visas. In fact, as we shall see, many foreign students make successful bids to remain in the United States. Today, in some technical fields, foreign graduates outnumber citizens. Demographers note that universities may seek even more foreign nationals to fill their graduate programs as we enter an era of fewer 18-year-old citizens entering universities (see Figure D-12).

The defense industry employs a large fraction of our technical talent and has enjoyed generous funding during recent years. Some students of federal-funding patterns speculate that demands for technical personnel will lessen in response to completing some of the new defense systems and in response to political pressures. For perspective, Figure D-13 indicates the apportionment of R&D funds in the United States and various other countries. Figure D-14 demonstrates the wide fluctuations in undergradate engineering enrollment in response to various stimuli. Note that graduate-level programs are much less influenced than are undergraduate programs.

Employment is not the sole concern: effective laboratories must maintain extensive interactions with industry, universities, and government, especially if they are to contribute fully to U.S. commercial competitiveness. Corporations and large-scale experiments involving universities, federal laboratories, or industry are becoming increasingly multinational. Large research efforts meet economic and per-sonnel limitations by employing pooled resources, which may have connections beyond our national boundaries. To the extent that foreign nationals affect these interactions, we must broaden the focus of this study. While the statistics introduced above give some useful perspectives, many questions about the effects of foreign nationals cannot be quantified on the basis of data that the author could identify. However, personal contacts and respondents to telephone inquiries were very helpful in providing perspectives on this multifaceted subject.

As preparation for some of the questions to be explored in the last section, we briefly describe the federally supported laboratory system, give some background information on foreign interactions with the laboratories, and present data on trends.

THE FEDERALLY SUPPORTED LABORATORIES

There exist 388 federally supported laboratories (Wyckoff, 1983) that in the early 1980s employed over 220,000 individuals. These institutions comprise a system with missions and support levels tailored to specific government agency needs. Areas of work deemed appropriate for federal laboratories are projects of national need that are too large or too long in duration to be attractive for direct support by industry. Some laboratories have unique facilities that are widely used for international experiments, while other laboratories may provide skills or facilities that are useful for proprietary research by industry. It is possible for industry or governmental bodies (including foreign) to independently fund work at the laboratories. Frequently, cooperative research efforts arise in which laboratory missions and outside interests have close relationships, but no funds change hands. Many of our federally funded laboratories find advantages in working closely with universities on specific programs.

Some of the larger laboratories bear the designation "national," signifying a broad range of capabilities but generally focused on certain major objectives. The smaller laboratories generally support one or two very specific missions and have capabilities centered on those missions. Laboratory size varies from over 8,000 to fewer than 10 employees. Certain entities--such as the Federal Bureau of Investigation, Central Intelligence Agency, Defense Information Agency, and some military bases--also employ large numbers of scientists and engineers that are not included in listings of federal laboratories; many of our observations should also apply to such entities.

Many of the federally funded laboratories have extensive involvement with national security, and this limits foreign interactions even in areas that would normally be available for open exchanges. For instance, at some Department of Energy nuclear weapon laboratories, all employees must have security clearances, and with few exceptions laboratory facilities are within secure areas. In such labs foreign nationals can enter under escort after approval is granted by high-level management; Communist bloc visits and visits from certain "sensitive" countries are even more restricted. Even though visits may be in unclassified areas, there is a belief that prolonged proximity to workers who participate in secret activities will result in some undesirable diffusion of knowledge. However, in recent years the large laboratories have seen a broadening of their charters, and some facilities with more open access have appeared. Examples are the Combustion Research Facility at Sandia's Livermore, California, site; the magnetic fusion energy and accelerator facilities at Los Alamos National Laboratories; and a Sandia nuclear reactor complex that serves a classified role for weapon-related tests but is usually available for reactor safety studies that may include temporary workers from abroad. Some laboratories--for example, Brookhaven and Oak Ridge--that formerly conducted secret work are now almost completely open. In 1985 the estimated share of federal research funds allocated for national defense was 70 percent (Batelle-Columbus, 1987). We may presume that a sizable fraction of this activity would employ citizens only, but statistics seem to be unavailable.

Some federally funded laboratories operate under direct government management with government employees, while others are operated for the government by industrial or university contractors; a few are self-contained entities. Operating within any constraints caused by security requirements, these different arrangements have varying personnel requirements and pay scales that influence relations with foreign nationals relative to citizens. The pay scales at the entry level of laboratories operated directly by the government tend to be less competitive than contractor-operated and private-sector pay scales. Lower entry-level pay makes it more difficult to compete for the best candidates from the pool of U.S. citizens. Even in cases for which foreign nationals are eligible for laboratory positions, the preference is to seek U.S. citizens. Only under exceptional circumstances, when an outstanding candidate becomes known or there is no identifiable citizen available to fill a position, will most of the labs seek conversion of a student visa to a resident visa. There are, however, some exceptions where hiring foreign nationals is almost routine. Of course, if a foreign national becomes a citizen by some other means, such as marriage or by working for some time in private industry, that person is treated on a basis equal to any citizen. Another interesting question is whether naturalized citizens who obtain security clearances present any enhanced security risks on a statistical basis, but there seem to be no data available on this subject.

Owing to heightened interest in our nation's technical and commercial competitiveness, the Congress and the President have issued new laws and orders [Ref. Technology Transfer Act of 1986 (HR3773-13) and Executive Order "Facilitating Access to Science and Technology," issued April 10, 1987]. Among other items, these documents mandate more laboratory interaction with U.S. industry, seek ways to increase technology transfer returns from abroad, and enable laboratory officials from some agencies to act more effectively in consideration of net U.S. benefit in effecting technology transfers. Other initiatives have increased the emphasis on technology security in both commercial and military sectors. The new climate created by these actions will, at least indirectly, affect laboratory interactions with foreigners. Although basic science is supposed to be widely shared, according to government directives, one frequently finds difficulty in distinguishing basic science from developments that can lead quite directly to commercialization or improved weapons. Such uncertainties create problems in dealing with foreign nationals in technology.

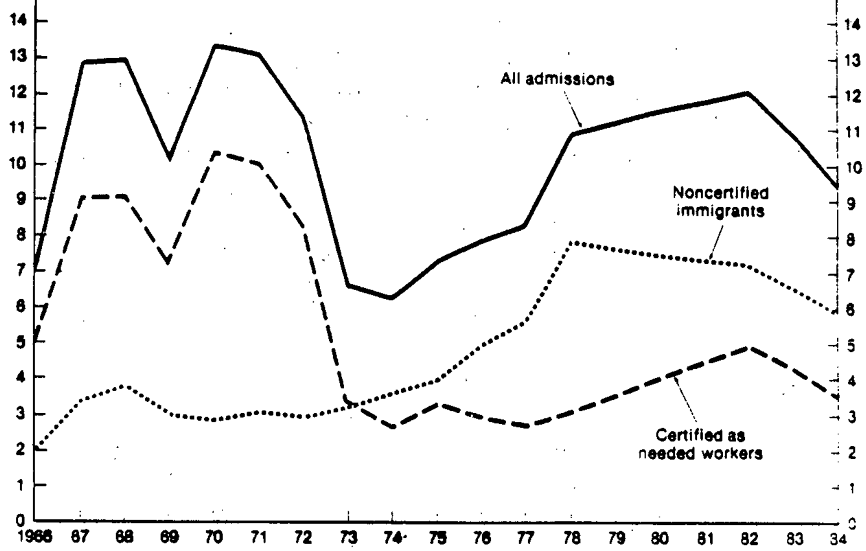
THE FOREIGN SCIENTIST OR ENGINEER

Foreign-born scientists and engineers play a major role in American technical enterprise, carrying on a tradition that has existed for many years. Intellectuals from abroad seek freedom and better educational and career opportunities in the United States and frequently are the elite from their native lands. They are chosen owing to outstanding academic credentials or because their families can afford to send them to the United States. Those who stay in the United States generally benefit our nation and create a "brain drain" for their home countries.

Presently, the U.S. technical monopoly is under challenge, and it is increasingly important for us to retain the best personnel from abroad and to assure encouragement and incentives for U.S. students to pursue technical careers. While foreign nations may not gracefully accept the loss to the United States of some of their brightest people, frequently those who are trained at advanced levels become overqualified with respect to technical opportunities in their homelands. Pressures from abroad are behind a new immigration rule that requires students to return home for two years before they can apply for citizenship. Exceptions are possible, however. A prospective employer must certify that the skills offered by the foreigner are critical and that no similarly skilled citizens are available in the labor pool. Figure D-15 shows the various types of immigrant admissions, but it does not extend to recent years, so the impact of the new immigration laws cannot be discerned. Only about one of three immigrant researchers achieves permanent admission through the certification process.

