NUCLEAR SCIENCE

A Survey of
Funding, Facilities, and Manpower

**Reports by
Three Ad Hoc Panels
of the
Committee on Nuclear Science
Assembly of Mathematical and Physical Sciences
National Research Council**

NATIONAL ACADEMY OF SCIENCES
Washington, D.C.

The work presented in this report was supported under contracts with the National Science Foundation (NSF-C310, Task Order No. 47) and the Atomic Energy Commission (now the Energy Research and Development Administration) [No. AT(11-1)-3368].

Available from
Committee on Nuclear Science
2101 Constitution Avenue
Washington, D.C. 20418

Order from
National Technical
Information Service,
Springfield, Va
22161
Order No. COO-3368-6

PART I

INTRODUCTION

Prepared by

P. D. Parker
Yale University

L. Grodzins
Massachusetts Institute of Technology

R. S. Livingston
Oak Ridge National Laboratory

John Schiffer
Argonne National Laboratory

David Shirley
University of California, Berkeley

Joseph Weneser
Brookhaven National Laboratory

ORIGIN OF THE SURVEY AND MAJOR FINDINGS

BACKGROUND

In 1969-1970, as part of the work of the Physics Survey Committee, three subpanels of the Nuclear Physics Panel examined in detail funding, manpower, and facilities in nuclear science. Four years later (1973-1974), in view of a number of significant changes that appeared to be taking place, the Committee on Nuclear Science (CNS) of the National Research Council initiated a re-examination of these three aspects of the organization and operation of nuclear-science research in order to evaluate any such changes and their implications. The reports of the three CNS *ad hoc* panels established for this purpose are presented in Part II. Although they identify current problems in nuclear science, these reports do not provide any simple solutions. Instead, they attempt to provide an updated data base that can be used in conjunction with the earlier Nuclear Physics Panel report [*Physics in Perspective*, Volume II, Part A, pp. 161-398 (National Academy of Sciences, Washington, D.C., 1972)] as the necessary background for continuing decisions. The interpretation of these data provides also a chronicle of the adjustments--the shifts and contractions--that have occurred during the past four years as the effective total budget for nuclear science continued to decrease.

STATUS OF THE FIELD

The frontiers of nuclear science are continually shifting and being redefined. Although the frontier areas of 10 to

20 years ago have been refined to the point of detailed and precise study, the examination of new areas, such as heavy-ion physics and medium-energy physics, is just beginning, and other nuclear phenomena are still virtually unexplored. Of the 6000 to 7000 nuclei that are expected to be particle stable, only about 1600 of the most stable have even been detected. Even for those nuclei that have been well studied, most of the information is limited to the electromagnetic decays of nuclear levels and the structure of shell-model single-nucleon orbits. Nuclear scientists are now developing the capability to go beyond these details to the examination of bulk properties of nuclear matter in heavy-ion fusion and fission reactions. At the same time, with the continuing technological advances in nuclear instrumentation and nuclear accelerators, they are now able to make and study some of the more exotic nuclei, far from the center of the valley of stability, where whole new varieties of clustering and correlation phenomena may be found. The maturity of some of the older areas of nuclear science is a mark of success; it would be discouraging indeed if, after all these years of effort, these areas had not developed beyond the exploratory phase. Nuclear scientists working in these areas must now face the more exacting challenge of applying the quantitative precision now available in accelerator facilities, instrumentation, and computers to the conduct of the more difficult and complex experiments and the larger systematic studies that are needed to gain a more nearly complete and quantitative understanding of fundamental nuclear interactions and correlations.

The present status of nuclear-science research, exacting and quantitative as it may be in some areas, can be compared to the study of the astrophysical universe by examining only the radiation in the visible spectrum or to the study of geophysics by examining only the surface of North America. In nuclear science, entirely new phenomena and unifying principles are yet to be discovered. The process of deep inelastic scattering in heavy-ion reactions, the search for superheavy nuclei on a possible island of stability near $A = 300$, nuclear compressibility and nuclear shock waves, the details of fundamental meson-nucleon interactions, even the possibility of an entirely new state of nuclear matter near $A = 500$--these are but a few of the exciting frontiers for future research. It is not within the scope of these reports to present a complete examination of all these possibilities; the CNS is considering a much more detailed and critical evaluation of this sort. Rather, the reports in Part II update the data base developed by the earlier Nuclear Physics Panel.

Nuclear science has never been a narrow, self-serving field; it has always had close and multifaceted relationships with other disciplines. Entire fields, such as nuclear astrophysics (nucleosynthesis, stellar energy generation and evolution, cosmochronology, and the like), nuclear engineering, and nuclear medicine, have been created by the development of nuclear science and remain heavily dependent on the continuing research and growth of the parent field. Significant aspects of, for example, geophysics, space science, atomic physics, and solid-state physics also depend on the development of techniques based on the results and discoveries of nuclear-science research. Nuclear power, whether from fission or fusion, and nuclear medicine, using both tailored radioisotopes and accelerator-induced radiation (from low-energy x rays to high-energy mesons), are major direct applications of nuclear science that are also clearly dependent on the continuing development and progress of basic nuclear research. It cannot be emphasized too strongly that the task of understanding the basis of nuclear science is as intellectually exciting and challenging as it has ever been, with major discoveries--deep inelastic interactions, regularities in very high angular momentum states, giant quadrupole modes of nuclear oscillations, discoveries of exotic nuclei--occurring at least as frequently as they ever did.

SUMMARY OF MAJOR FINDINGS

After a period of rapid development and expansion during the 1960's, federal support for nuclear physics, measured in constant dollars (as represented by funding from the Atomic Energy Commission* Division of Physical Research and the National Science Foundation), has leveled off; it is, in fact, decreasing slightly (~3 percent per year, a decrease of 15 percent from 1969 to 1974) under the influence of inflation. Furthermore, the Panel on Funding and Level of Effort found that a most significant change during this period was the shift in funding and emphasis to the emerging subfields of heavy-ion and medium-energy nuclear physics. Such a shift, occurring within the constraints

*Now the Energy Research and Development Administration.

of an effectively smaller total support, raises questions concerning the maintenance of a balanced program that must be considered carefully. If particular subfields are not now being supported as well as they should be, every effort should be made by nuclear scientists at all levels to ensure the proper allocation of support through vigorous, positive, constructive promotion of the importance, excitement, and significance of nuclear science and of the potential contributions of the endangered programs. The problem of determining the proper allocation of limited resources is obviously not unique to nuclear science but is a general one encountered in all research.

One of the results of the shift toward heavy-ion and medium-energy research has been the continuing concentration of facilities at large centers, with a corresponding increase in user-group operations. In view of this shift away from local in-house facilities, the report of the Panel on Nuclear Facilities is a census of existing accelerators, their characteristics and unique capabilities, which is intended as a useful reference for prospective "outside" researchers.

The capability of nuclear physicists to adapt and apply their knowledge and expertise to a variety of contexts and problems is a special strength of this field. This capability has allowed nuclear-physics PhD's a much greater mobility in the migration among scientific disciplines than has been possible for almost any other subfield of physics or any science. In addition to discussing in detail the severe employment problems in physics (the stagnation of academic employment and a decline in employment in federally funded research and development laboratories), one major purpose of the report of the Panel on Manpower and Education was to describe the nature and scope of interfield migration. This type of mobility has always been a part of nuclear physics; because the mode of nuclear-physics research is intermediate between big-group physics and individual physics, it has long been recognized as an excellent training ground for physics PhD's, regardless of the field in which they eventually choose to work. Of the nearly 3000 PhD's with degrees in nuclear physics, this Panel found that only 30 percent have stayed in nuclear physics, most of the others having moved into other parts of physics (31 percent) or into other sciences (25 percent). In analyzing the details of the migration, the Panel concluded that nuclear physics continues to be a strong and exciting subfield of physics whose doctorate holders can and do apply their expertise in a variety of other fields of science and engineering. A

PhD program in nuclear physics, based on a well-grounded preparation in fundamentals and coupled with a broad, open-minded outlook at all the aspects of this multifaceted discipline, is an excellent preparation for a wide variety of scientific careers.

An additional problem that should be noted is the sharp decline in first-year graduate student enrollments in physics in general and nuclear physics in particular. First-year graduate student enrollments in physics over the past eight years have declined 40 percent; the nuclear-physics share remains above 10 percent but has also been slowly declining. On the basis of projections involving students already well on the way to the PhD degree, by 1976 the production of nuclear-physics doctorates will fall to ~55 percent of its 1969-1972 rate. For the moment this situation is at least a more realistic one than that in some other sciences in which enrollments are still rising in spite of employment markets that are substantially worse than those in nuclear physics. However, this dwindling supply of young scientists raises serious concerns about the long-term maintenance of a vigorous research capability, and serious consideration must be given to the urgent problem of finding ways to develop more faculty and staff positions, beyond the usual postdoctoral appointments, for the continuing flow of young scientists who are necessary to maintain the vigor of the field.

Recent reports by the National Board on Graduate Education [*Graduate School Adjustments to the "New Depression" in Higher Education* (National Academy of Sciences, Washington, D.C., 1975)], the Astronomy Manpower Committee [*Employment Problems in Astronomy* (National Academy of Sciences, Washington, D.C., 1975)], and the Economic Concerns Committee of the American Physical Society [*The Manpower Crisis in Physics* (American Institute of Physics, New York, 1971)] have emphasized the importance of keeping graduate students and prospective students well informed about employment prospects and placement experience. We hope that one of the uses of the three reports that follow will be to provide the types of data needed as the basis for informed decisions by current and prospective nuclear-physics students. It must be borne in mind, however, that difficult though the current employment situation may be in the physical sciences, it is a cause of even greater concern in the humanities and a number of the social sciences.

We believe that nuclear science continues to offer challenging research opportunities and highly significant applications to other sciences and society, even though the present, limited financial support does not allow maximum accomplishment.

PART II

REPORTS OF THE PANELS

AD HOC PANEL ON FUNDING AND LEVEL OF EFFORT

P. D. Parker (Chairman)
Yale University

F. Ajzenberg-Selove
University of Pennsylvania

J. Weneser
Brookhaven National Laboratory

REPORT OF THE AD HOC PANEL ON FUNDING AND LEVEL OF EFFORT

INTRODUCTION

As part of the Physics Survey Committee activity, a subgroup chaired by Thomas Lauritsen undertook an extensive study of the funding of nuclear physics. The results were published in *Physics in Perspective*, Volume II, Part A. The study included a detailed analysis of the distribution of federal funds among the various subfields of nuclear physics in FY 1969, together with projections of the distribution in FY 1977 based on several possible levels of federal support of nuclear physics during the intervening eight years. In 1973, midway through this interval, the Committee on Nuclear Science of the National Research Council (NRC) appointed a Panel on Funding and Level of Effort to evaluate any changes in the level and distribution of federal support of nuclear physics in relation to the FY 1977 projections and to re-examine the implications and consequences of these projections. The Panel members were P. D. Parker (chairman), F. Ajzenberg-Selove, and J. Weneser, and they were assisted throughout this study by C. K. Reed and B. E. Compton of the NRC staff.

To make the comparison between the 1969 and 1973 analyses as meaningful as possible, the Panel tried to adhere closely to the definitions, conventions, and formats of the earlier study. Four of the individuals involved in the present survey (Ajzenberg-Selove, Weneser, Reed, and Compton) had also participated in the earlier study; and in the initial stages of the 1973 survey, the Panel consulted closely with Thomas Lauritsen.

CHANGES IN THE LEVEL OF FUNDING FOR NUCLEAR PHYSICS

By far the largest fraction of federal support for basic nuclear physics comes from the Atomic Energy Commission, Division of Physical Research [AEC(Res.)] and the National Science Foundation (NSF). Table 1 shows the level of support from these agencies from FY 1964 through FY 1974. With the exception of the bottom line in Table 1, the dollar figures are expressed as "current dollars," that is their value in the fiscal year in question. In the bottom line, the total AEC(Res.) plus NSF figures have been normalized to "1969 dollars" to facilitate comparison with the 1969 report. The Bureau of Labor Statistics Consumer Price Index is used as the inflation factor. Throughout the remainder of this report, unless specifically noted otherwise, all dollar figures have been converted to 1969 dollars.

The reader should also bear in mind that there are additional factors, such as the generally higher rate of inflation for high-technology products and the increases in the overhead and fringe-benefit rates charged against many contracts, which are much harder to quantify, that have further reduced the real level of federal funding available for research. For example, as part of this analysis we found that in the four years from FY 1969 to FY 1973 the overhead and fringe-benefit rates charged to contracts had increased by an average of 12 percent (typically from 50 percent to 62 percent) so that for a typical contract, in which overhead and fringe benefits are charged against salaries and wages, which make up approximately half of contract costs, this increase in the overhead and fringe-benefit rate represents a decrease in available contract funds of about 6 percent, effectively corresponding to an additional devaluation of the FY 1973 figures from \$48.5 million to about \$45.6 million.

TABLE 1 Federal Support of Basic Nuclear-Physics Research[a]

Agency[b]	Operating Funds in $ Millions, for Fiscal Year (Excluding DOD, NASA, NBS, and DMA Support[c])										
	1964	1965	1966	1967	1968	1969	1970	1971	1972[d]	1973	1974
AEC (CHEM)	(8.9)	8.9	9.4	9.8	10.4	10.3	10.4	10.4	10.4	9.8	9.4
AEC (LENP)	19.2	20.0	21.6	22.5	23.4	24.3	24.0	22.5	20.5	20.1	21.4
AEC (MEP)	5.5	5.6	9.2	11.0	11.1	11.3	12.8	13.0	13.1	15.9	18.0
AEC (RES) Total	33.6	34.5	40.2	43.3	44.9	45.9	47.2	45.9	44.0	45.8	48.8
NSF (NS)	2.7	2.8	4.7	5.0	6.4	8.0	6.5	9.3	11.3	11.8	12.6
(Theo)	0.5	0.5	0.8	0.8	0.8	0.9	1.0	0.6	1.0	1.0	1.0
(EP)	0.0	0.0	0.5	1.2	1.2	1.4	1.1	0.0	0.0	0.0	0.0
NSF Total	3.2	3.3	6.0	7.0	8.4	10.3	8.6	9.9	12.3	12.8	13.6
AEC (RES) + NSF	36.8	37.8	46.2	50.3	53.3	56.2	55.8	55.8	56.3	58.6	62.4
Inflation factor[e]	1.159	1.142	1.116	1.085	1.049	1.000	0.946	0.900	0.867	0.828	0.764
AEC (RES) + NSF (1969$)	42.7	43.2	51.6	54.6	55.9	56.2	52.8	50.2	48.8	48.5	47.7

[a] Basic versus applied research: "In basic research the investigator is concerned primarily with gaining a fuller knowledge or understanding of the subject under study. In applied research the investigator is primarily interested in a practical use of the knowledge or understanding for the purpose of meeting a recognized need" (*Federal Funds for Research, Development and Other Scientific Activities*, NSF 69-31, p. 95).
Nuclear Physics: "Nuclear physics is here defined to include the study of nuclei, their structure, disintegration, interactions, and other properties. It includes also the study of the constituent parts of the nucleus, their interactions with one another and with nuclei" (By-Laws of the Division of Nuclear Physics, American Physical Society).