The United States is not the only developed nation with many foreign students in technical programs. A recent article (Anonymous, 1986) quotes a survey showing that natural science and engineering student populations average about 20 percent foreign in the United States, West Germany, France, Japan, and the United Kingdom. Figure D-16 represents this data, which averages graduate and undergraduate pro-

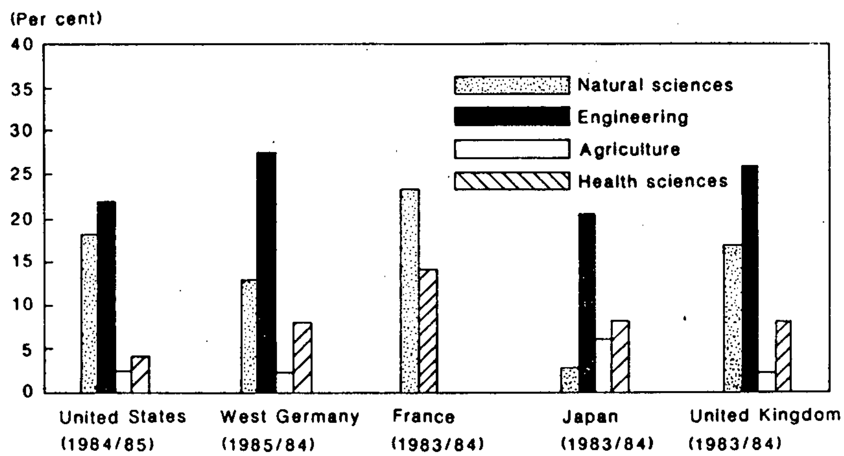
	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Total	7.2	12.5	13.0	10.3	13.3	13.1	11.3	6.8	5.3	7.4	7.9	8.4	10.9	NA	NA	NA	12.2	10.6	9.5
Certified	NA	3.0	3.1	7.2	10.3	10.0	8.3	3.4	2.6	3.4	3.0	2.8	3.1	NA	NA	NA	5.0	4.4	3.5
Noncertified	NA	3.5	3.9	3.0	3.0	3.1	3.0	3.2	3.7	4.0	5.0	5.6	7.8	NA	NA	NA	7.2	9.2	6.0



NOTE: Immigration of scientists and engineers rose sharply between 1966 and 1971, owing to changes in laws governing the entry of Asians. The sharp decline in the years 1971-1975 and the changes thereafter reflect changes in regulations, making immigration of persons seeking entry as professional and skilled workers dependent upon U.S. market conditions.

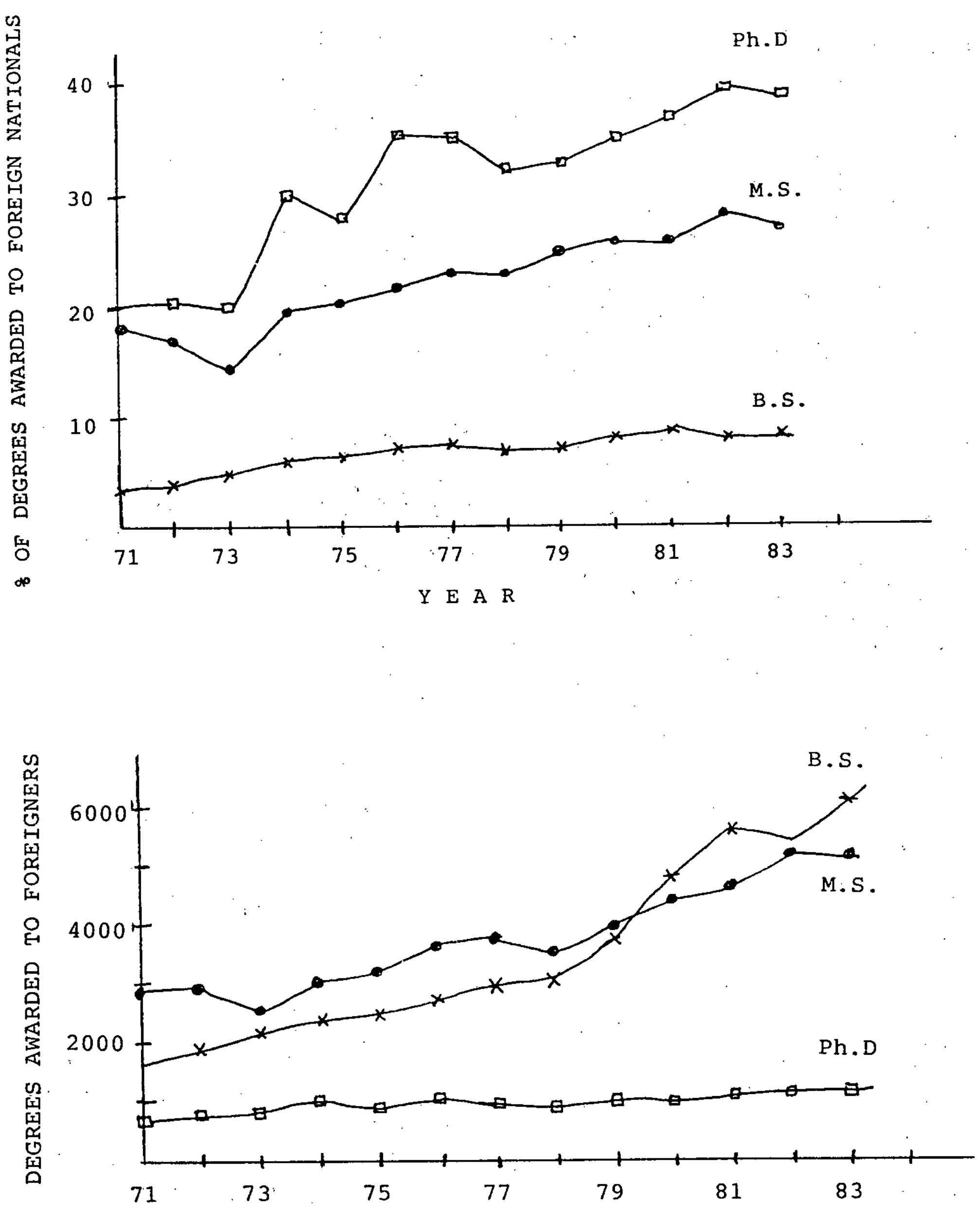
SOURCE: National Science Foundation, *Immigrant Scientists and Engineers 1962-84* (NSF 85-326), Washington, D.C.: U.S. Government Printing Office, 1985.

FIGURE D-15 Immigrant scientists and engineers, by type of admission, 1966-1984 (in thousands).



SOURCE: "Foreign Students in Science and Engineering," *Nature* 321 (6071):643.

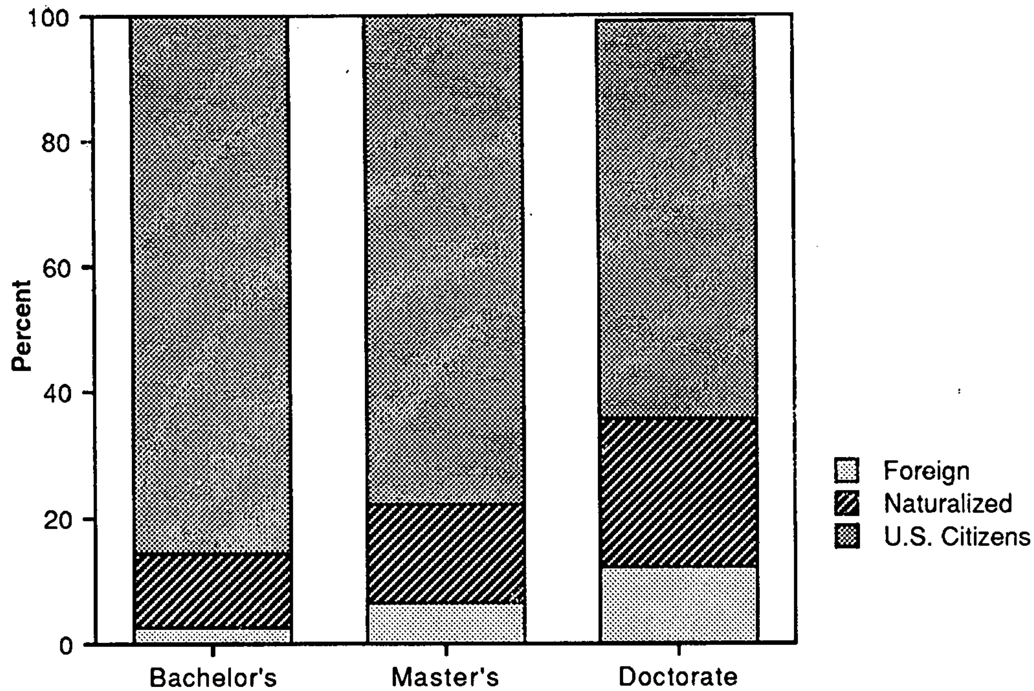
FIGURE D-16 Distribution of foreign technical students in programs of five developed countries (total graduate and undergraduate).



SOURCE: Committee on Education and Utilization of the Engineer, Commission on Engineering and Technical Systems, National Research Council, *Engineering Education and Practice in the United States: Foundations of Our Techno-Economic Future,* Washington, D.C.: National Academy Press, 1985, p. 57.

FIGURE D-17 Engineering degrees awarded to foreign nationals, 1971-1983 (percentages and numbers).

grams. The author has not located a data source for graduate-level students in other nations; but in the United States, there is a much greater concentration of foreign nationals at the graduate level. Moreover, this concentration is rising. The term "foreign" in the two