[b] AEC (CHEM): Estimated portion of chemistry research budget devoted to nuclear physics.
AEC (LENP): Nuclear-physics part of low-energy physics budget, separately listed in AEC budget.
AEC (MEP): Projects in range 50-1000 MeV, includes LAMPF, LBL 184", Bates, etc.
NSF (NS): Nuclear-structure program. (Low-energy nuclear science + intermediate-energy nuclear science = nuclear structure.)
NSF (Theo): Estimated part of theoretical-physics program devoted to nuclear theory.
NSF (EP): The Nevis cyclotron was transferred from "elementary particle" to "nuclear structure" in 1971.

[c] Department of Defense, National Aeronautics and Space Administration, National Bureau of Standards, and AEC Division of Military Applications.

[d] Between FY 1971 and FY 1972, at the direction of OMB, approximately $3.5 million of basic nuclear-physics research was transferred from AEC to be picked up by NSF.

[e] Consumers Price Index Office of the Bureau of Labor Statistics.

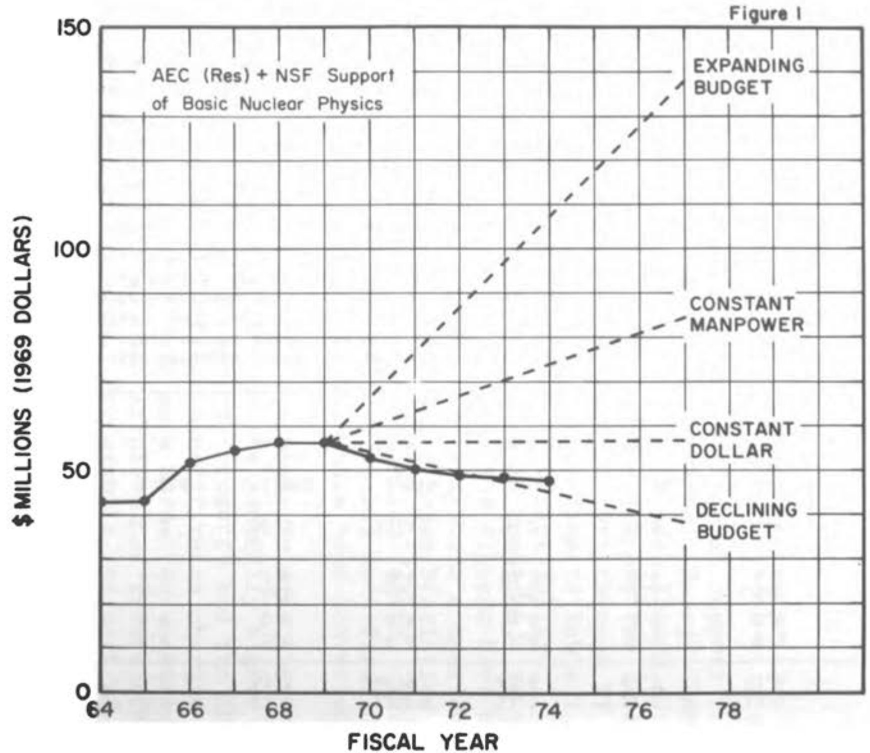

FIGURE 1 Support of basic nuclear-physics research by AEC(Res.) and NSF. (See Table 1.) The FY 1977 projections are taken from the 1969 report published in *Physics in Perspective, Volume II, Part A*, p. 325 ff.

The AEC(Res.) plus NSF figures in 1969 dollars from the bottom line of Table 1 are plotted in Figure 1 and compared with the four projected levels of support presented in the 1969 report. It is clear from this comparison that the recent pattern of funding is close to the "Declining Budget" projection, the most pessimistic view of the 1969 Panel. It may also be possible to conclude somewhat more optimistically that after an initial decline of ~13 percent in the years following 1969, a more nearly constant budget situation has now been achieved at a level ~15 percent below the 1969 level.

In regard to support from other federal agencies, the FY 1969 survey indicated an additional \$15.6 million in federal funds for basic nuclear-physics research from the AEC Division of Military Application (DMA), Department of Defense (DOD), National Atmospheric and Space Administration (NASA), and National Bureau of Standards (NBS). Our survey shows that for FY 1973 that support had been reduced to about \$7.0 million (1969 dollars), less than half the FY 1969 amount, a level considerably worse than even the most pessimistic "Declining Budget" prognosis of the 1969 survey, which projected a decrease in funding from these agencies to \$9.5 million (1969 dollars) by FY 1977, or about \$12.2 million (1969 dollars) by FY 1973. This drastic decline results from the complete withdrawal of NASA support, the reorientation of DOD toward more mission-oriented research, and a reduction of AEC(DMA) support for basic nuclear physics at both Los Alamos Scientific Laboratory (LASL) and Lawrence Livermore Laboratory (LLL). The net effect is that between FY 1969 and FY 1973 the total federal support for basic nuclear physics was reduced by some 23 percent, from \$72 million in FY 1969 to about \$55.5 million (1969 dollars) in FY 1973.

Although examples can be cited in which the decline or removal of federal funds has been compensated by increases in funds from other sources (for example, from universities or private foundations), such cases represent the exception rather than the general rule. From the responses to our questionnaire it is clear that in many cases university and state funds are directly related to federal funds; that is, they are substantial only when they are supplementing substantial federal support, so that the loss of federal funds often results in the loss of support from the other sources. There is no evidence that universities or other sources are now contributing more to the support of basic nuclear physics than they did in the years of less restricted funding around 1968. In

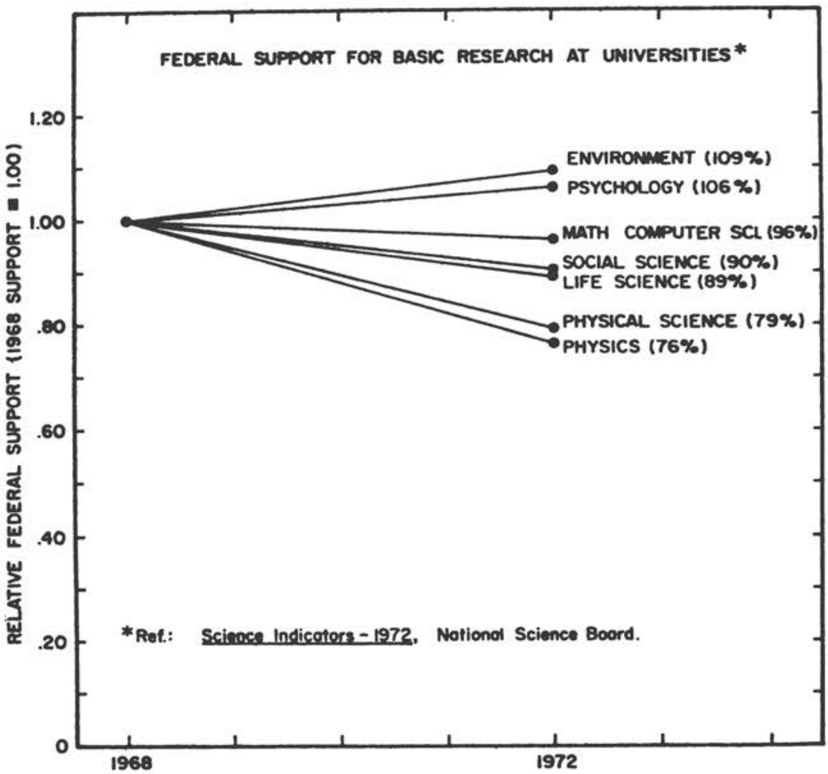

FIGURE 2 Relative changes in federal support of basic research at universities. Support is normalized to constant value dollars; 1968 support defined as 1.00. Source: Table 25 *Science Indicators-1972*, National Science Board (NSB-731).

fact, our survey shows that from FY 1969 to FY 1973, support for basic nuclear physics from nonfederal sources remained essentially constant (declining about 2 or 3 percent) in 1969 dollars. Data from *Science Indicators 1972*, published by the National Science Board (NSB-731), are consistent with this finding and show that during the period from 1966 to 1972 nonfederal support of basic research in all physics at universities and colleges remained virtually constant in 1969 dollars.

The reduction in federal support is not a problem unique to basic nuclear physics. Figure 2, based on information from *Science Indicators 1972*, shows that federal support of basic research in all physics at universities declined by an average of 24 percent in the four-year period from 1968 to 1972. (During the same interval, however, support for life sciences and social sciences declined by only 10 percent, and for mathematics and computer science by only 4 percent; for psychology and environmental research, support increased by 6 percent and 9 percent, respectively.)

TABLE 2 Analysis of Federal Support for Basic Nuclear-Physics Research Excluding DOD, NASA, NBS, and DMA Support[a]

	FY 1969 Operation and Research Cost ($ Millions)[b]	SMY[c]	FY 1973 Operation and Research Cost ($ Millions)[b]	SMY[c]	FY 1977[d] Estimated Operation and Research Cost ($ Millions)[b]	Estimated SMY[c]
					Declining Budget	
Primarily Accelerator-Centered						
1. Neutron facilities	4.0	45	3.5	40	3.5	25
2. Potential-drop machines	14.5	300	12.5	250	9.0	115
3. Cyclotrons	10.5	150	6.5	110	6.5	70
4. Heavy-ion accelerators	3.0	15	2.0	10	3.0	15
5. Electron accelerators	2.0	25	1.5	20	2.0	15
6. High-energy and medium-energy facilities	7.0	60	14.0	120	2.5[e]	15
7. Small-scale projects					1.0	20
Nonaccelerator-Centered						
8. Theory	4.0	170	3.5	165	4.5	140
9. Nuclear spectroscopy[f]	3.5	60	1.0	30	2.5	40
10. Nuclear chemistry[f]	4.0	85	1.5	40	2.5	35
11. Accelerator development and instrumentation	1.0	15	1.0	20	1.0	10
12. Nuclear data	1.0	15	1.0	20	1.0	15
13. Other	1.5	35	0.5	15	0.5	10
TOTALS	56.0	975	48.5	840	38.5	535
					Level Dollar Budget	
Primarily Accelerator-Centered						
1. Neutron facilities					3.5	35
2. Potential-drop machines					9.0	120
3. Cyclotrons					6.5	70
4. Heavy-ion accelerators					7.5	65
5. Electron accelerators					2.5	20
6. High-energy and medium-energy facilities					14.5	75
7. Small-scale projects					1.0	20
Nonaccelerator-Centered						
8. Theory					4.5	145
9. Nuclear spectroscopy[f]					2.5	40
10. Nuclear chemistry[f]					2.5	40
11. Accelerator development and instrumentation					1.0	15
12. Nuclear data					1.0	15
13. Other					0.5	15
TOTALS					57.0	675

Primarily Accelerator-Centered	*Constant Manpower Budget*	
1. Neutron facilities	4.0	40
2. Potential-drop machines	17.0	220
3. Cyclotrons	9.5	95
4. Heavy-ion accelerators	10.5	100
5. Electron accelerators	3.0	25
6. High-energy and medium-energy facilities	22.5	125
7. Small-scale projects	2.0	40
Nonaccelerator-Centered		
8. Theory	6.0	185
9. Nuclear spectroscopy[f]	2.5	40
10. Nuclear chemistry[f]	2.5	40
11. Accelerator development and instrumentation	2.0	20
12. Nuclear data	1.5	25
13. Other	1.5	30
TOTALS	84.5	985

P21

Primarily Accelerator-Centered	*Expanding Budget*	
1. Neutron facilities	9.5	80
2. Potential-drop machines	31.0	400
3. Cyclotrons	12.0	120
4. Heavy-ion accelerators	12.0	100
5. Electron accelerators	4.0	40
6. High-energy and medium-energy facilities	22.5	125
7. Small-scale projects	4.0	70
Nonaccelerator-Centered		
8. Theory	13.0	400
9. Nuclear spectroscopy[f]	4.0	50
10. Nuclear chemistry[f]	7.0	100
11. Accelerator development and instrumentation	4.0	50
12. Nuclear data	2.0	30
13. Other	3.0	60
14. Future facilities	10.0	70
TOTALS	138.0	1695

[a] For a more complete description of what is included in each category and how the various FY 1977 projections were obtained refer to the 1969 report (*Physics in Perspective*, Volume II, Part A, p. 325ff).

[b] Federal dollars, 1969 value. Costs include total support of user groups.

[c] Scientific man-years (SMY) are estimated totals, including both federally and nonfederally supported scientists.

[d] In the 1977 projections the estimated dollars and scientific man-years (SMY) for a particular category are written for definiteness to the nearest half-million dollars and 5 SMY, but, by the very nature of this exercise, no such accuracy is implied.

[e] Under the severe funding restrictions represented by this 5% per year declining budget, the 1969 report omitted LAMPF funding from the FY 1977 projection in order not to cause a serious unbalance in the field as a whole.

[f] Nuclear chemistry and spectroscopy groups presumed to be working directly with specific accelerators are included in the facilities category above.