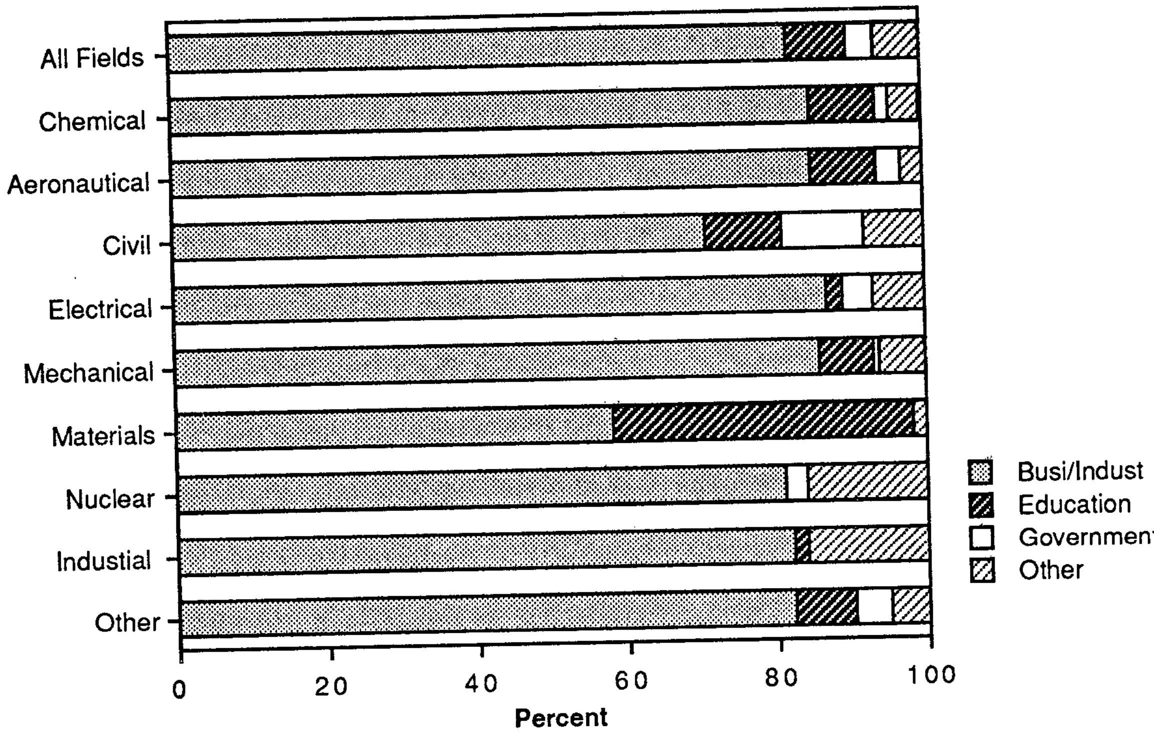


NOTE: Includes only individuals reporting employment in engineering occupations in 1982.
SOURCE: Special tabulations of Oak Ridge Associated Universities, based on the National Science Foundation's 1982 Postcensal Survey.

FIGURE D-18 Foreign engineers in the U.S. labor force, by degree level, 1982.

charts of Figure D-17 means "non-U.S. citizens on temporary visas." Only about 8 percent of all undergraduate engineering degrees were awarded to foreigners in the United States during 1983, but for graduate degrees the foreign percentage is much greater.

Naturalized plus foreign engineers at the B.S. level already constituted 14.5 percent of the work force in 1982 (see Figure D-18). This percentage exceeds the percentage of foreign students at the B.S. level, as seen in Figure D-17, and probably reflects earlier immigration of engineers trained outside the United States. In 1982, 36 percent of the engineering labor force at the Ph.D. level was of foreign origin, and during the same year the portion of foreign students awarded Ph.D. degrees was about 40 percent. Presently, about 60 percent of the graduate-level engineering students plan to stay in the United States (SMC, 1985). Thus, we might not expect to see large changes in the constitution of our work force caused solely by the presence of foreign students; changes would be brought about by importing already trained engineers. One might expect industry and universities to receive larger numbers of the foreign-born group owing to the hiring practices in most government-funded laboratories (see Figure D-19).



NOTE: Includes only individuals reporting employment in engineering occupations in 1982.
SOURCE: Special tabulations of Oak Ridge Associated Universities, based on the National Science Foundation's 1982 Postcensal Survey.

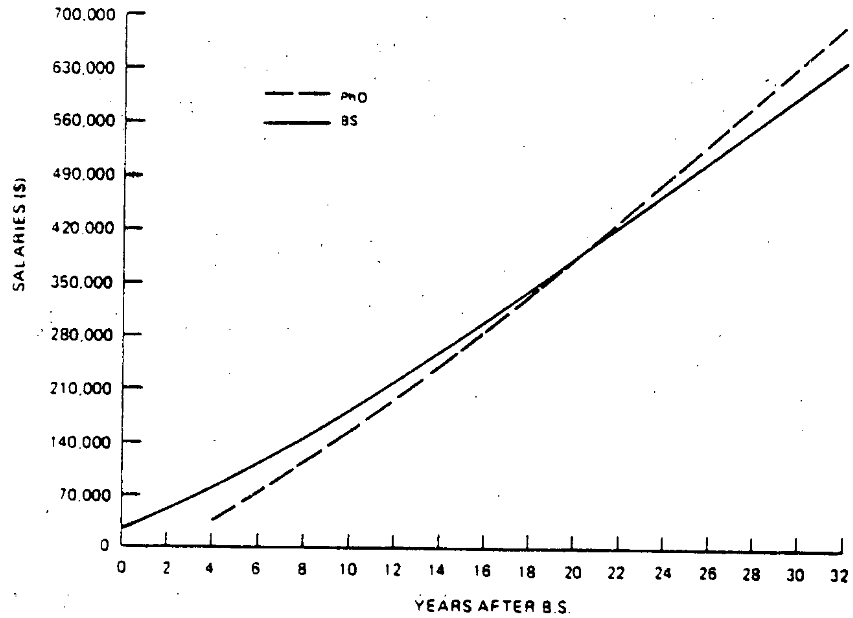
FIGURE D-19 Distribution of foreign engineers, by sector of employment, 1982.

EFFECTS OF FOREIGN NATIONALS

Hiring Practices

In my limited queries of federally supported laboratories, I found that those engaged in defense research rarely or never hired foreign nationals. Most other laboratories had a strong preference for citizens but were willing to apply for immigration for very exceptional candidates. At least one major nondefense laboratory is not hesitant to hire the best candidates, providing that the necessary visas are obtainable. There was a wide disparity of viewpoints, ranging from a view that the supply of citizen graduates is critically short to the belief that there is not a pressing problem.

There is nearly universal agreement that the United States should make it more attractive for citizens to seek advanced training. Some observers believe that we should place particular emphasis on our underutilized minority population. Women constitute about 15 percent of the undergraduate engineering body, and now account for 5-6 percent of the engineering work force. Minorities comprise 28 percent of the U.S. population, but only 4.6 percent of our engineers come from this group; of this 4.6 percent group, about two-thirds are Asian Americans,



SOURCE: Committee on Education and Utilization of the Engineer, Commission on Engineering and Technical Systems, National Research Council, *Engineering Education and Practice in the United States: Foundations of Our Techno-Economic Future,* Washington, D.C.: National Academy Press, 1985, p. 101.

FIGURE D-20 Cumulative B.S./Ph.D. salaries in engineering.

and the balance is black. There is room for make-up in manpower in the female and minority groups if the proper incentives are used and we improve preparatory schools for inner-city blacks (NSF, 1986). Graduates with B.S. degrees can command starting salaries that are close to the levels received by master's and Ph.D. levels, and the pay-back time in cumulative earnings for obtaining an advanced degree in engineering is about 20 years (see Figure D-20). Foreign students generally cannot qualify for B.S.-level positions because their visas do not permit them to seek full-time employment, and employers cannot readily certify that a U.S. citizen is not available to fill a B.S. level position. This may be one reason that foreign students preferentially seek advanced training. In future years many of these foreigners will have attained citizenship and may become the bosses of those who sought more immediate cash returns.

At least three government agencies that I contacted reported that they cannot compete with industrial salaries for starting Ph.D.s, so they hire bright B.S. graduates and grant liberal benefits to obtain more schooling. Owing to salary increases that come with increasing tenure and to loyalty that develops on the job, these individuals tend to remain in government positions.

Performance on the Job

In the laboratory environment, foreign-born individuals perform at least as well as their native counterparts. There may be certain isolated instances where language problems or cultural differences cause impediments, but none of my contacts could recall a negative instance worth sharing. On the contrary, I learned of several instances in which foreign-born laboratory employees facilitated the transfer of useful information from abroad to the United States. We may expect that language skills and familiarity with foreign cultures will become increasingly important in assuring a more balanced flow of information back to the United States. One large laboratory that maintains records comparing performance of foreign-born and native employees reports that the foreign-born contingent command salaries determined on merit about 5 percent above their native peers.

Interaction with Universities Having Foreign Faculty or Students

When university programs include foreign graduate students, national laboratories that handle sensitive information are hesitant to place research contracts or plan major collaborations. Even when a subject is unclassified, it may fall under export control regulations, or it may have consequences in commercial competitiveness. For instance, foreign students from certain countries are forbidden access to supercomputers. If a federally funded laboratory were working with a university on some advanced technique in microcircuits, it would be hesitant to fund collaborative work in a program filled with students planning to return to Japan. The problem becomes even more troublesome when faculty are foreign citizens, who may be able to visit the sponsoring laboratory only after considerable red tape or may be forbidden altogether from laboratory visits. In nearly all cases, foreign faculty cannot obtain security clearances, with the consequence that laboratories cannot give faculty the necessary perspectives to guide students along paths most relevant to a project. Without guidance from fully informed faculty, university researchers have also been known to stray into research areas that are sensitive. Laboratories cannot benefit from intensive and frequent visits of foreign-national faculty and students. Universities themselves are legally exempt from prosecution for transmitting sensitive information to foreign-national employees. The responsibility for protecting information lies with laboratories that collaborate with universities.

Some government agencies, such as the Defense Advanced Research Projects Administration (DARPA), fund research programs at universities, but there is frequently a government requirement that the research be openly publishable. If a laboratory researcher works in conjunction with such a program in sensitive areas, a conflict arises. In recent years a system of new orders and regulations concerning sensitive, but unclassified, information has emerged. While implementing rules are not yet fully in place, the consequences of the new system will most likely make dealing with foreign students and faculty even more difficult.

In summary, the presence of foreign nationals in universities impedes mutually beneficial interaction with laboratories working in sensitive, classified, or industrially competitive areas. The laboratories have limited control in this area, other than deciding not to work so intensively with universities. At least one laboratory, the National Bureau of Standards, sponsors a university-affiliated institute, the Joint Institute for Astrophysics, and in this way can interact fully with the international scientific community.

Interaction with Industry That Employs Foreign Nationals

A similar set of circumstances surrounds interactions at national laboratories engaged in national defense work with industry when industry employs foreign nationals. Many laboratories find it more difficult or strategically unwise to have extensive interactions with foreign nationals, even though they may be employed by American industry.