FUNDING PATTERNS IN THE SUBFIELDS OF NUCLEAR PHYSICS

To examine the ways in which this reduction in support affected the various subfields of basic nuclear physics, the Panel conducted a questionnaire survey (Appendix A) of all identifiable federal-contract-supported persons engaged in basic nuclear-physics research and all relevant government laboratory groups. The objective of the survey was to determine and compare FY 1969 and FY 1973 levels of support and levels of activity. The cooperation of the community in responding to this survey has been remarkable, probably reflecting deep concern for the problems we are examining. We received replies from some 90 percent of the more than 150 questionnaires that we sent. In those cases in which sufficient information was not available, we consulted with the appropriate agency administrators. The resulting data have been used to develop a table showing the division of federal funds among the various subfields for direct comparison with the tables in the FY 1969 analysis. Because sufficient detail was not as readily available for the AEC(DMA), DOD, and NBS, we present in Table 2 only data for "Budgets Excluding DOD, NASA, NBS, and AEC(DMA) Support," which may be compared directly with the corresponding tables published in *Physics in Perspective*, Volume II, Part A (Tables II.17, II.18, II.20, and II.21, respectively). The figures in Table 2 have all been corrected for inflation to read in constant 1969 dollars. The FY 1973 figures were compiled from the present survey; the FY 1969 figures and the FY 1977 estimates were taken from the 1969 report and its projections.

An examination of this table shows clearly that a significant change is occurring in the direction of the basic nuclear-physics research program. Although the contribution from basic nuclear-physics funding to the support of high-energy and medium-energy research [primarily of the Los Alamos Meson Physics Facility (LAMPF) and LAMPF users but also including the Lawrence Berkeley Laboratory (LBL) 184-inch cyclotron, the Space Radiation Effects Laboratory (SREL), Nevis, and some user programs on the AGS, ZGS, and Bevatron] has more than doubled between FY 1969 and FY 1973 (from $7.0 million to $16.5 million), funding for all the other subfields has decreased drastically, so that many are already operating at levels below those predicted for FY 1977 under the most pessimistic set of projections; that is, support has declined in these subfields at more than twice the projected rate. If the tables were presented excluding the high-energy and medium-energy funding, the funding for the remainder of nuclear physics would show a decline from $49 million in FY 1969 to $34.5 million in FY 1973, compared with a predicted $36 million for FY 1977 under the so called "Declining Budget" projection.

This change in emphasis was not unexpected. The 1969 study had predicted that, with the completion of LAMPF, by FY 1977 this area would be the largest single subfield in nuclear physics under either the "Level Dollar" budget projection or the more favorable "Constant Manpower" budget projection. This growth has occurred, however, under conditions much less favorable than were assumed under those budget projections--conditions under which the framers* of the 1969 report opted not to support LAMPF in favor of a more modest facility in order not to cause a serious unbalance in nuclear physics as a whole. The question of how to maintain a balanced program under the present conditions must be considered carefully.

During the present survey we have examined the questionnaire responses to try to understand the ways in which these cutbacks have affected research programs and how the field has reacted and reorganized in response to this redistribution of funding support. It should be noted that an analysis of the questionnaire data shows that the reduction in federal support has not been applied only unilaterally to "small" contracts for the benefit of "large" contracts. If one arbitrarily chooses about $300,000 as the boundary between "small" and "large" contracts, the survey data show that, between FY 1969 and FY 1973, for each "small" contract that suffered a reduction or cancellation there was another "small" contract that was started or expanded. Similarly, for "large" contracts the number of increases is matched by the number of decreases. It is also clear from the questionnaires that when there is

*Nuclear Physics Panel of the Physics Survey Committee.

a redistribution of funds from one program to another there is not a corresponding redistribution of staff. Among the responses to the questionnaire were some instances in which individuals whose contracts were terminated in one subfield successfully made the conversion to another subfield with new contract support. However, more frequently, the redistribution of contract support shown in Table 2 creates new jobs for people who were not previously being supported under basic nuclear-physics contracts, leaving the individuals who were formerly supported without the funds necessary to continue an active research program. In addition to cases in which programs have been cancelled and facilities shut down (the number of active facilities has been reduced from 90 in 1969 to about 65 in 1973), the questionnaires also indicate that about 25 percent of the remaining active facilities (facilities ranging from modest 4-MV accelerators to large cyclotrons and tandems) are being run at less than full levels of operation and at reduced efficiency because of the lack of adequate support, which is translated into inadequate staffing, termination of postdoctoral positions, inadequate electronic instrumentation and computer hardware, and the like.

DECLINE IN GRADUATE-STUDENT ENROLLMENT

Respondents to the questionnaire survey ranked the steady decline in graduate-student enrollment second only in importance to the financial problems of fixed and/or declining budgets, inflation, and rising overhead rates. An analysis of the questionnaire data shows that in FY 1973 there were only 67 percent as many graduate students in nuclear physics as there had been in FY 1969, with some laboratories showing reductions to less than 50 percent. A number of groups cited this decrease as a reason for reduced activity. The trend is also apparent in the steady decrease in the number of PhD's being awarded in nuclear physics, as shown in Figure 3. In FY 1976, the number of these degrees awarded will be only 57 percent of the average number awarded between FY 1969 and FY 1972. (This decline has been experienced equally in both theoretical and experimental nuclear physics.) This problem is not peculiar to nuclear physics. Limited data for this period from *Science Indicators 1972* show that between 1969 and 1971 first-year graduate enrollment in all physical sciences fell by 7.5 percent per year; at the undergraduate level the number of junior-year physics majors dropped 8.5 percent per year from 1970 to 1971.

Although our survey was not concerned primarily with manpower problems, and although we do not have nearly as complete data as those of the American Institute of Physics, we believe that it is worthwhile to call attention to this situation. In view of the condition of the job market in nuclear physics, we might be inclined to accept this trend as probably for the best. *However*, if the field is to remain productive and active during this period of contracting support, it is more important than ever to ensure that it continues to attract the most highly qualified students. No matter how unfavorable the job market is generally, the field will always have a need for the infusion of such students, and attractive opportunities must be found for them.

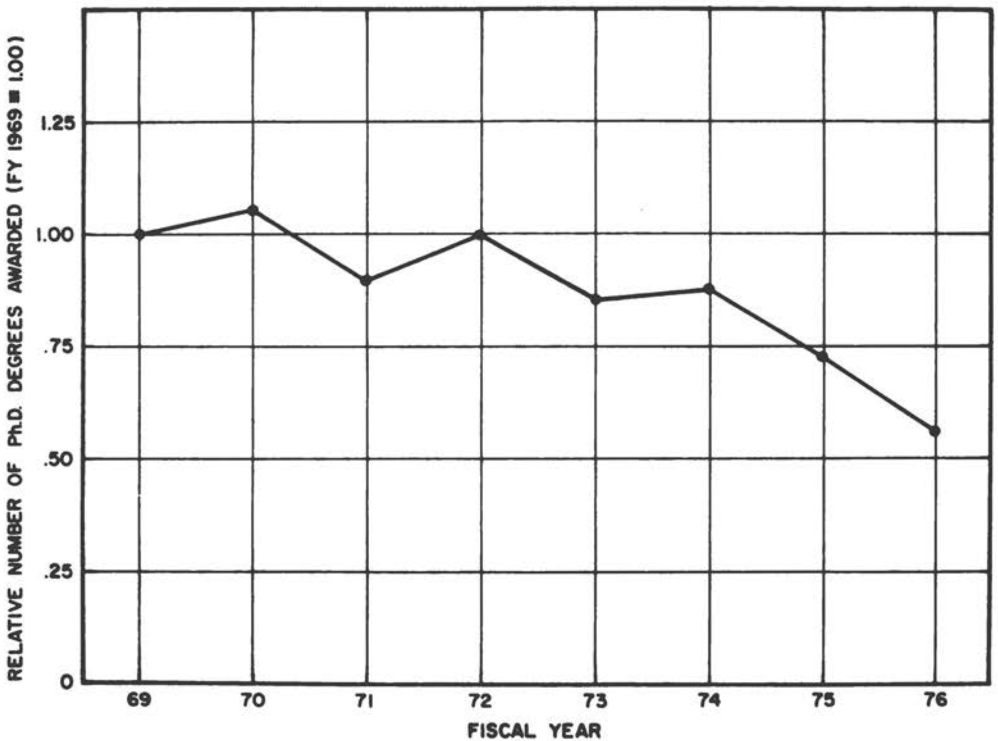

FIGURE 3 Relative changes in the number of PhD degrees awarded in nuclear physics, FY 1969 to FY 1976.

USER-GROUP RESEARCH PROGRAMS

The development of larger, more sophisticated, and more expensive facilities and the reduction in available research funds are forcing changes in the traditional pattern of nuclear-physics research programs centered on local, in-house facilities. The 1969 survey report indicated the important role of user-group programs in nuclear physics and the need for funding agencies to take into account the expenses involved in this type of research. In this survey we have examined the continued growth of such programs and have tried to evaluate their effectiveness, advantages, and disadvantages.

User-group programs are increasing. For 30 "host" facilities (about 45 percent of the active facilities that reported significant noncontract use and for which comparison could be made between such use in FY 1969 and FY 1973), the data showed an average increase of 7.5 percent in noncontract use during this interval. In general the reaction of the "host" facilities to this type of operation was highly favorable; respondents' comments indicated that outside user groups provided a means of expanding the scope of the program and activities of the "host" facility to the benefit of both in-house personnel and users. Researchers at many facilities stated that they would welcome even more outside users, especially if there were some way to fund additional technical staff at the facility to support user operations.

Forty groups who indicated some activity as users and were not already full-time users indicated an average increase in user activities over the next three years amounting to an additional 15 percent of their total effort. However, it is also clear that the field is not rushing headlong into this mode of operation; although the percentage is increasing, it is still a small percentage. From our survey we were able to identify only about \$3.0 million (5 percent of the FY 1973 budget) being spent by user groups on their operations. Roughly half of that figure was in medium-energy programs, particularly LAMPF. (Because of the relatively small role played by user-group operations in most of nuclear physics, it is not possible to analyze statistically many of the aspects of these operations; therefore, much of the description that follows is anecdotal, based on the questionnaire responses.)

In general, the users are working almost exclusively at national laboratory facilities or similar government laboratories, with some use of university-based tandem accelerators also reported. (It should be noted that there is not a complete overlap of these users with the user activity reported by the "host" institution, because a significant fraction of the institutional data pertained to non-basic-research programs such as nuclear medicine.) Users' comments about the value of such programs were generally favorable, although they frequently mentioned logistical problems and inconveniences. Those without any local facilities pointed to the absolute necessity of such programs if they were to stay in the mainstream of nuclear-physics research and noted that, in spite of the problems and inconveniences, this mode of operation was far better than struggling to continue a home-based program on an obsolete or noncompetitive facility. In the ideal situation, with a variety of facilities from which to choose, the user might be in the enviable position of being free to select the one best suited to each problem of interest rather than being tied to one particular facility. It should be recognized, however, that in some cases there can be opposition to off-campus user operations by department and university administrations because of the possible interruption of classes caused by the absence of faculty members.

Even groups with competitive local facilities saw strong advantages in the flexibility of also working in off-site user-group programs. They noted that the use of outside facilities was often indispensible to finish projects started in-house and provided a much more complete understanding of a problem than would otherwise have been possible. The unique opportunities available at other laboratories often made such user programs complementary to work at the home facility.

Although the data showed clearly these positive aspects of user-group programs, the inconveniences of working away from the home institution were equally apparent. The most satisfied users were those whose home institution was closest to the host facility. For efficient operation, most users recognized the value of an in-house collaborator at the "host" facility or a member of the user group based more or less permanently at the site. They also called attention to the need for more realistic budgets to support the additional travel and living expenses required by this mode of operation. These added costs must be specifically recognized by funding agencies and taken into account in their support budgets for such user groups; the budgets for the "host" institutions must also include sufficient funds for the provision of technical support of user operations at the facility.

Although it is clear that there will be a continuing steady increase in user-group operations at large, centralized nuclear-physics facilities, it is also clear that, no matter what their size, competitive facilities at local institutions are extremely important for the maintenance of a broad, multifaceted research discipline. In viewing the present situation we are in complete agreement with the discussion in the 1969 report (i.e., *Physics in Perspective*, Vol. II, Part A, pp. 367 ff). It is essential to maintain a balanced, diverse, and flexible program and to avoid the extreme positions of either clinging nostalgically to the "good old days" or adopting a "bigger is always better" attitude.

CONCLUSIONS

The statistics presented in this analysis show clearly that between FY 1969 and FY 1973 support for basic research in nuclear physics declined significantly. In constant dollars, AEC(Res.) and NSF support decreased to 86 percent of its FY 1969 level; although these agencies have maintained a nearly constant, or even slightly increasing, current budget, inflation has taken its toll (FY 1973 $ ≈ 0.83 × FY 1969 $). For other federal agencies, such as DOD, AEC(DMA), NBS, and NASA, the situation is even worse, with essentially a factor of 2 reduction in their support of basic nuclear-physics research. Furthermore, before any of these funds can be spent on actual research operations they are further reduced by approximately another 6 percent (FY 1973 compared with FY 1969) due to increases in the overhead and fringe-benefit rates charged by host institutions.

The component subfields have not shared equally in the fortunes and misfortunes of the field as a whole. The funding agencies indicate that the budgetary processes that produce such changes in established funding patterns are extremely complex and do not involve simply repartitioning some predetermined nuclear-physics budget. If projects such as LAMPF or the new heavy-ion facility at Oak Ridge National Laboratory were turned off, there is no reason to expect that those funds would then be simply redistributed to other subfields within nuclear physics. The Nuclear Physics Panel in its 1969 report strongly emphasized the need for a balanced program, including both support for the development of new frontier areas and support for the broad field of more classical nuclear physics that forms a necessary base for such new frontiers. In view of the drastic reductions that have already occurred in many subfields, to maintain a balanced and effective program at the present time it is essential to make every effort to expand the support for this broad base of nuclear physics, while at the same time continuing to support the growth of the new frontier areas.

In a period when research funds are exceedingly restricted, changes in the established patterns of funding and research activity occur. The results of this survey show three such changes that are taking place: one is the increasingly prominent role of medium-energy physics research; a second is the steady increase in the user-group mode of operation; the third is the continuing decrease in the number of graduate students entering nuclear physics.

None of these changes is surprising to those who are actively engaged in research in this field, but especially in this time of restricted support, it is essential to monitor and document such changes in order to anticipate and plan for both their positive and negative consequences. Such changes cannot be allowed to proceed unquestioned; informed and intelligent decisions must be made at each step if an active yet well-balanced and flexible program is to be maintained.

APPENDIX A

July 19, 1973

Dear Colleague:

We need your help in analyzing the changes which the funding policies of the last few years have made in basic nuclear physics research in the United States. As part of this analysis, we are making a detailed comparison between the situation in FY 73 and the FY 69 analysis presented in Volume IIA of the Physics Survey Committee Report, Physics in Perspective. It is clearly important to redo much of the original analysis for the present funding situation in order to make comparisons with the 8-year projections of that report and in order to identify and examine any trends which are developing. In order to make this analysis and comparison as meaningful as possible, we are asking you to answer the attached questions for both FY 69 and FY 73.

Although this questionnaire originates primarily from the Committee on Nuclear Science (CNS) Panel on Funding and Level of Effort and the Division of Nuclear Physics (DNP) Statistical Data Committee (Funding), access to the answers for relevant questions will also be provided to the appropriate members of the DNP Statistical Data Committee and to the Chairman of the appropriate CNS Panels on Manpower and Education, on Nuclear Facilities, and on Publication. In all cases, however, the answers you supply to this questionnaire will be kept confidential and will only be used statistically.

We have also learned that the Accelerator Information Center at ORNL is undertaking a new accelerator census on behalf of the CNS Panel on Facilities and the DNP Statistical Data Committee. When you receive their brief non-confidential census form, we hope that you will also supply them with the details which they are trying to collect regarding your research equipment.

This questionnaire is being sent to the Principal Investigators of all contracts and research groups which we could identify as involved with basic nuclear physics research. If you hear of any group which we may have overlooked, please let us know so that we can make this survey as complete as possible. On the other hand, if you are not an appropriate individual to answer this questionnaire, please either pass it on to the appropriate person or return it to us with a note so that we can correct our address list.

It is hoped that a preliminary report on this work can be presented at the DNP meeting in Bloomington at the beginning of November. To make this possible, please return your replies no later than August 17th directly to

Mr. C. K. Reed, Executive Secretary
Committee on Nuclear Science
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Thank you for your help. If you have any questions, do not hesitate to call Peter Parker (203-436-2320).

Sincerely,

CNS Panel on Funding and Level of Effort

F. Ajzenberg-Selove

E. Hyde

P. Parker (Chairman)

J. Weneser

DNP Statistical Data Committee (Funding)

F. Ajzenberg-Selove

CONFIDENTIAL

QUESTIONNAIRE ON BASIC NUCLEAR RESEARCH

PERSON RESPONDING:

PROJECT TITLE OR ADDRESS:

1. FUNDING AND PERSONNEL:

We need to know the number of people involved in basic low- and intermediate-energy nuclear physics research and the cost breakdown. This is part of an effort to estimate the total input cost in man years and dollars. By basic nuclear physics we mean research on the nature of the nucleus as distinguished from applications to other sciences and technology. The information is asked for in tabular form on the next page.

Explanatory Notes for Table on Page 2

The amounts of money to be listed in various parts of the table are intended to be the amount of money available to you in a given year. In agency parlance they are the oblication or prorated grant.

1) For these categories, indicate salary dollars but do not include overhead and fringe benefits.

2) MY = man year. Please prorate these figures to include only that time when individuals are working under your contract. A "typical" graduate student or post-doc who works full-time on research should be counted as 1.0. A typical faculty member who teaches 1/2 time during the academic year and works under your contract during the summer should be counted as ≈0.6, (1/2 x 9 months + 3 months)/(12 months); if he does not work under your contract during the summer this figure would be reduced to 0.4.

3) Other Research Support Funds. This includes support from state, university, or private sources. It does not include salaries paid to faculty members to cover the fraction of time they are teaching. However, if the university is paying more than this fraction of the academic year salary then the appropriate difference should be included as part of the university research support.

4) FY 1969 = fiscal year 1969, the period from July 1, 1968, through June 30, 1969. FY 1973 covers the period from July 1, 1972, through June 30, 1973. Estimate and prorate where necessary.

5) Include salaries, overhead and fringe, materials and supplies, etc.

6) Capital equipment. (Items costing more than $300 and with lifetimes of more than a few years.)

Please list below any specfic, large items of capital equipment and/or accelerator improvement, (e.g. computers, multi-channel analyzers, accelerator ion-source, beam transport system, spectrometer, etc.) for FY69 and FY73, indicating the cost of the item and the source of the funds.

A.

		FY 1969 /4 EXP	FY 1969 /4 Theory	FY 1973 /4 EXP	FY 1973 /4 Theory	Comments: (If you have any information on these items for FY 74, please estimate here)
Staff or Faculty /1 (Ph.D. or Equiv.)	MY /2					
	$ Federal Support					
	$ Other /3 Support					
Postdoctoral 1/1 Fellow or Equivalent	MY					
	$ Federal Support					
	$ Other Support					
Graduate Students /1	MY					What is the approximate percentage of foreign students: FY 69 FY 73
	$ Federal Support					
	$ Other Support					
Administrative and Technical Support /1	MY					
	$ Federal Support					
	$ Other Support					
Undergraduate Assistants /1	MY					
	$ Federal Support					
	$ Other Support					
Total Dollars /5 Spent Other than Capital Equipment	$ Federal Support					
	$ Other Support					
Total Capital Equipment Cost /6	$ Federal Support					
	$ Other Support					

B. What federal agencies, state agencies, private foundations, and/or other sources of funds provide what percentage of your group's support?

FY69		FY73	
________________	____%	________________	____%
________________	____%	________________	____%
________________	____%	________________	____%
________________	____%	________________	____%

C. What percentage of your group's total budget of funds is devoted to the following areas of research? (If one of your sources of funds is restricted specifically to one of these areas, please indicate this.)

	FY69	FY73
a) Basic nuclear physics (see definition on page 1)	________	________
b) Application to other sciences	________	________
c) Technological application	________	________
d) Other? Explain	________	________

D. Approximately how many papers on Basic Nuclear Physics were published by your group in scientific journals (NOT including abstracts, brief notes, internal reports, conference proceedings, etc.) in FY69________, FY70________, FY71________, FY72________, FY73________.

E. On what base (e.g. all salaries, Staff and Faculty salaries only, salaries and materials and supplies, etc.) and at what rate are overhead and fringe benefit charges calculated?

OVERHEAD

	Base	Rate
FY69	______________________________	____________
FY73	______________________________	____________
FY74(est)	______________________________	____________
FY75(est)	______________________________	____________

FRINGE BENEFITS
(If not included under overhead)

	Base	Rate
FY69		
FY73		
FY74(est)		
FY75(est)		

F. Please indicate by a check mark the types of supporting services you received from your parent institution.

	FY69	FY73
Business Office		
Library Facilities		
Building and Grounds		
Security		
Secretarial Services		
Drafting Services		
Computer Services		
Design and Engineering Services		
Machine Shop Services		
Instrumentation Services		
Other? (Explain)		

2. MANPOWER CONSIDERATIONS

A. How many Ph.D's were awarded in your group during each year FY69 to FY73, and on the basis of the number of graduate students presently in your group how many Ph.D's will be awarded during each year FY74 to FY77.

	FY69	FY70	FY71	FY72	FY73	FY74	FY75	FY76	FY77
Exp.									
Theory									

B. Research Positions in your Group

	FY69		FY73		FY75(est)	
	Exp	Theory	Exp	Theory	Exp	Theory
Tenured Positions	_____	_____	_____	_____	_____	_____
Non-Tenured Positions [e.g. Junior Faculty (Ass't Prof. and higher), Senior Research Associates, <u>but</u> <u>not</u> including "post-doc" appointments.]	_____	_____	_____	_____	_____	_____
"Post-Doc" Appointments (including Instructors)	_____	_____	_____	_____	_____	_____

C. Average Number of "Post-Doc" Positions to be filled <u>per year</u>

	Nuclear Experiment	Nuclear Theory
1965-70	_____	_____
1970-73	_____	_____
1973-78 (estimate)	_____	_____
Average duration of position (years)	_____	_____

If you do not have an in-house facility such as an accelerator or a reactor, please check appropriate boxes below

☐ My group does theoretical work only. (Please skip questions 3, 4 and 5 and go to questions 6 and 7.)

☐ My group does work involving only radioactive sources made at other locations. (Please skip questions 3 and 4, and please answer 5, 6 and 7.)

☐ My group is a user's group at one (or more) central facilities. (Please skip questions 3 and 4, and please answer 5, 6 and 7.)

3. FACILITIES

Please list below your major nuclear research facilities (i.e. accelerators and/or reactors) for FY69 and FY73.

A. If your laboratory has more than one facility, please indicate approximately the percentage of your total annual budget which is involved with each facility and the percentage involved with theory. (Should add to 100%.)

Please indicate approximately what percentage of your scientific man years are involved with each facility and with theory. (Should add to 100%.)

B. If any of your FY69 facilities have been turned off, please indicate which ones, why, and when.

C. If there have been any major changes in the capabilities of your facilities since FY69, or if you have added a major new facility since FY69, or if you are in the process of building a new facility now, please indicate,

a) What was the modification and/or what are the characteristics of the new facility?

b) How much capital equipment, accelerator improvement and construction money was required?

c) What was the source of these funds?

D. For each of your facilities, please indicate for FY69 and for FY73

a) How many hours was it operated per week, averaged over the year?

b) What would you consider a desireable level (hours/week) of operation for this facility, given your present scientific staff?

c) If the answers to a) and b) are different, why?

d) Excluding research costs, what did it cost to operate and maintain this facility?

E. What aspects of your laboratory would you consider as obsolete? Explain.

What modifications to the facility and/or what urgently needed capital equipment are required to rectify this problem?

How much money?

F. Do you have any active plans to request a new facility or a major upgrading of your present facilities within the next three years? ____Yes ____ No
If Yes, briefly describe its characteristics, its capital cost, its operating cost (in addition to present operating funds), and from whom you plan to request the necessary funds.

G. Do you plan to voluntarily retire any present facilities within the next three years? ____Yes ____No If Yes, which one, and why?

4. USERS GROUPS (Part I):

This question is addressed to those who have users-groups operating at their facility.

A. What percentage of the available accelerator time is utilized by

	FY69	FY73
a) Individuals directly associated with your contract?	____	____
b) Individuals not directly associated with your contract but who come from within your own institution or university?	____	____
c) Outside users	____	____

(Prorate time which is used in collaborative work involving individuals from more than one of these groups.)

B. Do you believe the present level of use by people not directly associated with your contract (figures A(b) and A(c) above) is too high or too low? Comments.

C. What fraction of the accelerator time included in A(b) and A(c) involves collaboration with in-house researchers supported by your contract?

D. Do you charge for accelerator time? At what rate?

E. Please comment on the effectiveness and utility of such user programs in the kind of nuclear physics carried on at your laboratory.

5. USERS GROUPS (Part II):

This question is addressed to those groups who have used an off-site accelerator or reactor facility to any significant extent, or who will do so in the near future.

A. What facility has been used? ____________________

B. What fraction of your research effort has been expended in this way in the last five years? ____________________

C. What is your expectation for the next 2 or 3 years?

D. Please comment on the effectiveness and utility of such off-site user-group programs for your kind of nuclear physics.

6. OFF-SITE COMPUTER USAGE:

This question is addressed to those groups who use an off-site computer facility to any significant extent.

A. What facility is used? ______________________________

B. Approximately what percentage of your computing measured in scientific man years is done on off-site computers? ______________________________

How many scientific man years of off-site computing per year? __________

C. Do you expect this percentage to increase or decrease in the next 5 years?

____

7. BUDGET PROBLEMS FOR YOUR RESEARCH GROUP AND PROJECTIONS:

Please comment in any way you prefer. We would like your permission to quote (without attribution) any particular comments which would illuminate the problems facing research groups. Please comment on whether you anticipate changes in any funding you may be receiving from State or private sources. Add pages if necessary.

AD HOC PANEL ON NUCLEAR FACILITIES

R. S. Livingston (Chairman)
Oak Ridge National Laboratory

W. C. Parkinson
The University of Michigan

J. P. Unik
Argonne National Laboratory

Staff to the Panel:

M. B. Lewis
E. Newman
Oak Ridge National Laboratory

REPORT OF THE AD HOC PANEL ON NUCLEAR FACILITIES

INTRODUCTION

The most recent census of accelerator facilities for basic nuclear research in the United States was taken in 1969 in conjunction with the Nuclear Physics Panel report to the Physics Survey Committee of the National Research Council.* To maintain and expand the base of information presented there, an Ad Hoc Panel on Nuclear Facilities was established under the Committee on Nuclear Science of the National Research Council.

In updating the information on nuclear research facilities, the Facilities Panel has attempted to document the considerable changes that have occurred since 1969. These changes not only reflect the changing research interest of the scientific community but also indicate significant new trends that are taking place in accelerator usage.

The information contained in the present census was obtained primarily from responses to a questionnaire distributed by the Facilities Panel in 1973. The responses to these questionnaires were analyzed and summarized by the Accelerator Information Center at Oak Ridge National Laboratory. The Facilities Subcommittee of the Division of Nuclear Physics of the American Physical Society provided cooperative support. No attempt was made in this report to update the information on nuclear reactors that was included in the 1969 census. The 1973 census is more extensive than those taken earlier in that the questionnaires sent to the various institutions requested additional information, such as the unique features of the respective laboratory, the particular type of research being carried out, and the use of the facilities by visiting research groups. Data obtained

**Physics in Perspective,* Vol. II, Part A, pp. 267-317, National Academy of Sciences (1972). Available from Printing and Publishing Office, National Academy of Sciences, 2101 Constitution Avenue, Washington, D.C. 20418.

on installation and operating costs were generally incomplete and were not analyzed. Some additional data acquired during 1974 are included in this report. Because the responses received in 1974 are incomplete, this census must be considered complete only through 1973.

The Facilities Subcommittee of the Division of Nuclear Physics collected more diverse data, such as source and amount of funding, personnel, publications, a variety of aspects of facilities, and budget problems. From that survey we have included only data dealing with the technical aspects of the facilities.

FINDINGS OF THE 1969 ACCELERATOR SURVEY

EVOLUTION OF ACCELERATORS 1939-1969

The Nuclear Physics Panel report published in 1972 traces the evolution of particle accelerators from the original Cockcroft-Walton voltage multiplier and the electrostatic Van de Graaff accelerators of the early 1930's to the more sophisticated accelerators in operation by 1970. In the 1930's the Cockcroft-Walton and Van de Graaff's, together with the cyclotron, provided beams of light ions, namely protons, deuterons, and alpha particles with energies of the order of 10 MeV, and by the end of the decade as many as 20 universities had such facilities.