Interaction with Visitors from Other Nations

Most laboratories are able to host casual visits that last a day or two, but as previously noted there is sometimes considerable red tape. Usually individual laboratories, guided by the judgment of individual scientists that host particular visitors, determine whether a visit should take place. The burden of assuring reciprocal value also lies largely with the host. Of course, when a laboratory hosts visits from developing nations, the information flow will expectedly be one-way. In agricultural exchanges with less developed nations, there is an unexpected benefit; the United States is able to replenish or expand its collection of genetic material from plants worldwide as part of our exchanges. In transactions with developed nations, there exist several factors that favor a net benefit to the foreigner.

Many foreigners live in a more competitive world, and they seek advantage in information exchanges. I learned of one extreme case that resulted in scientists from a U.S. host laboratory walking away from a visit during which the visitor blatantly refused to share his data. Experienced hosts provide ample time for visitors to talk and inform them in advance that this is expected.

Foreigners usually have a far better command of English than the U.S. hosts have of the foreigners' language. This often allows the visitors to obtain considerable information in preparation for the visit. Additionally, foreigners can usually converse with each other without their host's understanding. It is useful during foreign visits to have the participation of naturalized laboratory staff or someone familiar with the visitor's native language.

The level of funding for U.S. research, the comprehensiveness of programs, and the openness of our society are all factors that favor the learning process in the United States in comparison with most other nations. Visitors find it easy to exploit these factors. One area that has been newsworthy with respect to a foreign presence during the past several years is the research program carried on at the National Institutes of Health. There is some controversy about whether our open policies allow other nations to benefit unduly from U.S. health care research. This important area could warrant a separate, focused study.

The usefulness to the United States of separate visits by foreign nationals varies widely. In expensive multinational programs such as fusion and high-energy physics research, there is but small prospect for any near-term commercial utilization. Workers can more easily share data when the motives are scientific and commercial economic benefits are remote; under such conditions there is clear benefit from facility sharing. Most observers would cite exchanges in magnetic fusion and high-energy physics as models for mutual benefit. Sometimes visits become difficult to control when programs become highly visible. For example, foreign visits to solar energy programs at one national laboratory totaled 1,800 and domestic visits totaled 8,000 during a 5-year period; this became a major distraction to the staff, despite adding some dedicated guides. Owing to the large amount of publicity surrounding solar energy in the early days of the program, many nonexperts paid visits, hoping to gain information or, more cynically, complete a junket. We should emphasize that this example is an extreme one; in addition to the distractions, many useful interactions result from more serious visits. Again, experienced hosts try to assure that visitors have good credentials and insist that visitors divulge work from their home laboratories.

IMPLICATIONS FOR THE FUTURE

If present trends continue and foreign engineering and science graduates receive an even larger proportion of advanced degrees, the United States will find an inadequate supply of citizens for its national security missions. With the present fraction of Ph.D. degrees awarded to foreign nationals hovering near 50 percent, we expect to see increased numbers of these individuals in the U.S. labor force. These increases will occur first in the positions accessible to noncitizens, most notably in universities and nondefense industries. As time passes, many of the foreign nationals may become citizens, and some will move into defense-industry positions. The percentage of undergraduate degrees awarded to foreigners is not great enough to restrict the pool of available citizen talent; there seem to be no indicators that this will become a major problem in the predictable future.

While the emerging pattern may seem benign, there will be some problems. While the effect of foreigners on universities is beyond the scope of this study, it appears that teaching roles place stress on communications skills and cultural acclimation--the areas where foreigners are likely to be weakest. More importantly, we observed that a large foreign-national presence on faculties and student bodies greatly inhibits intercourse between universities and laboratories that engage in national defense or industrial competitiveness research.

If we subscribe to the premise that close university relationships with laboratories and industry are important, there exists a problem of national scope. However, solving the problem by arbitrarily limiting the number of foreigners in our educational system runs contrary to our ethos. Additionally, limiting foreigners would reduce an important source of intellectual talent. It appears that the most workable solution is a partial one. We should provide incentives for citizens receiving B.S. degrees to achieve higher levels of education. This is already happening, but may need more encouragement.

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AMERICAN ENGINEERS IN JAPAN

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There are not many good statistics about American engineers visiting Japan. We do have some data from which estimates--or guesstimates--may be made, however, for purposes of discussion. The single largest source of engineers traveling to Japan over the last 25 years has probably been the U.S.-Japan Cooperative Science Program. According to that program's *25th Anniversary Report* (USJCSP, 1986), 595 American engineers were involved in the Cooperative Research component of the program and 950 were involved in the Joint Seminar component over 25 years. One-half of the joint seminars are held in Japan, and fewer Americans are supported for travel to them than for travel to seminars in the United States. We can assume, then, that since Cooperative Research participants almost always go to Japan, about 1,000 American engineers went to Japan under this program in 25 years. The National Science Foundation's (NSF) engineering research support programs annually make 20-30 grants that involve travel to Japan--some to attend meetings and some to visit laboratories. In addition, the State Department reported earlier this year that 116 Americans received Japanese government support to visit government and university lab- oratories in both 1984 and 1986.[8] If we arbitrarily assume that half of these were engineers, we have a total of about 130 American engi- neers per year going to Japan on U.S. government or Japanese government support.

Japan's natural science and engineering research and development (R&D), however, is financed primarily (80 percent) by the private sector (industry and other private sources). So we must look at the private sector to see whether it is a source of significant exposure of American engineers to Japanese laboratories. While in Japan for NSF, I did two surveys of Japanese companies. In the first, 305 companies were asked about their willingness to have foreigners in their laboratories, and over 80 percent responded. One question--answered by 78 percent of the 305 companies--asked whether a foreigner was working in the labs at that time. Forty-two laboratories (16 percent) responded affirmatively, but 19 indicated that the foreigners were there

[8] U.S. Department of State, telegram from the U.S. Embassy in Tokyo, 1987.

under the support of the Japan International Cooperation Agency (JICA), their equivalent of the U.S. Agency for International Development. So, these did not come from the United States. At that moment in time, then, 23 people who could have been Americans were in this group of labs. Following my previous estimate of the scientist/engineer split and extrapolating to the full 305 companies, we might have 15 American engineers, at most, in this group.

For another survey, I used 1,270 firms that had at least 500 employees and research facilities. I think that this represented a very large percentage of the industry laboratories at which American engineers might find research places. If we extrapolate our very tenuous figures from the first survey to the second sample (which included the first), we might get 62 American engineers--at most. By this tortured and imprecise method, we came to 130 with government support throughout the year and 62 maximum from industry at any given moment. Adding in other possible sources of support, I suspect that the total for any year would not be more than 300. It is more likely fewer.

Most of the visitors supported in the cooperative science program go to Japan for just a few weeks per year. Most get to know only a few Japanese and see relatively few facilities. The visitors to Japan paid for by the Japanese government are almost all in Japan to give lectures and to impart their knowledge rather than to gather it. The visitors to industrial laboratories are most often probably in the same category --training Japanese in a technique as part of a cooperative exchange or connected with a sale of technology to the Japanese. Considering these facts and conjectures as a whole, the following are apparent:

- Not many American engineers go to Japan.
- Not many who do go are involved in research experiences.
- Most visits are short-term.
- Many visits are initiated at the behest of the Japanese and respond to a Japanese agenda.

Since Japan has a number of notable achievements--in engineering for earthquake-resistant buildings, tunnels, and bridges; in microelectronics; in manufacturing applications; and in consumer product engineering--one wonders why so few of our engineers turn up there. The Japanese have over 13,000 science and engineering students here at any given time. We have about 800 students of all kinds in Japan. In 1985, over 219,000 Japanese visited the United States in visa categories for business purposes and for other skilled professional activities. It is safe to say that several thousand of these visitors are Japanese engineers. They are here because they like the way we do things and feel they can benefit from studying how we do them. Do we admire the way Japanese engineers do things? Some things?

There is probably more going on there than we are benefiting from --because we are not participants in the Japanese system in the same way they are participants in ours. Our researchers are not prepared to benefit from Japanese advances in the same measure that the Japanese prepare to benefit from ours. Japan can be a daunting place because of cultural differences and expectations (such as in housing and food).

Japanese language is exceedingly complex and not easy to learn for Americans. On the other hand, surely the cultural and language difficulties run the other way as well. The difference is that the Japanese made a conscious decision that learning English and putting up with greasy hamburgers and other disgusting American delicacies was important to the future of Japan. They were right.

The Japanese have recently adopted a national policy for the promotion of basic research and the production of new knowledge. They have also made it a policy to "internationalize" their research resources. What is to be our response to this situation? Fifteen or twenty years from now, the Japanese are going to be better than they are today in science and engineering research. Is it important to our future that we position ourselves to benefit from Japan's advancements? I think so. Our engineers need to take the time to learn some Japanese. We need to send more engineers (and scientists) to Japan for longer periods to learn more about directions of Japanese research and the results that can advance our own research. The government can help by providing opportunities and incentives to our students, postdocs, and researchers. Some such support already exists (as described above), and NSF is proposing a Japan initiative in its fiscal year 1988 budget submission. The initiative would provide funds for improving the curriculum for teaching technical Japanese, making more technical Japanese available to science and engineering students and researchers, providing incentives for scientists and engineers to study Japanese, and improving support for American researchers who want to make a long-term (six months or more) research visit to Japan. Hopefully, these efforts will have some impact. Perhaps, more important, however, will be the extra effort that will have to come from students and researchers and faculty advisers who counsel young researchers. Extra effort will be involved in identifying potentially rewarding research opportunities in Japan and in preparing for them. It will take extra effort as well to plan for a researcher's reintroduction to the American mainstream on returning from an extended stay in Japan. It all goes back to how important we think it is. We should look closely at the potential benefits to our research and to our long-term posture as a leader in science and engineering--and as a economic power. Then we need to make the investment and do the hard things that will be necessary to build a stronger and increasingly mutually beneficial relationship with the Japanese in engineering and in science.