In the decade following World War II, the intense interest in nuclear physics, coupled with federal support, stimulated the development of higher-energy accelerators such as the frequency-modulated (FM) synchrocyclotron, capable of accelerating protons to several hundred MeV, the proton and electron linear accelerators, and the betatron.

In the 1960's the higher-energy tandem Van de Graaff's and the azimuthally varying field (AVF) or isochronous cyclotrons became operational. This new generation of cyclotrons made available not only more energetic particles but also more intense, high-quality beams. Coupled with this were improvements in nuclear instrumentation. For example, the analysis of reaction products was enhanced by the development of high-resolution magnetic spectrographs and solid-state particle gamma-ray detectors.

DISTRIBUTION OF ACCELERATORS (1969)

In the decades following World War II, federal policies in support of nuclear science led to the development of the large national laboratories and to the growth, both in number and size, of university laboratories. By 1969, some 89 institutions were operating approximately 150 accelerators. The research programs of the university laboratories were for the most part modest and were centered around conventional Van de Graaff's and cyclotrons. The annual operating costs varied from some $100,000 for the smaller programs to about $2 million for the larger programs. The distribution of accelerators among government, university, and industry laboratories were 43, 101, and 4, respectively.

In the evolutionary process of accelerator development, some 60 accelerators were shut down between 1941 and 1969, with some 18 being shut down in the peak year of 1968. The conventional (single-stage) Van de Graaff's were generally replaced with tandem machines, and the conventional (fixed-frequency) cyclotrons were superseded by the newer AVF cyclotrons. By 1969, the distribution by type of accelerators shut down was Cockcroft-Walton and cascade, 7; Van de Graaff's, 18; electron linacs, 1; proton linacs, 2; betatrons, 5; electron synchrotrons, 7; fixed-frequency (FF) cyclotrons, 15; and FM cyclotrons, 5.

ORGANIZATION OF THE 1973 DATA

A master list of the accelerators in use during 1973 for basic nuclear research is given in Table 1. This table is an update of Table II.5 of the 1969 census.* The organization parallels that of the 1969 census, beginning with potential-drop accelerators, followed by circular accelerators, heavy-ion linacs, electron linacs, betatrons, and electron synchrotrons. The abbreviations used for accelerator identification are listed in the Glossary. Facilities that have become operational since the 1969 census are tabulated in Table 2, and those shut down since 1969 are tabulated in Table 3. Tables 4 and 5 provide the results of the analysis on the number of laboratories participating in a given type research program together with the total hours per week and percent of research effort within each accelerator category. The "unique" features of facilities given in Table 6 were tabulated directly from the responses on the questionnaires. Although there is no specific criterion of what constitutes "unique," and thus great variance occurs in the replies, such a table may be valuable to potential users. An accelerator directory is included as Table 7 to permit individuals to obtain further information more easily on a particular facility.

The nature of accelerator usage as well as the changes in usage with time are illustrated in the bar graphs presented in Figures 1-4. Figure 1 illustrates the breakdown of research time between basic and applied research for accelerators is different energy ranges. The pattern of use of potential-drop accelerators among the various research categories by particle energy is shown in Figure 2. The use of AVF cyclotron time by university and nonuniversity

**Physics in Perspective,* Vol. II, Part A, pp 281-284.

users within various areas of research is shown in Figure 3. Figure 4 illustrates the division of major use of "recently" installed accelerator facilities (during the years 1966-1973) between basic and applied research. Figure 5 is a graphical comparison between U.S. and foreign cyclotron usage in various fields of research.

TABLE 1 CENSUS OF OPERATING ACCELERATORS IN BASIC AND APPLIED PHYSICS RESEARCH, 1973 (This table, provided for reference, is a catalog of the operating accelerators in the United states. It is an update of Table II.5, *Physics in Perspective*, Vol. II, Part A, p. 281. The terms and abbreviations are explained in the Glossary.)

	Energy[a] (MeV)	Ions[b]	Operating[c] Since	Identification[d]
Tandem, Three-Stage				
Brookhaven NL	32	p to I	1970	MP + MP[e]
U California, Livermore	27	p to O	1971	AVF + EN[e]
Duke U	32	p,d	1968	AVF + FN[e]
Los Alamos SL	25	p to I	1964	Single + FN[e]
U Pittsburgh	18	p to Ni	1967	EN + EN[e]
U Texas, Austin	17.5	p to Cl	1963	CN + EN[e]
U Washington	24.6	p,d	1967	FN + FN[e]
Tandem, Two-Stage				
Aerospace Res. Lab.	8	d to α	1967	T-8[f]
Argonne NL	18	p to Cl	1967	FN
Army Nuc. Eff. Lab.	15	p to K	1969	FN[f]
Brookhaven NL	20	p to I	1970	MP[g]
Brookhaven NL	24	p to I	1970	MP[g]
U California, Livermore	12	p to O	1970	EN[g,h]
California Inst. of Technol.	12	p to F	1961	EN
Duke U	17	p to Cl	1968	FN[g]
Florida State U	18	p to Bi	1970	FN
High Voltage Eng.	32	p to I	1969	XTU
Kansas State U	12	p to Cl	1969	EN
Los Alamos SL	18	p and O	1964	FN[g]
W Michigan U	12	p to O	1969	EN
U Minnesota	20	p to S	1966	MP
SUNY, Stony Brook	17	p to Cl	1968	FN
U Notre Dame	15	e to O	1968	FN
Oak Ridge NL	13	p to U	1962	EN
Ohio U	10.5	p to α	1972	T-11
U Pennsylvania	12	p to U	1962	EN
U Pittsburgh	12	p to A	1967	EN[g]
Purdue U	16	p to Br	1969	FN
Rice U	12	p to O	1961	EN
U Rochester	20	p to Au	1966	MP
Rutgers	18	p to S	1964	FN
Stanford U	19	p to I	1965	FN
U Texas, Austin	12	p to Cl	1963	EN[g]
U Washington	18	p to I	1965	FN[g]
U Wisconsin	13	p to S	1960	EN
Yale U	22	p to I	1966	MP
High Voltage, Single-Stage, ≥5 MeV				
U Arizona	5.5	p to U	1968	CN
Bartol Res. Found.	5.5	e	1952	CN
U Georgia	5	p to α	1970	VdGraaff[h]
U Iowa	6	p to Li	1964	CN
U Kentucky	6	p to α	1964	CN
Los Alamos SL	8	p to U	1950	Home Made VdG[g]
Lowell Tech. Inst.	6	p to α	1969	CN
Naval Res. Lab.	5.5	p to Xe	1953	CN
Oak Ridge NL	6	p to U	1950	CN
Ohio State U	6	p to α	1963	CN
Rice U	5.5	p to α	1953	CN
U Virginia	5.5	p to Ne	1966	CN
U Texas, Austin	5.5	p to Cl	1963	CN

TABLE 1 (Continued)

	Energy[a] (MeV)	Ions[b]	Operating[c] Since	Identification[d]
High-Voltage, Single-Stage, <5 MeV				
Aerospace Res. Lab.	1	e	1962	VdGraaff
Aerospace Res. Lab.	0.15	p to U	1972	Ion Implant
Aerospace Res. Lab.	0.4	p	1974	VdGraaff[h]
Argonne NL	4	p to N	1969	Dynamitron
Argonne NL	2	p to α	1974	VdGraaff[g]
U Arizona	2	p to U	1964	VdGraaff
U Arizona	2	p,d	1966	VdGraaff
U Arizona	1.25	p,e	1963	Dynamitron
Ballistic Res. Lab.	0.75	p to A	1960	Cockcroft-W
Bell Tel. Labs.	2	p to A	1968	VdGraaff
Bell Tel. Labs.	0.3	p to Bi	1968	--
Brigham Young U	2.5	p to α	1965	VdGraaff
Brigham Young U	4	p to α	1973	VdGraaff[g]
Brookhaven NL	4	p to α	1954	VdGraaff
Brown U	0.4	p	1963	Cockcroft-W
U California, Livermore	3.5	p	1953	VdGraaff
U California, Livermore	0.5	p,d	1965	ICT
California Inst. of Technol.	0.6	p to α	1952	Home Made VdG
California Inst. of Technol.	2.8	p to α	1949	Home Made VdG
California Inst. of Technol.	1.8	p to α	1939	Home Made VdG
California St., Los Angeles	4	p	1973	VdGraaff
Carnegie Inst.	4	p to Cs	1938	VdGraaff
Case Western R U	4	p to α	1958	VdGraaff
Concordia Col.	0.4	p,d	1960	Cockcroft-W
Duke U	3.3	p to α	1961	VdGraaff
Duke U	4.2	p to α	1952	VdGraaff
U Florida	4.2	p to α	1964	VdGraaff
U Florida	2	p-A	1974	VdGraaff[h]
Florida St. U	3	e	1958	VdGraaff
Georgetown U	0.4	p to α	1964	VdGraaff
Georgetown U	2	p to α	1966	VdGraaff
Georgia Inst. of Technol.	1	p to A	1959	VdGraaff
U Iowa	2	p	1961	VdGraaff
Johns Hopkins U	3	p to α	1963	VdGraaff
U Kansas	4	p to α	1963	VdGraaff
Kansas St. U	0.15	p to Cu	1967	Cockcroft-W
Kansas St. U	0.15	p to Cu	1968	Cockcroft-W
U Kentucky	0.25	e	1968	Home Made
U Kentucky	0.25	d	1966	--
Lockheed, Palo Alto	3	p to α	1958	VdGraaff
Los Alamos SL	3.75	p to α	1969	VdGraaff
Los Alamos SL	0.3	p,d	1962	Cockcroft-W
Los Alamos SL	0.15	d	1969	Cockcroft-W
U Maryland	3.5	p to A	1958	VdGraaff
NASA-SREL	3	e	1966	Dynamitron
Nat. Bur. Stand.	0.5	e	1952	Cascade
Nat. Bur. Stand.	4	e	1965	VdGraaff
Nat. Bur. Stand.	1.5	e	1965	Dynamitron
Nat. Bur. Stand.	2.3	e	1969	Marx Gen.
Nat. Bur. Stand.	0.6	e	1970	Marx Gen.
Nat. Bur. Stand.	3	p	1972	VdGraaff[h]
Oklahoma St. U	2	p	1973	VdGraaff[h]
SUNY, Albany	0.15	d	1967	--
SUNY, Albany	4.5	d to A	1970	Dynamitron
U Notre Dame	4	e, p to α	1956	VdGraaff
Oak Ridge NL	3	p to α	1948	VdGraaff

TABLE 1 (Continued)

	Energy[a] (MeV)	Ions[b]	Operating[c] Since	Identification[d]
U Oregon	4.5	p to α	1966	VdGraaff
Rutgers U	2	p	1972	VdGraaff[h]
U South Carolina	0.5	p to α	1962	VdGraaff
Stanford U	3	p to α	1960	VdGraaff
U Texas, Arlington	2	p to α	1973	VdGraaff[h]
U Texas, Austin	4	p to A	1963	VdGraaff
U Texas, Austin	1	p to O	1972	VdGraaff
Virginia Poly. Inst.	4	p to N	1968	VdGraaff
Washington St. U	0.35	p to α	1973	VdGraaff[h]
U Wisconsin	2	p to Ni	1951	VdGraaff
Worcester Poly. Inst.	2	p to α	1959	VdGraaff
Synchrocyclotrons (FM)				
U California, Berkeley	730	p to α	1946	184 in.
Columbia U	(560)	p	1974	170 in.-AVF
Harvard U	160	p	1949	95 in.
NASA-SREL	660	p,α	1967	197 in.
Isochronous Cyclotrons (AVF)				
Brookhaven NL	36	p to α	1968	60 in.
U California, Berkeley	60	p to A	1962	88 in.
U California, Davis	65	p to α	1967	76 in.
U California, Livermore	15	p to O	1971	30 in.[g]
U California, Los Angeles	22	p to α	1971	CS-22
U Chicago	15	p to α	1969	CS-15
U Colorado	28	p to α	1962	52 in.
Duke U	15	p,d,H^-	1968	31 in.[g]
U Indiana	15	p to α	1972	Injector[e]
U Indiana	(200)	(p to U)	(1975)	260 in.
U Maryland	100	p to A	1969	105 in.
Medi-Physics, Inc.	22	p to α	1971	CS-22
Medi-Physics, Inc.	22	p to α	1973	CS-22
U Michigan	35	p to A	1963	83 in.
Michigan State U	50	p to α	1965	67 in.
Mt. Sinai	26	p to α	1973	--
NASA-Lewis	55	p	1973	83 in.
Naval Res. Lab.	70	p to α	1967	76 in.
New England Nuclear	22	p to α	1970	CS-22
Oak Ridge NL	66	p to Ta	1964	76 in.
Princeton U	56	p to α	1970	69 in.
Sloan-Kettering	15	p to α	1967	CS-15
Texas A & M	55	p to A	1967	88 in.
Washington U	13	p to C	1965	54 in.
Lawrence Cyclotrons (FF)				
Argonne NL	23	p to α	1952	60 in.
Oak Ridge NL	22	p	1950	86 in.
St. Louis U	3.5	d	1966	27 in.
U Washington	11	p to α	1951	60 in.
Washington U	6.2	d	1964	--
Positive-Ion Linacs				
U California, Berkeley	8.5/μ	α to U	1972	Super-HILAC
Los Alamos SL	800	p,H^-	1972	LAMPF
Electron Linacs, >150 MeV				
Mass. Inst. of Technol.	400	e	1974	Bates
Electron Linacs, ≤150 MeV				
Argonne NL	22	e	1969	
Armed Forces, Md.	50	e	1970	
U California, Livermore	100	e	1970	

TABLE 1 (Continued)

	Energy[a] (MeV)	Ions[b]	Operating[c] Since	Identification[d]
U Chicago	50	e	1957	
Intelcom Rad. Technol.	100	e	1958	
U Illinois	(60)	e	(1974)	Supercond.
NASA-SREL	12	e	1966	
Nat. Bur. Stand.	150	e	1966	
Naval Postgrad.	100	e	1965	
Naval Res. Lab.	60	e	1964	
Oak Ridge NL	140	e	1969	
Ohio St. U	6	e	1965	
Ohio St. U	4	e	1970	
Rensselaer Poly. Inst.	100	e	1961	
Yale U	75	e	1961	
Betatrons				
U Cincinnati	12	e	1966	
Ohio State U	25	e	1960	
Electron Synchrotons				
U Oklahoma	70	e	1968	

[a] Maximum energy, proton unless otherwise indicated; design goals in parentheses.

[b] Symbols used throughout: d for deuteron, e for electron, p for proton, α for ionized helium-4, and t for ionized tritium and the chemical symbol for heavier ions; energy and intensity of heavier ions may be limited.

[c] Projected date of operation in parentheses.

[d] Commercial accelerator models, cyclotron pole diameters, etc.

[e] Can also be operated as two-stage.

[f] To be transferred to another laboratory.

[g] Can also be coupled for three-stage operation.

[h] Transferred from another laboratory.

TABLE 2 NEW ACCELERATOR FACILITIES (This is a list of accelerators that have begun operation since 1970. Note that data for 1974 are included but are not necessarily complete. The facilities listed are not necessarily newly manufactured, and some, as noted, are known to have been transferred from other institutions. For an explanation of the abbreviations of the facilities, see the Glossary.)

Year	Institution	Facility
1970	Brookhaven NL	2 MP-TVdG
	West. Michigan U	EN-TVdG
	Nat. Bur. Stand.	e-Marx Gen.
	New England Nuc.	AVF-Cyc
	Princeton U	AVF-Cyc
	Armed Forces Rad. Res. Inst.	e-LINAC
	U California, Livermore	e-LINAC
	Ohio St. U Hosp.	e-LINAC
	Los Alamos NL	Cockcroft-W
	SUNY, Albany	Dyn (4.5 MV)
1971	U California, Los Angeles Medical	AVF-Cyc
	Medi-Physics, Inc.	AVF-Cyc
1972	Ohio U	TVdG
	Aerospace Res. Lab.	RT
	Nat. Bur. Stand.	VdG (transferred from ANL)
	Los Alamos SL	LINAC, LAMPF
	U Texas, Austin	VdG
	U California, Berkeley	Super HILAC
	Indiana U	AVF Cyc (injector for IUCF)
1973	Oklahoma St. U	VdG (transferred from W.Va. U)
	Washington St. U	VdG
	U Texas, Arlington	VdG (transferred from NBS)
	Medi-Physics, Inc.	AVF-Cyc
	Mt. Sinai Hosp.	AVF-Cyc
	Brigham Young U	VdG (transferred from ANL)
	NASA-Lewis	AVF-Cyc
1974	Aerospace Res. Lab.	VdG
(partial list)	U Florida	VdG
	Mass. Inst. Technol.	e-LINAC (Bates)

TABLE 3 ACCELERATOR SHUTDOWNS (This list of accelerator shutdowns since 1970 includes some information as to disposition. See the Glossary for an explanation of the abbreviations used in column 2. The phrase "shut down" indicates that the accelerator facility could be activiated if funding were available. Note that the list for 1974 is not necessarily complete.)

Year	Institution	Identification	Disposition
1970	Columbia U	5.5-MV VdG	Shut down
	Mass. Inst. Technol.	8-MV VdG	Stored
	U Wyoming	0.1-MV Cockcroft-W	Stored
	U Michigan	50" FF Cyc	Shut down
	U California, Livermore	35-MeV e-LINAC	Dismantled
1971	Georgia Inst. Technol.	Cockcroft-W	Relocated
	U California, Livermore	90" FF Cyc	Dismantled
	U Chicago	170" FM Cyc	Dismantled
1972	Los Alamos SL	0.19-MV Cockcroft-W	Shut down
	Ohio State U	45" FF Cyc	Shut down
	Los Alamos SL	30-MeV e-LINAC	Sent to Yugoslavia
	Iowa State U	e-synchrotrons (2)	Dismantled
	Texas Nuclear	3-MV VdG	Shut down
	Aerospace WPAFB	T-8 TVdG	Shut down
	U Illinois	Betatron	Shut down
1973	Penn St. U	6-MV VdG	Shut down
	Tulane U	3-MV VdG	Sold
	U California, Los Angeles	50-MeV AVF Cyc	Dismantled
	Oregon St. U	37" AVF Cyc	Dismantled
	Washington St. U	2-MV VdG	Shut down
1974	Army Rad. Lab.	FN-TVdG	To go to U Penn.
(partial list)	Yale U	HILAC	Dismantled
	Los Alamos SL	FF-Cyc	Dismantled

TABLE 4 RESEARCH PROGRAMS--NUMBER PARTICIPATING (The character and diversity of the research programs for different accelerator types and energy ranges is shown by indicating the number of laboratories participating. Also shown in the table is the number of accelerator laboratories responding in the census as well as their average hours of operation per week.)

Type of Accelerator /energy range (p)	Number Reporting A[b]	B[b]	C[b]	Average h/wk	Research Programs--Number Participating[a] Heavy Ions	Nuclear Science	Material Science	Neutron Physics	Bio-medical	Solid State	Atomic Physics	Isotope Production	Other	Off-Site Users
Electron/ ≤ 6 MeV	10	0	0	33	-	3	2	0	3	5	2	0	6	5
Electron/ Betatrons Synchrotrons	1	2	3	48	-	0	1	0	1	0	0	0	0	1
Electrons/Linacs 6-150 Mev	12	2	3	80	-	6	2	7	3	3	2	3	7	5
TOTAL	23	4	6	58	-	9	5	7	7	8	4	3	13	11
Potential Drop														
CW's/ > 1 MeV	14	3	4	29	5	4	4	5	3	5	6	1	4	3
VDG/1 ≤ E < 5 MeV	35	5	3	48	10	22	10	10	10	11	17	0	10	8
VDG/ ≥ 5 MeV	12	1	2	61	6	9	5	4	3	4	5	0	1	4
TVDG/8 ≤ E < 12 MeV	3	0	0	123	1	2	0	1	0	0	1	0	0	2
TVDG/12 ≤ E < 16 MeV	14	0	0	124	14	14	5	5	5	1	6	0	3	9
TVDG/16 ≤ E < 20 MeV	7	0	0	146	7	7	1	2	2	2	3	0	2	6
TVDG/ ≥ 20 MeV	6	0	0	130	6	5	2	0	3	0	1	0	3	3
TOTAL	91	9	9	74	49	63	27	27	26	23	39	1	23	35
Cyclotrons														
Fixed Freq./ ≤ 25 MeV	4	1	4	56	0	2	2	1	3	1	0	3	0	3
AVF/ ≤ 26 MeV	8	1	2	64	0	1	0	0	3	0	0	7	2	5
AVF/ > 26 MeV	13	2	2	128	6	12	4	4	9	2	1	7	7	11
FM/ 160 < E ≤ 750 MeV	3	1	1	71	0	2	0	0	3	2	1	0	1	3
TOTAL	28	5	9	93	6	17	6	5	18	5	2	17	10	22
Proton Linacs														
All	1	0	0	88	-	No Meaningful Data Yet								
HILAC														
All	2	0	0	80	1	2	0	0	1	1	1	0	0	2

[a]Number of labs reporting at least 1% of research time.

[b]A, operational; B, standby or being refitted; C, shut down.

TABLE 5 RESEARCH PROGRAMS--PERCENTAGE OF TOTAL TIME (The percentage of available research time utilized by the accelerator laboratories for various scientific efforts is shown. Also shown is the number of accelerator laboratories in the census as well as their average hours of operation per week.)

Type of Accelerator /energy range (p)	Number Reporting A[a]	B[a]	C[a]	Average h/wk	Research Programs--Percent of Total Time: Heavy Ions	Nuclear Science	Material Science	Neutron Physics	Bio-medical	Solid State	Atomic Physics	Isotope Production	Other	Off-Site Users
Electrons/ $\leq$ 6 MeV	10	0	0	33	-	18	3	0	10	19	7	0	43	17
Electrons/ Betatrons Synchrotrons	1	2	3	48	-	0	5	0	95	0	0	0	0	5
Electrons/Linacs 6-150 MeV	12	2	3	80	-	20	5	43	8	3	1	1	20	11
TOTAL or AVERAGE	23	4	6	58	-	19	5	35	10	5	2	1	23	12
Potential Drop														
CW's/ < 1 MeV	14	3	4	29	56	11	6	19	3	22	30	1	8	4
VDG/1 $\leq$ E < 5 MeV	35	5	3	48	24	33	9	12	4	13	24	0	5	5
VDG/ $\geq$ 5 MeV	12	1	2	61	18	39	10	24	4	9	13	0	1	7
TVDG/8 $\leq$ E < 12 MeV	3	0	0	123	11	65	0	33	0	0	2	0	0	8
TVDG/12 $\leq$ E < 16 MeV	14	0	0	124	38	72	2	6	3	1	12	0	4	10
TVDG/16 $\leq$ E < 20 MeV	7	0	0	146	40	82	2	3	3	4	4	0	2	23
TVDG/ $\geq$ 20 MeV	6	0	0	130	58	84	3	0	1	0	1	0	11	24
TOTAL or AVERAGE	91	9	9	74	35	58	5	11	3	6	13	0	4	12
Cyclotrons														
Fixed Freq./ $\leq$ 25	4	1	4	56	0	22	4	2	48	4	0	20	0	40
AVF/ $\leq$ 26 MeV	8	1	2	64	0	9	0	0	8	0	0	79	4	4
AVF/ > 26 MeV	13	2	2	128	13	75	2	4	7	0	0	6	6	8
FM/ 160 < E $\leq$ 750 MeV	3	1	1	71	0	63	0	0	19	11	6	0	1	78
TOTAL or AVERAGE	28	5	9	93	8	57	2	3	12	1	0	21	4	16
Proton Linacs														
All	1	0	0	88	-	No Meaningful Data Yet								
HILAC														
All	2	0	0	80	100	94	0	0	4	1	2	0	0	60

[a] A, operational; B, standby or being refitted; C, shut down.

TABLE 6 UNIQUE ANCILLARY FACILITIES (This table of the unique experimental facilities at various accelerator installations is based on lists provided by each laboratory and considered such by the same laboratory. For an explanation of the abbreviations of the facilities, see the Glossary.)

High-Resolution Spectrograph

MP-TVdG
- Brookhaven NL
- U Minnesota
- U Rochester
- Yale U

FN-TVdG
- Argonne NL
- Los Alamos SL
- U Notre Dame
- Rutgers U

EN-TVdG
- Oak Ridge NL
- U Pennsylvania
- U Pittsburg

CN-VdG
- Penn St. U

AVF-Cyc
- U California, Berkeley
- U Colorado
- U Michigan
- Michigan St. U
- Oak Ridge NL
- Princeton U
- Texas A & M

e-LINAC
- Mass. Inst. Technol. (Bates)
- Naval Postgrad. Sch.
- Nat. Bur. Stand.

p-LINAC
- Los Alamos SL (LAMPF)

Pulsed Beam, Chopper, Buncher, Time of Flight

MP-TVdG
- U Rochester

FN-TVdG
- Rutgers U
- SUNY, Stony Brook

EN-TVdG, TDyn, T11-TVdG
- Argonne NL
- California Inst. Technol.
- Los Alamos SL
- Oak Ridge NL
- Ohio U
- Rice U
- U Texas, Austin

CN-VdG
- U Kentucky
- Lowell Tech. Inst.
- U Virginia

VdG and Cockcroft-W
- U Arizona
- Case Western Reserve
- U Florida
- U Georgia
- Los Alamos SL
- Nat. Bur. Stand.
- U Oregon
- U Texas, Arlington

TABLE 6 (Continued)

Polarized Beam	
FN-TVdG	
Duke U (p,d)	Rutgers U (p,d)
Los Alamos SL (p,d)	Stanford U (p,d)
U Notre Dame (p,d)	U Washington (p,d)
EN-TVdG	
Oak Ridge NL (p,d)	U Wisconsin (p,d)
VdG	
Carnegie Inst. (p)	Ohio St. U (p,d)
AVF-Cyc	
U California, Berkeley (p,d)	Oak Ridge NL (p,d)
U California, Davis (n)	Texas A & M (p,d)
Polarized Target	
FN-TVdG	
Stanford U	
AVF-Cyc	
U California, Davis	
e-LINAC	
Oak Ridge NL	
Neutron Beam, AVF-Cyc	
U California, Davis	Oak Ridge NL
U Michigan	
Naval Res. Lab.	Texas A & M
Positron Beam, e-LINAC	
U California, Livermore	Nat. Bur. Stand.
Intel. Rad. Tech.	
Tritium Beam, VdG	
Brookhaven NL	Nat. Bur. Stand.
Lockheed, Palo Alto	
On-Line Isotope Separator, AVF-Cyc	
Oak Ridge NL (UNISOR)	Princeton U
10" × 10" NaI Detectors, TVdG	
Brookhaven NL	Stanford U
U Florida	SUNY, Stony Brook
Cryogenic Target	
Duke U	

TABLE 7 ACCELERATOR DIRECTORY (This list, included primarily for the benefit of extramural users, includes the name and address of the person to contact for information concerning the use of his facility for research. The current policy toward facility use by outside researchers is indicated. Statistical information on this subject is also shown in Tables 3 and 4. For an explanation of the abbreviations of the facilities, see the Glossary.)