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IMPACT OF FOREIGN STUDENTS ON ENGINEERING PROGRAMS AT THE UNIVERSITY OF CALIFORNIA*

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University of California-San Diego

INTRODUCTION

The administration of the University of California (U.C.) is committed to a policy of increasing the proportion of domestic graduate students in engineering and computer science. As part of this policy, the number of foreign graduate students in engineering will not be allowed to increase until a goal of 24 to 28 percent nondomestic enrollment is reached. In the interim, any authorized growth in graduate enrollments in engineering will be limited to domestic students. The aim of increasing the number of domestic graduate students in engineering and computer science within the U.C. is laudable, given the current demographic situation and the differential in salaries between industry and academe, but it is unlikely that a significant increase in the number of qualified domestic graduate students will occur without a major infusion of resources. Since the national undergraduate enrollment in engineering peaked in 1983, it is very likely that a reduction in the number of domestic applicants for graduate study will take place in the next few years. Under these conditions, a policy that sets limits on the number of foreign graduate students may have very serious implications.

At the national level, the production of domestic doctorates in engineering is insufficient to meet the combined demands of academe, industry, and government. At the local level, the number of domestic graduate students in engineering is insufficient to meet the demand for research and teaching assistants. The imposition of a limit on the absolute number of foreign graduate students (rather than a limit on the relative representation of foreign students) will also place unequal constraints on the developing programs vis-a-vis the more established schools in the U.C. system.

The objective of this paper is to summarize the trends in the impact of foreign students in engineering at the national and state levels, as well as within the University of California. Views expressed in

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this paper are those of the author and do not necessarily reflect the position of the U.C.

FOREIGN STUDENTS IN ENGINEERING: NATIONAL TRENDS

Although the number of foreign postsecondary students in all disciplines is large (343,377 in 1985-86) (Zikopoulos, 1986), this number constitutes only 2.7 percent of the total number of students attending postsecondary institutions in the United States. The situation is quite different in engineering. In the fall of 1985, according to a survey conducted by the Engineering Manpower Commission (EMC), nonresident foreign nationals accounted for 4.2 percent of part-time undergraduate students, 7.0 percent of full-time undergraduate students, 10.4 percent of part-time graduate students, 32.5 percent of full-time graduate students enrolled in master's degree programs (including engineering professional degrees), and 42.9 percent of full-time students in doctoral programs (Table D-6). The EMC also reports that nonresident foreign students received 7.7 percent of the bachelor's degrees, 27.2 percent of the master's degrees, and 41.4 percent of the doctoral degrees awarded in 1985 (EMC, May 1986). Similar statistics reported by the National Research Council indicate that foreign nationals on temporary visas received 44.6 percent of the doctoral degrees awarded in engineering in 1985. Foreign nationals on permanent visas received an additional 10 percent of the doctoral degrees, and U.S. citizens received 40.4 percent (the status of the recipients of the remaining 5.0 percent of degrees is unknown) (Coyle, 1986).

The relative importance of foreign engineering students has grown drastically in the past 15 years. As shown in Table D-7, in 1970, foreign students received 3.7 of the bachelor's degrees, 14.6 of the master's degrees, and 14.0 of the doctoral degrees awarded. In 1985, the corresponding percentages were 7.7, 27.2, and 41.4, respectively.

The number of bachelor's, master's, and doctoral degrees in engineering awarded annually to U.S. residents (including resident foreign students) and to nonresident foreign nationals are shown as a function of time in Figures D-21, D-22, and D-23. The statistics illustrated in Figure D-21 show a very rapid increase in the number of bachelor's degrees awarded yearly in the period 1976-1985. In 1976, a total of 37,970 bachelor's degrees were awarded; in 1985, this number had doubled to 77,946. The corresponding number of degrees awarded per year to nonresident foreign nationals grew from 2,810 in 1976 to 5,650 in 1981, and to 6,000 in 1985. Since 1981, the number of foreign undergraduate students has grown only gradually, due in part to enrollment limits placed as a result of the high domestic demand for undergraduate studies in engineering. Since the total undergraduate enrollment in engineering peaked in 1983 (Figure D-24), it is possible that these limits will be relaxed and that the number and relative importance of foreign undergraduate students will continue to grow.

The number of master's degree recipients per year (including professional degrees) is shown in Figure D-22. The total number of mas-

TABLE D-6: Engineering Enrollment, Fall 1985

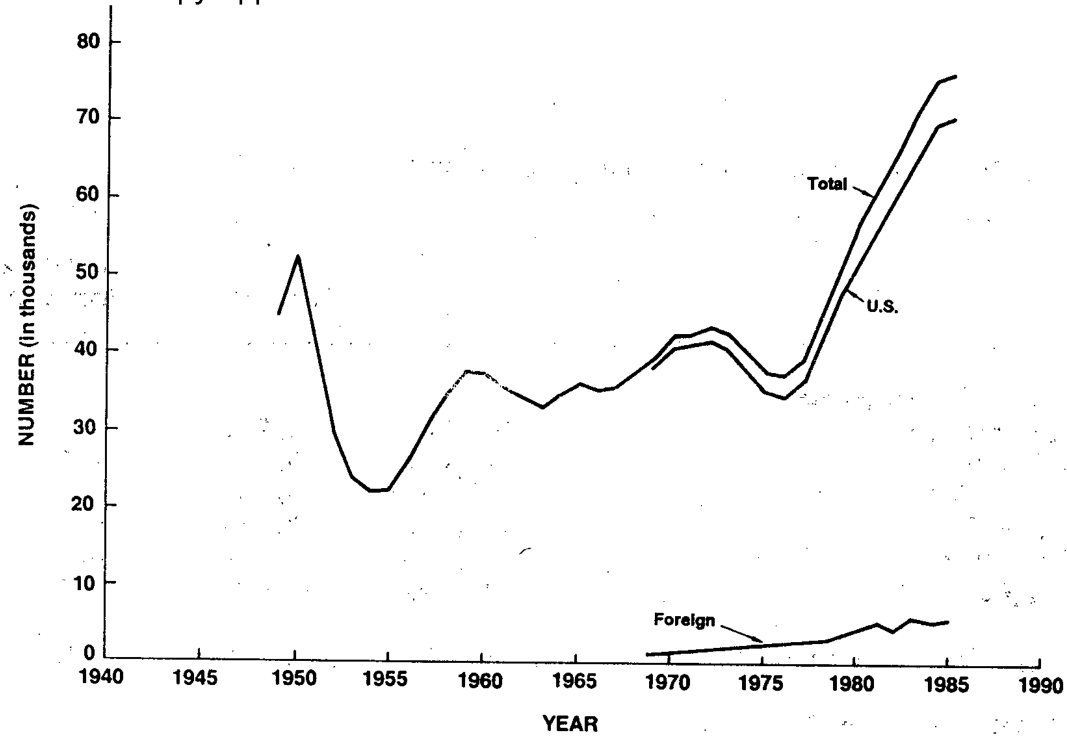
	Total	Foreign	Percentage Foreign
Full-Time Undergraduates			
Freshman Year	103,225	5,282	5.1
Sophomore Year	79,627	5,553	7.0
Junior Year	84,875	6,756	8.0
Senior Year	110,305	9,165	8.3
Fifth Year	6,159	299	4.9
Total	384,191	27,055	7.0
Part-Time Undergraduates	36,673	1,536	4.2
Full-Time Graduate Students			
Master's Degree	39,147	12,741	32.5
Doctorate	21,494	9,212	42.9
Total	60,641	21,953	36.2
Part-Time Graduate Students	34,864	3,622	10.4

SOURCE: Engineering Manpower Commission, "Engineering and Technology Enrollments," *Engineering Education,* New York: EMC, October 1986.

TABLE D-7: Bachelor's, Master's, and Doctoral Degrees in Engineering Awarded Annually to Nonresident Foreign Students (in percent)

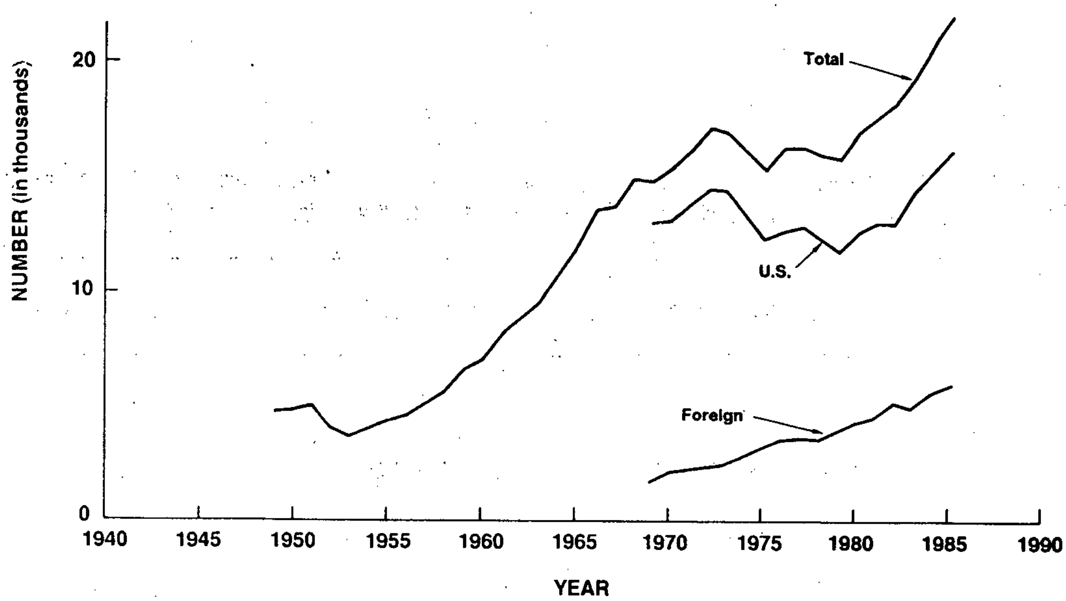
Year	Bachelor's	Master's*	Doctorate
1970	3.7	14.6	14.0
1975	(6.5)	(19.9)	(27.1)
1980	8.4	26.1	35.7
1985	7.7	27.2	41.4

*Includes engineering professional degrees.
SOURCE: Engineering Manpower Commission, "Engineering and Engineering Technology Degrees Granted," *Engineering Education,* 1970-1986.