Contact	Facility	Off-Site Users (Y, Yes; N, No)
Arizona		
Prof. Stanley Bashkin Dept. of Physics University of Arizona Tucson, AZ 85721	CN-VdG, VdG	Y Y
R. L. Seale Dept. Nucl. Eng. University of Arizona Tucson, AZ 85721	VdG	N
M. E. Wacks Nucl. Eng. Dept. University of Arizona Tucson, AZ	Dyn	N
California		
Dr. K. Crowe Lawrence Berkeley Lab. Berkeley, CA 94720	FM-Cyc	Y
Dr. David Hendrie Lawrence Berkeley Lab. Berkeley, CA 94720		
Dr. Hermann A. Grunder Lawrence Berkeley Lab. Berkeley, CA 94720	Super HILAC	Y
Prof. John A. Jungerman Dept. of Physics University of California Davis, CA 95616	AVF-Cyc	Y
Dr. D. K. Wells Medi-Physics, Inc. Emeryville, CA	AVF-Cyc	Y
J. D. Anderson Lawrence Livermore Lab. P.O. Box 808, L-503 Livermore, CA 94551	e-LINAC	Y
Jhan M. Khan Lawrence Livermore Lab. P.O. Box 808, L-503 Livermore, CA 94550	VdG	N

TABLE 7 (Continued)

Contact	Facility	Off-Site Users (Y, Yes; N, No)
Dr. J. C. Davis Lawrence Livermore Lab. P.O. Box 808, L-330 Livermore, CA 94550	Cyclograaff	Y
Calvin Wong Lawrence Livermore Lab. P.O. Box 808 Livermore, CA 94550	RT	Y
Dr. N. S. McDonald Center for Health Sciences School of Medicine University of California Los Angeles, CA 90024	AVF-Cyc	Y
Dr. L. Margaziotis California State U Los Angeles, CA 90032	VdG	Y
F. R. Buskirk Naval Postgraduate School Physics Dept. Monterey, CA 93940	e-LINAC	N
R. E. McDonald Lockheed Research Lab. Palo Alto, CA 94304	VdG	Y
Dr. R. W. Kavanagh also C. A. Barnes California Inst. of Technol. Kellogg Radiation Lab. Pasadena, CA 91109	FN-TVdG VdG VdG VdG	N N N N
Prof. S. S. Hanna Dept. of Physics Stanford University Stanford, CA 94305	EN-TVdG VdG	Y Y
James Naber Intelcom. Rad. Tech. 10955 John Jay Hopkins Dr. P.O. Box 80817 San Diego, CA 92138	e-LINAC	Y
Colorado		
Dr. R. A. Ristinen Nuclear Physics Lab. University of Colorado Boulder, CO 80302	AVF-Cyc	Y

TABLE 7 (Continued)

Contact	Facility	Off-Site Users (Y, Yes; N, No)
Connecticut		
Prof. D. A. Bromley Wright Nuclear Structure Lab. Yale University New Haven, CT 06520	MP-TVdG	N
Prof. Howard L. Schultz Dept. of Physics Yale University New Haven, CT 06520	e-LINAC	N
Florida		
Prof. F. E. Dunnam Dept. of Physics & Astronomy University of Florida Gainesville, FL 32601	VdG VdG	Y Y
Mr. Joe Beaver Mt. Sinai Hospital of Greater Miami Miami Beach, FL	AVF-Cyc	Y
Prof. J. W. Nelson also R. H. Johnson Dept. of Physics Florida State University Tallahassee, FL 32306	FN-TVdG e-VdG	Y
Georgia		
Prof. M. F. Steuer Dept. of Physics & Astronomy University of Georgia Athens, GA 30601	CN-VdG	N
Prof. C. W. Thomas Physics Dept. Georgia Inst. of Technol. 225 North Avenue, N.W. Atlanta, GA 30332	VdG	Y
Illinois		
Dr. J. Aron Chemistry Division Argonne National Lab. Argonne, IL 60439	FF-Cyc	Y
Dr. A. B. Smith Applied Physics Division Argonne National Lab. 9700 S. Cass Avenue Argonne, IL 60439	TDyn	Y

TABLE 7 (Continued)

Contact	Facility	Off-Site Users (Y, Yes; N, No)
Dr. F. Paul Mooring Argonne National Lab. 9700 S. Cass Avenue Argonne, IL 60439	FN-TVdG Dyn VdG	Y Y Y
Dr. G. Mavrogenes Physics Division Argonne National Lab. Argonne, IL 60439	e-LINAC	N
Dr. Paul Harper Argonne Cancer Research Hospital University of Chicago Chicago, IL 60637	AVF-Cyc	N
Lester S. Skaggs Franklin McLean Mem. Res. Inst. University of Chicago 950 E. 59th Street Chicago, IL 60637	e-LINAC	Y
Dr. Peter Axel Dept. of Physics University of Illinois Urbana, IL 61801	e-LINAC	N
Indiana		
Prof. G. T. Emergy Dept. of Physics Indiana University Bloomington, IN 47401	2 AVF-Cyc	Y
Prof. P. C. Simms Purdue Accelerator Lab. Purdue University Lafayette, IN 47907	FN-TVdG	Y
Prof. Cornelius P. Browne Nuclear Structure Lab. University of Notre Dame Notre Dame, IN 46556	FN-TVdG VdG	Y N
Iowa		
Prof. Richard R. Carlson Dept. of Physics & Astronomy University of Iowa Iowa City, IA 52240	CN-VdG VdG	N N

TABLE 7 (Continued)

Contact	Facility	Off-Site Users (Y, Yes; N, No)
Kansas		
Prof. James C. Legg	EN-TVdG	N
Dept. of Physics	CW	N
Kansas State University	CW	N
Manhattan, KS 66502		
Prof. R. W. Krone	VdG	Y
Physics Dept.		
University of Kansas		
Lawrence, KS 66044		
Kentucky		
Prof. B. D. Kern	CN-VdG	Y
also M. T. McEllistrem	RT	N
also P. K. Leichner	e-RT	N
Dept. of Physics & Astronomy		
University of Kentucky		
Lexington, KY 40506		
Maryland		
Dr. W. R. Von Antwerp	CW	Y
U.S. Army Ballistic Research Lab.		
Aberdeen Proving Ground, MD 21005		
Prof. Y. K. Lee	VdG	N
Dept. of Physics		
Johns Hopkins University		
Baltimore, MD 21218		
Prof. F. W. Martin	VdG	Y
Dept. of Physics & Astronomy		
University of Maryland		
College Park, MD 20742		
Dr. H. Holmgren	AVG-Cyc	Y
Dept. of Physics		
University of Maryland		
College Park, MD 20742		
R. E. Carter	e-LINAC	Y
Armed Forces Radiobiology Res. Inst.		
Bethesda, MD 20014		
Massachusetts		
J. Bromberger	TVdG	N
High Voltage Eng. Corp.		
Burlington, MA		

TABLE 7 (Continued)

Contact	Facility	Off-Site Users (Y, Yes; N, No)
Prof. W. M. Preston Physics Dept. Harvard University Cambridge, MA 02138	FM-Cyc	Y
Prof. Gunter H. R. Kegel Dept. of Physics Lowell Technological Inst. Lowell, MA 01854	CN-VdG	Y
John L. Need New England Nuclear Corp. 601 Treble Cove Road N. Billerica, MA 01862	AVF-Cyc	Y
Prof. B. A. Wooten Dept. of Physics Worcester Polytechnic Inst. Worcester, MA 01609	VdG	N
Peter T. Demos Bates LINAC Facility Mass. Inst. Technol. Middleton, MA	e-LINAC	Y
Michigan		
Prof. W. C. Parkinson Dept. of Physics University of Michigan Ann Arbor, MI	AVF-Cyc	Y
Prof. Henry Blosser Dept. of Physics Michigan State University East Lansing, MI 48823	AVF-Cyc	Y
Prof. E. M. Bernstein Dept. of Physics Western Michigan University Kalamazoo, MI 49001	EN-TVdG	Y
Minnesota		
Prof. J. H. Broadhurst Williams Lab. of Nuclear Physics University of Minnesota Minneapolis, MN 55455	MP-TVdG	N
Prof. Carl L. Bailey Physics Dept. Concordia College Moorhead, MN 56560	CW	Y

TABLE 7 (Continued)

Contact	Facility	Off-Site Users (Y, Yes; N, No)
Missouri		
Prof. J. T. Hood	AVF-Cyc	Y
also Dr. J. Barker	FF-Cyc	N
Physics Dept.		
St. Louis University		
221 North Grand Blvd.		
St. Louis, MS 63130		
Dr. M. M. Ter-Pogossian	FF-Cyc	N
Dept. Radiology		
Washington University		
510 South Kings Highway		
St. Louis, MS 63110		
New Jersey		
Dr. Walter L. Brown	RT	N
Bell Telephone Laboratories	VdG	N
Murray Hill, NJ 07974		
Prof. Georges M. Temmer	FN-TVdG	N
Rutgers - The State University	VdG	Y
Nuclear Physics Lab. - Physics Bldg.		
New Brunswick, NJ 08903		
Prof. M. G. White	AVF-Cyc	Y
Dept. of Physics		
Princeton University		
Princeton, NJ 08540		
R. L. Hubbard	AVF-Cyc	Y
Medi-Physics, Inc.		
900 Durham Road		
South Plainfield, NJ		
New Mexico		
Dr. R. L. Henkel	FN-TVdG	N
Los Alamos Scientific Lab.	CN-VdG	N
Box 1663		
Los Alamos, NM 87544		
Dr. G. R. Keepin	VdG	N
also A. D. McGuire	CW	Y
Los Alamos Scientific Lab.	CW	N
P.O. Box 1663		
Los Alamos, NM 87544		
Dr. Louis Rosen	p-LINAC	Y
LASL, LAMPF-Facility		
P.O. Box 1663		
Los Alamos, NM 87544		

TABLE 7 (Continued)

Contact	Facility	Off-Site Users (Y, Yes; N, No)
New York		
Prof. H. Bakhru	Dyn	Y
Dept. of Physics	RT	Y
State University		
Albany, NY 12222		
Prof. Leon M. Lederman	FM-AVF-Cyc	Y
Columbia University		
P.O. Box 137		
Irvington, NY 10533		
Dr. Thomas Kuo	AVF-Cyc	Y
Sloan-Kettering Inst. for Cancer Res.		
410 E. 68th Street		
New York, NY		
Prof. Harry E. Gove	MP-TVdG	Y
Nuclear Structure Research Lab.		
University of Rochester		
River Campus Station		
Rochester, NY 14627		
Prof. Linwood L. Lee, Jr.	FN-TVdG	Y
Nuclear Structure Laboratory		
SUNY-Stony Brook		
Stony Brook, NY 11790		
R. Krasse	e-LINAC	Y
Rensselaer Poly. Inst.		
LINAC Facility		
Tibbits Avenue		
Troy, NY 12180		
Dr. P. Thieberger	MP-TVdG	Y
also D. E. Alburger	VdG	N
also C. P. Baker	AVF-Cyc	N
Brookhaven National Lab.		
Upton, Long Island, NY 11973		
North Carolina		
Prof. Henry Newson	Cyclograaff	N
Triangle Universities Nuclear Lab.	VdG	N
Duke University	VdG	N
Durham, NC 27706		
Ohio		
Prof. R. O. Lane	T11-TVdG	N
Edwards Accelerator Lab.		
Ohio University		
Athens, OH 45701		

TABLE 7 (Continued)

Contact	Facility	Off-Site Users (Y, Yes; N, No)
Dr. W. F. Stubbins Dept. of Physics University of Cincinnati Cincinnati, OH 45221	VdG Betatron	N N
Prof. H. B. Willard Dept. of Physics Case Western Reserve University Cleveland, OH 44106	VdG	N
Dr. James W. Blue Radiation Physics Branch Lewis Research Center 21000 Broadpark Road Cleveland, OH 44135	AVF-Cyc	Y
Dr. L. Dorfman Dept. Chemistry Ohio State University Columbus, OH 43210	e-LINAC	N
Prof. Hershel J. Hausman Dept. of Physics Ohio State University Columbus, OH 43210	CN-VdG	Y
Dr. F. Batley Dept. Radiology Ohio State University Columbus, OH 43210	e-LINAC Betatron	N
Dr. Y. S. Park Aerospace Reserach Lab. Wright-Patterson AFB Dayton, OH 45433	VdG VdG Rt	Y Y Y
Oklahoma		
Prof. D. W. Anderson Dept. of Physics University of Oklahoma Norman, OK 73069	Synchrotron	N
W. A. Sibley Physics Dept. Oklahoma State University Stillwater, OK 74074	VdG	N

TABLE 7 (Continued)

Contact	Facility	Off-Site Users (Y, Yes; N, No)
Oregon		
Prof. H. W. Lefevre Dept. of Physics University of Oregon Eugene, OR 97403	VdG	Y
Pennsylvania		
Prof. Roy Middleton Dept. of Physics University of Pennsylvania Philadelphia, PA 19104	EN-TVdG	Y
Prof. Bernard L. Cohen Nuclear Physics Lab. University of Pittsburgh Pittsburgh, PA 15213	EN-TVdG	Y
Dr. C. P. Swann Bartol Research Foundation Whittier Place Swarthmore, PA 19081	CN-VdG	N
Rhode Island		
Prof. Russel A. Peck Physics Dept. Brown University Providence, RI 02913	RT	N
South Carolina		
Prof. R. D. Edge Dept. of Physics & Astronomy University of South Carolina Columbia, SC 29208	VdG	N
Tennessee		
Dr. C. D. Moak Van de Graaff Lab. Oak Ridge National Lab. P.O. Box X, Bldg. 5500 Oak Ridge, TN 37830	EN-TVdG CN-VdG VdG	Y Y Y
Dr. J. A. Harvey Electron Linear Accelerator Oak Ridge National Lab. P.O. Box X, Bldg. 6010 Oak Ridge, TN 37830	e-LINAC	Y

TABLE 7 (Continued)

Contact	Facility	Off-Site Users (Y, Yes; N, No)
Dr. Carl Ludemann Oak Ridge National Lab. P.O. Box X, Bldg. 6000 Oak Ridge, TN 37830	AVF-Cyc	Y
Mr. M. R. Skidmore Oak Ridge National Lab. P.O. Box Y, Bldg. 9201-2 Oak Ridge, TN 37830		
Texas		
Dr. L. A. Rayburn University of Texas Arlington Arlington, TX 76019	VdG	N
Prof. Peter J. Riley also Prof. C. F. Moore Center for Nuclear Studies University of Texas Austin, TX 78712	EN-TVdG VdG CN-VdG VdG	Y Y N Y
Prof. T. T. Sugihara Cyclotron Institute Texas A & M University College Station, TX 77843	AVF-Cyc	Y
Prof. G. C. Phillips Bonner Nuclear Lab. Rice University Houston, TX 77001	EN-TVdG CN-TVdG	Y Y
Utah		
Prof. Dwight R. Dixon Dept. of Physics & Astronomy Brigham Young University Provo, UT 84601	VdG	N
Virginia		
Prof. D. D. Long Dept. of Physics Virginia Polytechnic Inst. Blacksburg, VA 24061	VdG	N
Prof. Rogers C. Ritter Dept. of Physics University of Virginia Charlottesville, VA 22903	CN-VdG	Y