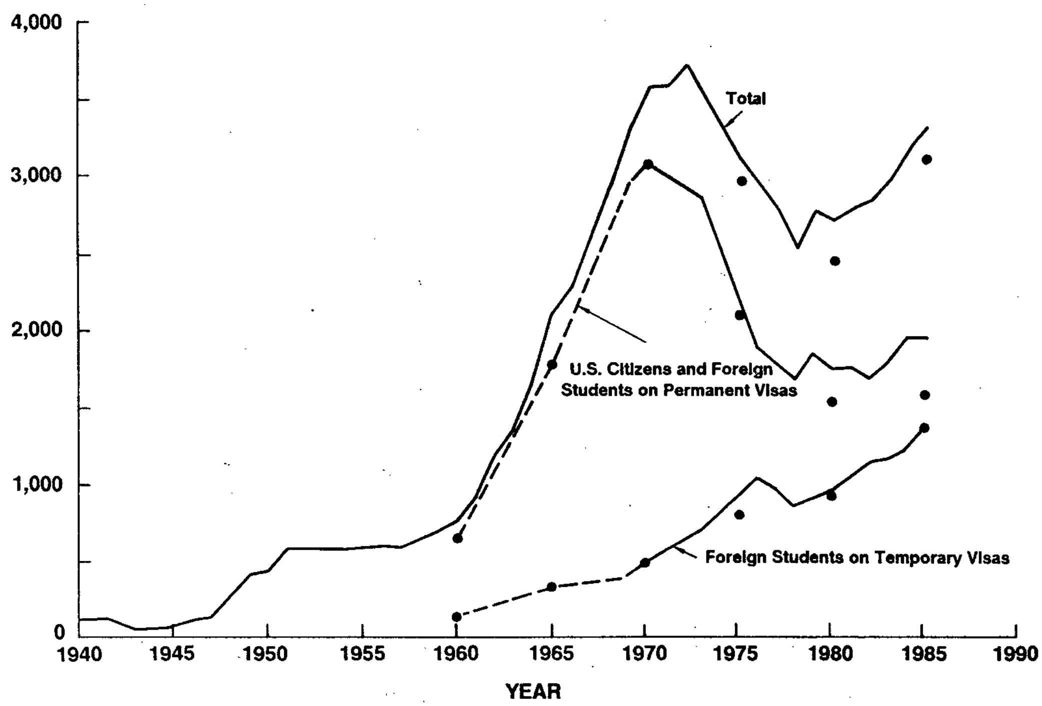
SOURCE: Engineering Manpower Commission, "Engineering and Engineering Technology Degrees Granted, *Engineering Education,* New York: EMC, May 1986.

FIGURE D-21 Bachelor's degrees awarded in engineering, 1949-1985.



SOURCE: See Figure D-21.

FIGURE D-22 Master's and professional degrees awarded in engineering, 1949-1985.



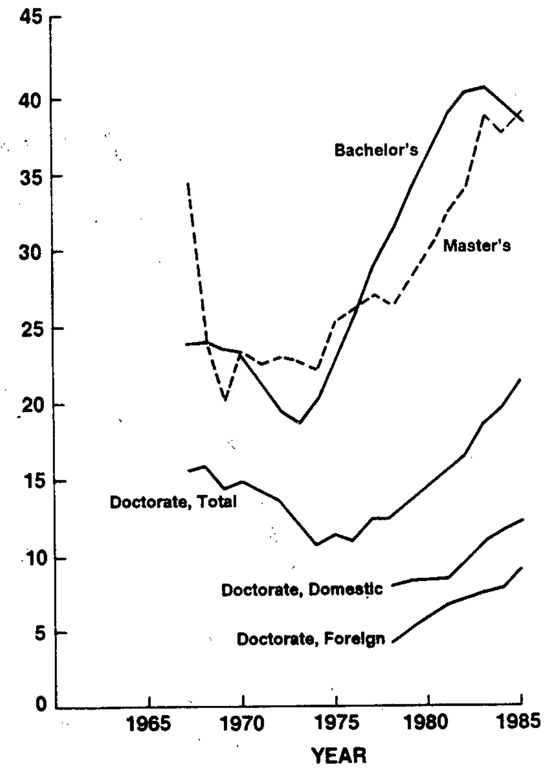
SOURCES: Engineering Manpower Commission and National Research Council's Doctorate Records File.

FIGURE D-23 Doctorates awarded in engineering, 1940-1985.

ter's degrees awarded per year tripled from 5,790 in 1958 to 17,360 in 1972. Since 1972, this number declined to 16,040 in 1979 and then grew again to 22,490 by 1985. Sixty-eight percent of the increase between 1979 and 1985 in the total number of master's degrees recipients per year can be attributed to domestic students. The remaining 32 percent of the increase is associated with nonresident foreign students. Foreign students accounted for 6,120 (27.2 percent) of the master's degrees awarded in 1985.

The total enrollment in master's degree programs in 1985 is not very different from that in 1983 (Figure D-24). This observation and the fact that the undergraduate enrollment peaked in 1983 suggest that a reduction in enrollment in master's degree programs may take place in the next few years. If this is the case, the importance of foreign students at the master's degree level may increase even further.

The number of doctorates in engineering awarded annually for the period 1940-1985 is shown in Figure D-23. Also shown are the data on nonresident foreign recipients and degrees awarded to U.S. residents including U.S. citizens and foreign nationals on permanent visas. Two slightly different sets of data are shown in the figure. The first set (solid lines) corresponds to that assembled since 1968 by the Engineering Manpower Commission and by the U.S. Office of Education for earlier years. The second set of data (shown as dots in the figure) stems from the National Research Council's Survey of Earned Doctorates.



NOTE: Bachelor's = x 10,000; master's = x 1,000; doctorate = x 1,000.
SOURCES: National Research Council's Survey of Earned Doctorates and Engineering Manpower Commission, "Engineering and Engineering Technology Enrollments, *Engineering Education,* New York: EMC, October 1986.

FIGURE D-24 Full-time enrollment in engineering, 1965-1985.

The data in Figure D-23 show a very rapid increase from 786 doctoral degrees per year in 1960 to a peak of 3,774 per year in 1972 followed by a steep reduction to 2,573 degrees per year in 1978. Since 1978, a gradual increase in doctoral degrees has taken place, leading to 3,384 degrees awarded in 1985. The data also show several important features. First, the steady increase in the importance of nonresident foreign recipients in both absolute and relative terms is apparent. In 1985, nonresident foreign nationals accounted for 41.4 percent (Engineering Manpower Commission) to 44.6 percent (National Research Council) of the total number of doctoral degrees awarded. Secondly, most of the increase since 1978-1980 in the number of degrees awarded per year is associated with nonresident foreign recipients. Depending on the data set used, 66 percent (Engineering Manpower Commission) to 82 percent (National Research Council) of the increase in doctoral degrees in the period 1980-1985 can be attributed to nonresident foreign students. Finally, since 1980 the number of doctoral degrees awarded per year to U.S. residents has been in the range from 1,500 to 2,000. This number is one-half to two-thirds of the 3,000 degrees awarded to U.S. residents in 1970.

The total enrollment of graduate students in doctoral programs in engineering has grown continuously since 1974 (Figure D-24). This trend suggests that the production of doctorates in engineering will continue to grow for at least the next 3-5 years. However, a major portion of the increase in doctoral enrollments is due to foreign students: from 1978 to 1985, the enrollment of domestic students in doctoral programs grew by 4,200 students while the enrollment of nonresidents grew by 5,000 students. The high proportion of foreign students in the 1985 doctoral enrollment suggests that for the next several years foreign students will continue to receive a high percentage of the doctoral degrees awarded by U.S. institutions.

The large proportion of foreign graduate students and of doctoral degrees being awarded to foreign nationals have raised a number of concerns. These concerns range from the quality of the work performed by foreign teaching assistants to the future composition of engineering faculties and the manpower requirements of national research laboratories. A number of interventions have been proposed, but no national policy has emerged. Eighteen percent of engineering departments in public institutions and seven percent of those in private institutions have set limits to the maximum percentage of non-U.S. citizens admitted for graduate study (Barber and Morgan, 1987). The mean value of the limit percentage set by these institutions is 31 percent. Another proposed intervention is to increase financial support to graduate students to the point where they are no longer captivated by jobs in industry. Some would consider limiting this increased support to U.S. students only (Dowell, 1987).

A critical issue is to identify the minimum number of doctoral degrees that needs to be awarded to U.S. residents to satisfy the needs of the nation. In 1985, a total of 1,595 doctoral degrees were awarded to U.S. residents, according to the National Research Council (the Engineering Manpower Commission estimate is 1,983). To judge this number, it must be considered that the total number of doctorates in engineering in the labor force was 55,600 in 1983 (National Research Council) and that the estimated number of authorized full-time engineering faculty positions in 1985 was 20,450, of which 1,800 were vacant (Doigan and Gilkeson, 1986). Indeed, a survey of engineering deans suggests that 1,600 additional faculty positions beyond those authorized would be required to restore the quality of engineering programs (Doigan and Gilkeson, 1986). Based on these figures, it would seem that the annual replacement needs of engineering faculty is of the order of 800-1,000 doctorates. The statistical profile of the 1985 doctorate recipients indicates that of the 1,595 domestic doctorate recipients, 72 percent had definite employment plans and of these, 27.3 percent (or 314 doctorates) were committed to academic positions (Coyle, 1986). It is not surprising to find that while foreign nationals constituted only about 14 percent of the faculty of engineering schools in 1986 (NSF, 1987), 30.6 percent of all faculty numbers were foreign-born and 41.4 percent of full-time faculty appointments during the period 1985-1987 involved foreign citizens (Barber and Morgan, 1987). Clearly, the number of domestic doctorates awarded per year is not sufficient to fulfill the combined needs of academe, industry, and government.

TABLE D-8: Full-Time Enrollment in Engineering, Fall 1985

	Undergraduate	M.S.	Doctorate
U.C. System	11,450	1,914	2,256
California	39,005	6,860	3,947
U.S.	384,191	39,147	21,494

SOURCE: Engineering Manpower Commission, "Engineering and Engineering Technology Enrollments," *Engineering Education,* New York: EMC, October 1986.

FOREIGN STUDENTS IN ENGINEERING: UNIVERSITY OF CALIFORNIA

To consider the impact of foreign students in engineering in the U.C. system, it must be understood that California is the state with the largest number of foreign students. The Institute for International Education estimates that 47,586 foreign students, corresponding to 13.0 percent of all postsecondary foreign students in all disciplines, reside in California (Zikopoulos, 1986). Since 21.7 percent of all foreign students in the United States are in the field of engineering (including engineering technology), it can be estimated that the state of California had in 1985-86 about 10,000 foreign students in engineering and engineering technology. Again, using the figures for the United States as a whole, it can be estimated that in 1985-86 the state of California had 4,300 foreign undergraduate engineering students in 4-year institutions and 3,900 foreign graduate students in engineering.

The state of California also has the largest number of engineering students in the nation (39,000 full-time undergraduates, 6,720 full-time master's level students, and 3,950 full-time doctoral level students (EMC, October 1986). In terms of the state as a whole, it is estimated that 11 percent of the undergraduate and 36 percent of the full-time graduate students in engineering are foreign. The total enrollment in graduate and undergraduate engineering programs in the U.C. system (Berkeley, Los Angeles, Davis, Santa Barbara, San Diego, Irvine) is compared in Table D-8 with those in the state of California and the United States. The U.C. system accounts, respectively, for 29, 28, and 57 percent of the bachelor's, master's, and doctoral level enrollments in the state of California and for 3, 5, and 10 percent of the corresponding enrollments in the nation.

The number of bachelor's, master's, and doctoral degrees in engineering awarded per year by the U.C. is compared in Figures D-25, D-26, and D-27 with the corresponding number of degrees awarded by all institutions in the state of California. Since 1975, the U.C., following the trends for the state and the nation (see Figure D-21), has doubled

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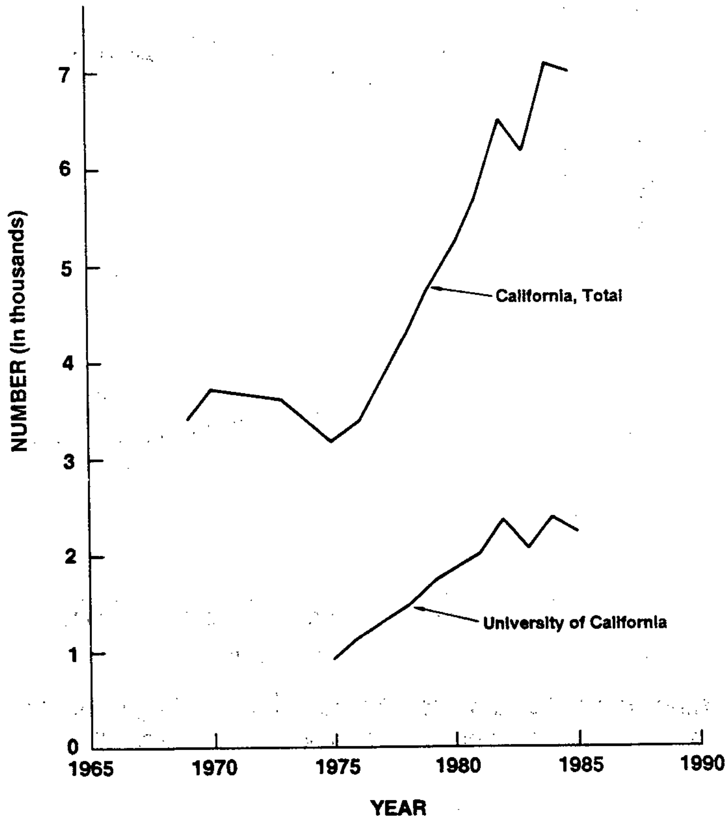


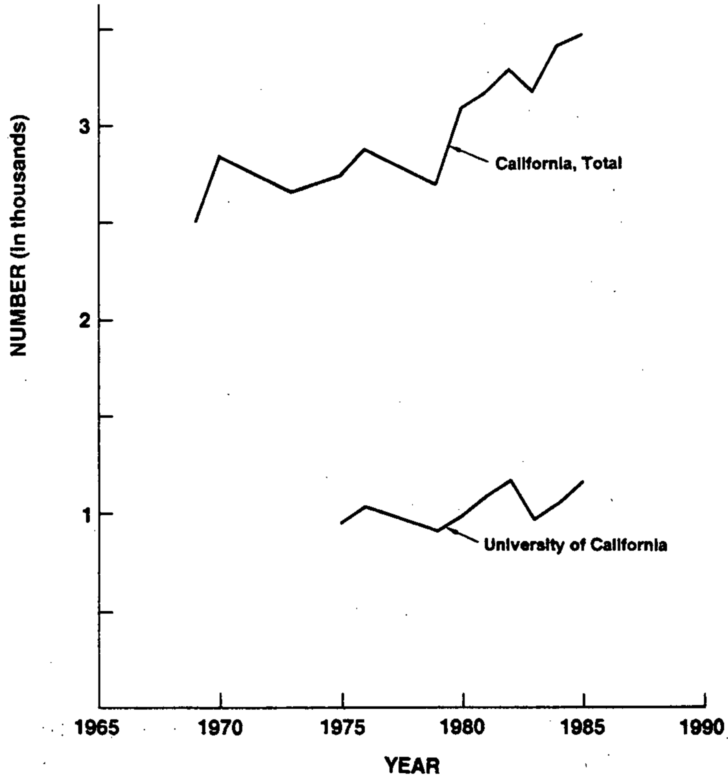
SOURCE: Engineering Manpower Commission, "Engineering and Engineering Technology Degrees Granted," *Engineering Education,* New York: EMC, May 1986.

FIGURE D-25 Bachelor's degrees awarded in engineering, 1969-1985.

its output of bachelor's degree recipients per year (Figure D-25). This growth pattern for the university stopped in 1982, when the resources were exceeded and some engineering applicants had to be diverted. At the master's degree level (see Figure D-26), the growth in the U.C. has been much smaller than the growth for the state as a whole, which is similar to that of the nation (Figure D-22). The number of doctoral degrees in engineering awarded per year by the U.C. grew by about 19 percent from 1978 to 1985. This rate of growth is similar to that of the state of California but much lower than the 32 percent growth for the United States as a whole in 1978-1985.

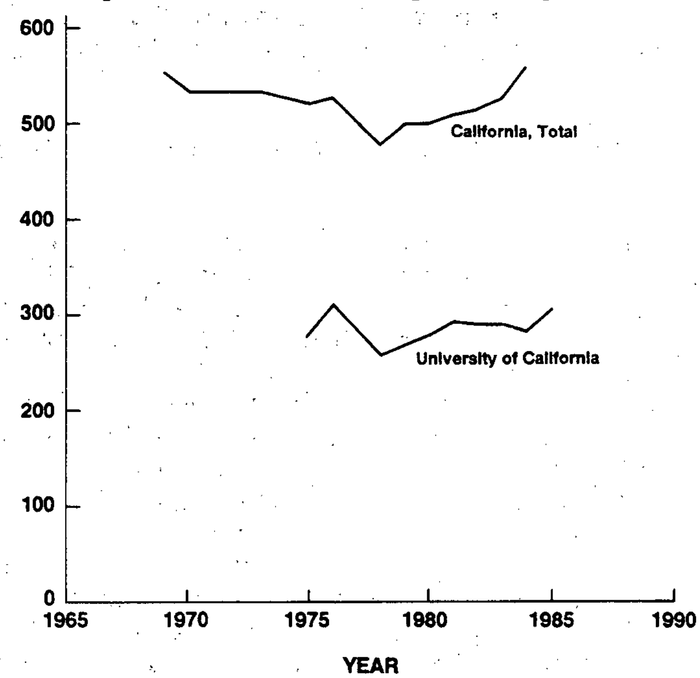
The impact of foreign graduate students in engineering and computer science at California's public universities has been studied by the California Postsecondary Education Commission (CPEC, 1985). In its report to the California legislature, the CPEC concludes that:

(1) Qualified domestic students are not being denied admission to graduate programs in engineering and computer science because of the presence of foreign students,



SOURCE: Engineering Manpower Commission, "Engineering and Engineering Technology Degrees Granted," *Engineering Education,* New York: EMC, May 1986.

FIGURE D-26 Master's degrees awarded in engineering, 1969-1985.



SOURCE: Engineering Manpower Commission, "Engineering and Engineering Technology Degrees Granted," *Engineering Education,* New York: EMC, May 1986.

FIGURE D-27 Doctoral degrees awarded in engineering, 1969-1985.

TABLE D-9: University of California Graduate Enrollment in Engineering, Fall 1985

	Total	Domestic	Foreign	Percentage Foreign
Berkeley	1,578	998	580	36.8
Los Angeles	1,019	711	308	30.2
Davis	535	391	144	26.9
Santa Barbara	431	290	141	32.7
San Diego	350	248	102	29.1
Irvine	314	238	76	24.2
Total U.C. System	4,227	2,876	1,351	32.0
Total U.S. (Full-Time)*	60,641	38,688	21,953	36.2

* These data are from the Engineering Manpower Commission.

(2) The percentages of foreign graduate students in engineering and computer science in California's public universities have been declining since 1981,
(3) The proportion of foreign graduate students in engineering and the sciences in California is lower than that of several other large states, and
(4) The proportion of graduate foreign students in California's public universities is lower than that in the private universities.

The statistical data pertaining to the U.C. system used as a basis for these conclusions and some additional data are presented next.

The numbers of domestic and foreign graduate students in engineering enrolled at Berkeley, Los Angeles, Davis, Santa Barbara, San Diego, and Irvine in the fall of 1985 are listed in Table D-9. The percentage of foreign students ranges from 24.2 percent at U.C. Irvine to 36.8 percent at U.C. Berkeley. The percentage of foreign graduate students for the U.C. system averages to 32.0 percent, which is slightly lower than the 36.2 percent representation for the United States as a whole.

The total number of foreign graduate students in engineering has varied only slightly, but their relative representation has decreased from 33.6 percent in 1982 to 32.0 percent in 1985 (Table D-10). In this period, the total number of domestic graduate students has increased by 253 students (or 9.6 percent) while the total number of foreign students has increased only by 22 students (or 1.7 percent). A more detailed analysis reveals that the percentage of foreign graduate students has declined at Santa Barbara, Davis, Irvine, and San Diego;

TABLE D-10: University of California Graduate Enrollment in Engineering, 1982-1985

Year	Total	Domestic	Foreign	Percentage Foreign
1982	3,952	2,623	1,329	33.6
1983	4,098	2,803	1,295	31.6
1984	4,250	2,879	1,371	32.3
1985	4,227	2,876	1,351	32.0

TABLE D-11: University of California Foreign Students as Percent of Total Graduate Enrollment in Engineering, 1982-1985

U.C. Campus	1982	1983	1984	1985
Berkeley	35.1	33.8	36.6	36.8
Santa Barbara	44.2	40.6	37.1	32.7
Los Angeles	29.3	30.4	29.7	30.2
San Diego	33.3	28.2	27.2	29.1
Davis	33.0	27.6	29.3	26.9
Irvine	30.0	23.6	22.3	24.2
Total	33.6	31.6	32.3	32.0

TABLE D-12: New Foreign Graduate Students in Engineering, University of California, 1982-1985

U.C. Campus	1982	1983	1984	1985
Berkeley	172	178	192	140
Los Angeles	88	114	99	80
Santa Barbara	51	57	57	72
San Diego	39	20	32	35
Irvine	24	17	22	32
Davis	31	30	37	31
Total	405	416	439	390

TABLE D-13: New Domestic Graduate Students in Engineering, University of California, 1982-1985

U.C. Campus	1982	1983	1984	1985
Berkeley	352	397	322	324
Los Angeles	176	198	173	152
Santa Barbara	62	85	84	100
San Diego	61	76	83	75
Irvine	51	42	44	68
Davis	72	99	104	72
Total	774	897	810	791

TABLE D-14: Master's Degrees in Engineering Awarded to U.S. and Foreign Students, 1978-1984

Year	Region	Total	U.S.	Foreign	Percentage Foreign
1978-80	U.C.	863	551	312	36.1
	California	2,414	1,537	877	36.3
	U.S.*	17,299	12,784	4,515	26.1
1980-81	U.C.	856	581	275	32.1
	California	2,261	1,465	796	35.2
	U.S.*	17,914	13,238	4,676	26.1
	U.S.**	16,358	11,794	4,564	27.9
1981-82	U.C.	1,005	622	383	38.1
	California	2,802	1,788	1,014	36.1
	U.S.*	18,543	13,184	5,359	28.9
1982-83	U.C.	934	609	325	34.8
	California	2,764	1,749	1,015	36.7
	U.S.*	19,673	14,597	5,076	25.8
1983-84	U.C.	959	638	321	33.5
	California	2,911	1,906	1,005	34.5
	U.S.*	21,226	15,495	5,731	27.0

* Data from Engineering Manpower Commission
** Data from *Digest of Educational Statistics 1985-86.*

remained essentially constant at Los Angeles; and increased at Berkeley (Table D-11).

The impact of foreign graduate students in the immediate future can be assessed by examining the composition of the class of new graduate students enrolled each year. For the period 1982-1985, an average of 410 new foreign and 820 new domestic graduate students in engineering are enrolled each year in the University of California system (Tables D-12 and D-13). This corresponds to a 33.3 percent representation for the new foreign students. It should be noted that while the number of new foreign graduate students in 1985 was lower than the corresponding number in the previous 3 years, the number of new domestic graduate students in 1985 was also lower than the new enrollments in 1983 and 1984.

TABLE D-15: Doctoral Degrees in Engineering awarded to U.S. and Foreign Students, 1979-1984

Year	Region	Total	U.S.	Foreign	Percentage Foreign
1979-80	U.C.	229	135	94	41.0
	California	421	252	169	40.1
	U.S.*	2,753	1,770	983	35.7
	U.S.+	2,479	1,554	850	34.3
1980-81	U.C.	258	174	84	32.5
	California	457	285	172	37.6
	U.S.*	2,841	1,787	1,054	37.1
	U.S.**	2,551	1,595	956	37.5
1981-82	U.C.	246	135	111	45.1
	California	456	281	175	38.4
	U.S.*	2,887	1,721	1,166	40.4
1982-83	U.C.	275	147	128	46.5
	California	470	260	210	44.7
	U.S.*	3,023	1,832	1,191	39.4
1983-84	U.C.	255	146	109	42.7
	California	562	320	242	43.1
	U.S.*	3,234	1,982	1,252	38.7

* Data from Engineering Manpower Commission
** Data from *Digest of Educational Statistics 1985-86*.
+ Data from *Summary Report: Doctorate Recipients from United States Universities*, published annually by National Academy Press, Washington, D.C.

TABLE D-16: Number of Domestic and Foreign Applications, Admissions, and New Graduate Students in University of California System, Fall 1985

	Applied		Admitted		New		Admissions/ Applications	
U.S. Campus	D*	F*	D*	F*	D*	F*	D*	F*
Berkeley	1,790	2,029	731	331	324	140	0.41	0.16
Los Angeles	788	744	337	228	152	80	0.43	0.31
San Diego	394	550	181	109	75	35	0.46	0.20
Davis	349	597	214	132	72	31	0.61	0.22
Santa Barbara	336	776	224	241	100	72	0.67	0.31
Irvine	231	419	126	83	68	32	0.55	0.20
Total	3,888	5,115	1,813	1,124	791	390	0.47	0.22
Foreign Percent		56.8		38.3		33.0		

* D = domestic; F = foreign

The number of master's and doctoral degrees in engineering awarded to U.S. and foreign students by the University of California and by all institutions in the state of California and the nation during the period 1980-1984 are listed in Tables D-14 and D-15. The data for the U.C. system and for the state of California are from the California Postsecondary Education Commission. The data for the United States are from the Engineering Manpower Commission, the U.S. Department of Education (Digest of Education Statistics 1985-86), and the National Research Council's *Summary Report*. As Tables D-14 and D-15 indicate, the proportion of master's and doctoral degrees in engineering awarded to foreign students is similar to the average proportion for all institu- tions in the state of California but somewhat higher than the propor- tion for the country as a whole.

It is important to establish that foreign students are not displacing domestic students from admission to the University of California. Table D-16 lists the number of applications, number of admissions, and resulting number of new graduate students in engineering registered in the fall of 1985. This information indicates that foreign applicants outnumber domestic applicants in the ratio of 5:4. The admission rate for domestic applicants ranges from 0.41 to 0.67 with an average value of 0.47. The admission rate for foreign students is much lower, ranging from 0.16 to 0.31 with an average value of 0.22. Clearly, foreign students are admitted only after all qualified domestic applicants have been admitted. Considering the complete process, only 1 out of 13 foreign applicants becomes a registered student while 1 out of 5 domestic applicants becomes a new graduate student.

One of the issues involved in the discussion of the impact of foreign graduate students in engineering is the placement of these students after they receive their graduate degrees. The California Postsecondary Education Commission found only limited information. The most complete data comes from a poll conducted by the College of Engineering, Berkeley, covering the period 1965-1982. It was found that 68, 72, and 62 percent of the foreign doctorates (at the time of admission) in electrical engineering and computer science, mechanical engineering, and nuclear engineering, respectively, remained in the United States. Partial records from U.C. Davis for the period 1980-1985 indicate that slightly over half of foreign degree-recipients are still in this country. Additional records from U.C. San Diego for the period 1982-1985 indicate that 75 percent of the foreign doctoral recipients are employed in the United States, half of them in California.

SUMMARY

At the national level, foreign graduate students constitute a large proportion of the total graduate enrollment in engineering and receive a large percentage of the master's and doctoral degrees awarded each year. There are several indications that without a national effort to increase the number of domestic graduate students, the relative representation of foreign students will continue to increase. The enrollment in undergraduate engineering programs peaked in 1983, and it has been declining at a rate of about 10,000 students per year; the enrollment of domestic students in master's degree programs was equal in 1985 to that in 1983, but it may start to decrease in the next few years as a smaller class of undergraduates makes its way through the system. Finally, the enrollment of domestic students in doctoral programs in engineering continues to increase, but the rate of increase in 1985 was lower than in the previous 3 years. The increasing number of women and minorities in engineering may not be sufficient to overcome the demographic wave, and the total graduate enrollment of domestic students is likely to decrease in the next few years.

At the present time, the annual production of domestic doctorates in engineering is insufficient to meet the teaching and research demands of engineering schools as well as the needs of industry and government. Out of necessity, a significant portion of new appointments is going to foreign nationals. Under these conditions, efforts to limit the enrollment of foreign graduate students without a concomitant effort to increase the number of domestic graduate students may lead to serious consequences.

The impact of foreign students on the graduate engineering programs at the University of California is similar to that on the nation as a whole. Limits on the number of foreign graduate students in a climate of declining or nonincreasing domestic graduate enrollment will reduce the overall quality of the student body, will make it difficult to fill the requirements for research and teaching assistants, and will reduce the output of doctorates needed to cover the demand in the state and the nation.

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