TABLE 7 (Continued)

Contact	Facility	Off-Site Users (Y, Yes; N, No)
Dr. Robert T. Siegel	e-Dyn	Y
Space Radiation Effects Lab.	FM-Cyc	Y
College of William and Mary	e-LINAC	Y
11970 Jefferson Avenue		
Newport News, VA 23606		
Washington		
Dr. Frank Ruddy	VdG	Y
Nuc. Rad. Cen.		
Dept. of Physics		
Washington State University		
Pullman, WA 99163		
Dr. W. G. Weitkamp	FN-TVdG	Y
Nuclear Physics Lab.	FF-Cyc	
University of Washington		
Seattle, WA 98195		
Washington, D.C.		
Dr. R. C. Placious	e-Dyn	Y
Linac Radiation Division	e-RT	Y
National Bureau of Standards	e-Marx Gen.	Y
Washington, DC 20234	e-Marx Gen.	Y
Dr. C. D. Bowman	VdG	Y
also C. E. Dick	e-VdG	Y
National Bureau of Standards	e-LINAC	Y
Washington, DC 20234		
Mr. Ralph Tobin	e-LINAC	Y
Naval Research Lab.		
4555 Overlook Avenue		
Washington, DC		
Dr. K. L. Dunning	CN-VdG	N
also Dr. R. O. Bondelid	AVF-Cyc	Y
Naval Research Lab.		
Washington, DC 20390		
Prof. James M. Lamberg	VdG	N
Dept. of Physics	VdG	N
Georgetown University		
Washington, DC 20007		

TABLE 7 (Continued)

Contact	Facility	Off-Site Users (Y, Yes; N, No)
Dr. Louis Brown Carnegie Institution of Washington Dept. of Terrestrial Magnetism 5241 Broad Branch Road N.W. Washington, DC 20015	VdG	N
Wisconsin		
Prof. H. T. Richards Dept. of Physics University of Wisconsin-Madison Madison, WI 53706	EN-TVdG	N
Prof. J. M. Donhowe B101 Sterling Hall University of Wisconsin Madison, WI 53706	VdG	N

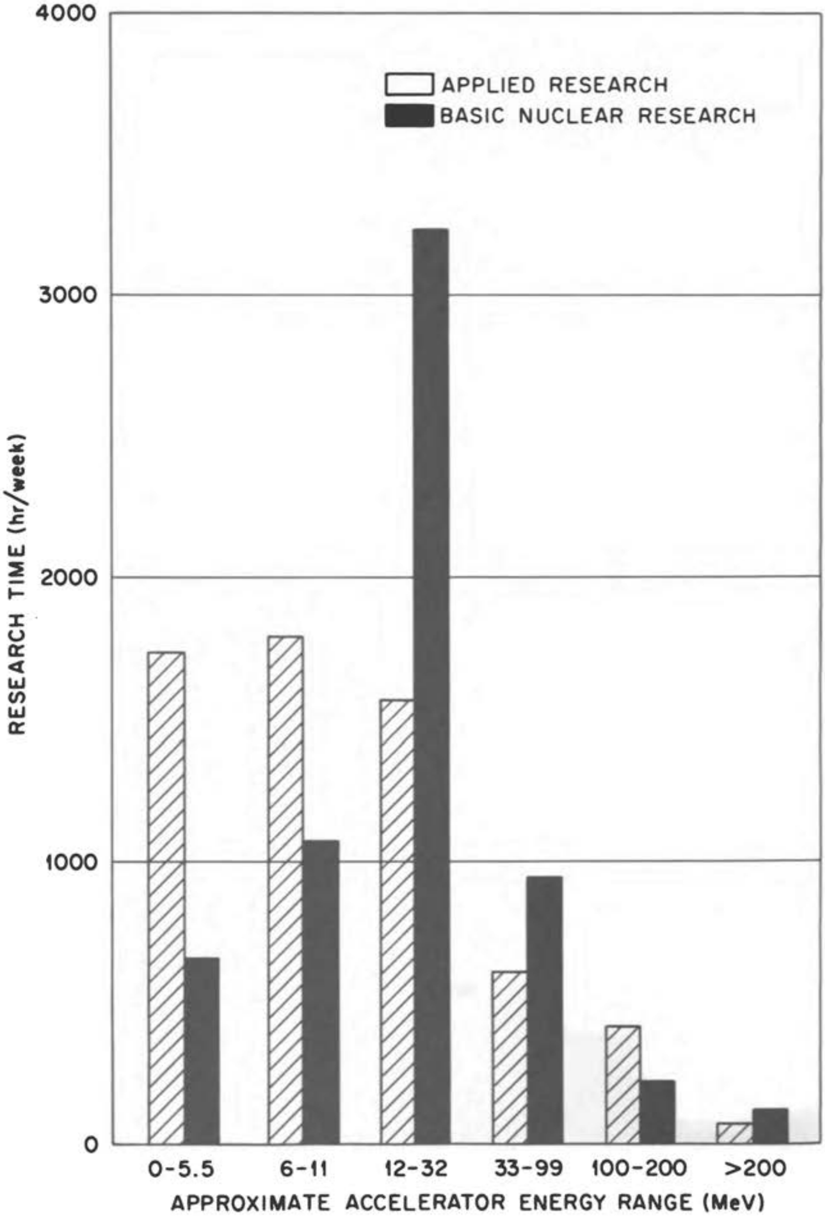

FIGURE 1 Basic nuclear and applied research effort. A graphical illustration of some of the statistical data given in Table 5. Basic nuclear research is represented by the shaded bars and is derived from the column labeled "nuclear science." The hatched bars representing applied research are derived from a sum of the remaining (research program) columns.

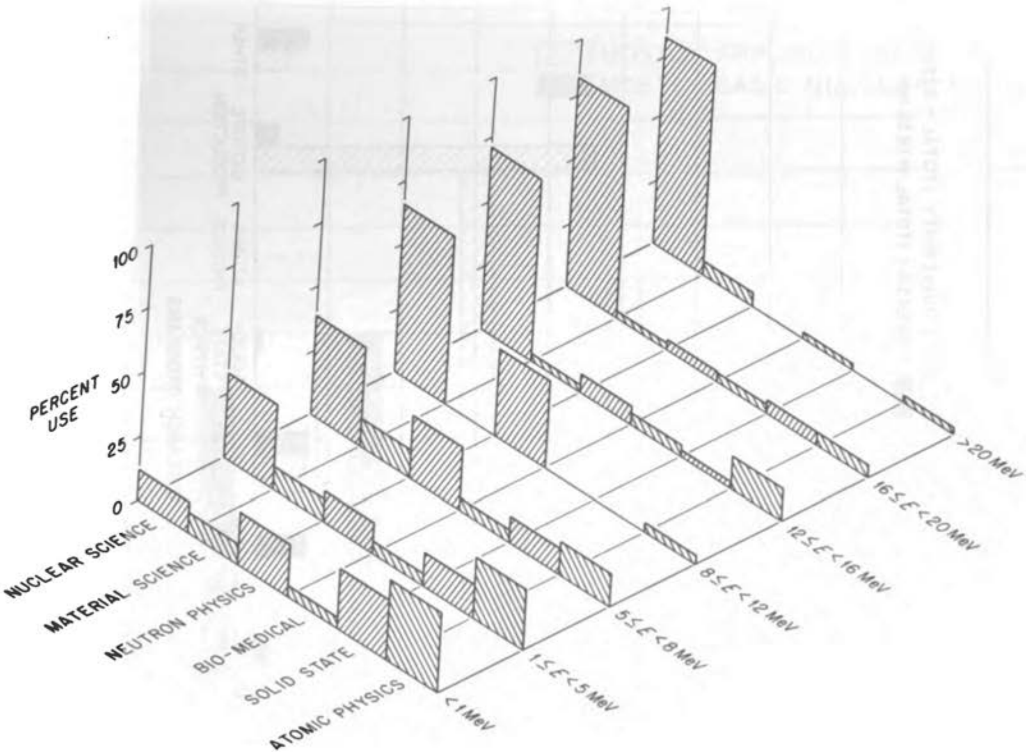

FIGURE 2 High-voltage accelerator use. The data of Table 5 presented graphically showing the pattern of use within the six research categories. The character of the research program is seen to vary significantly with energy.

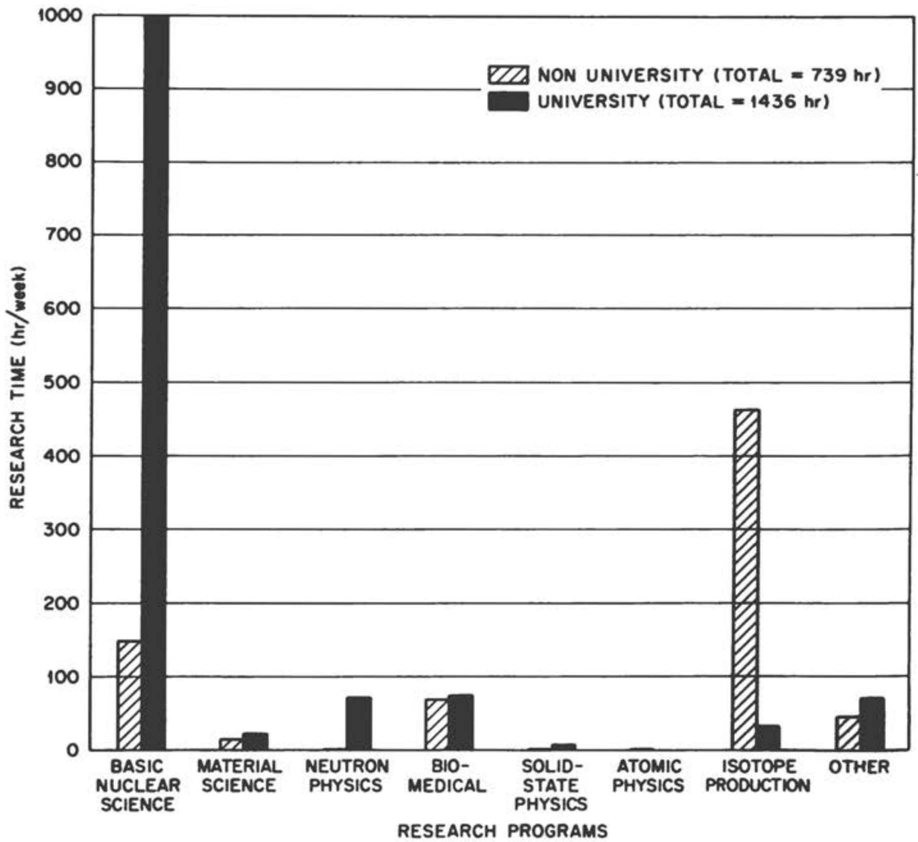

FIGURE 3 AVF cyclotron use. A graphical illustration of some of the statistical data given in Table 5 and original questionnaires. University research is shown by the shaded bars, while all other institutions, referred to as nonuniversity, are represented by the hatched bars. The research programs shown are the same as those listed in Table 5.

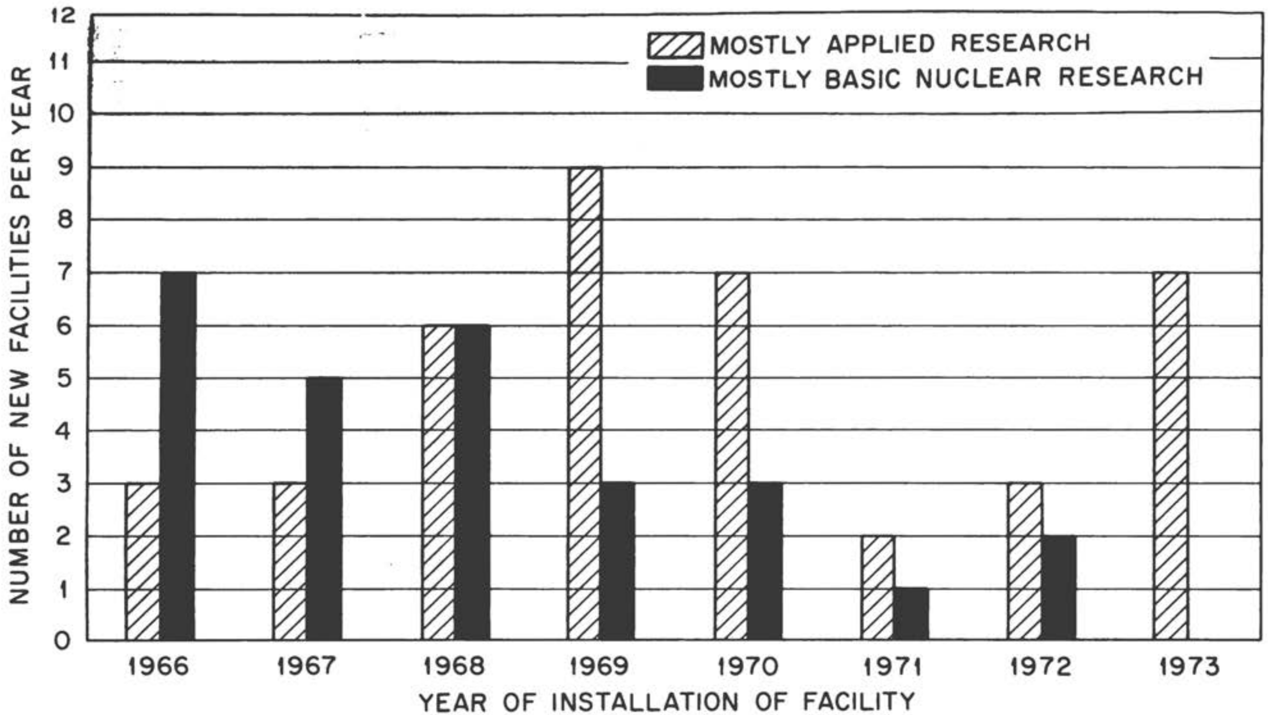

FIGURE 4 Basic and applied research facilities. A graphical illustration of data taken directly from the original questionnaires. The number of newly installed (not necessarily newly manufactured) facilities during the calendar year is shown versus the year in which the facility was installed. The shaded bars refer to facilities that at the time of the census reported at least 50 percent of their research directed toward basic nuclear science. The remaining facilities were classified as "applied research" and are shown as hatched bars.

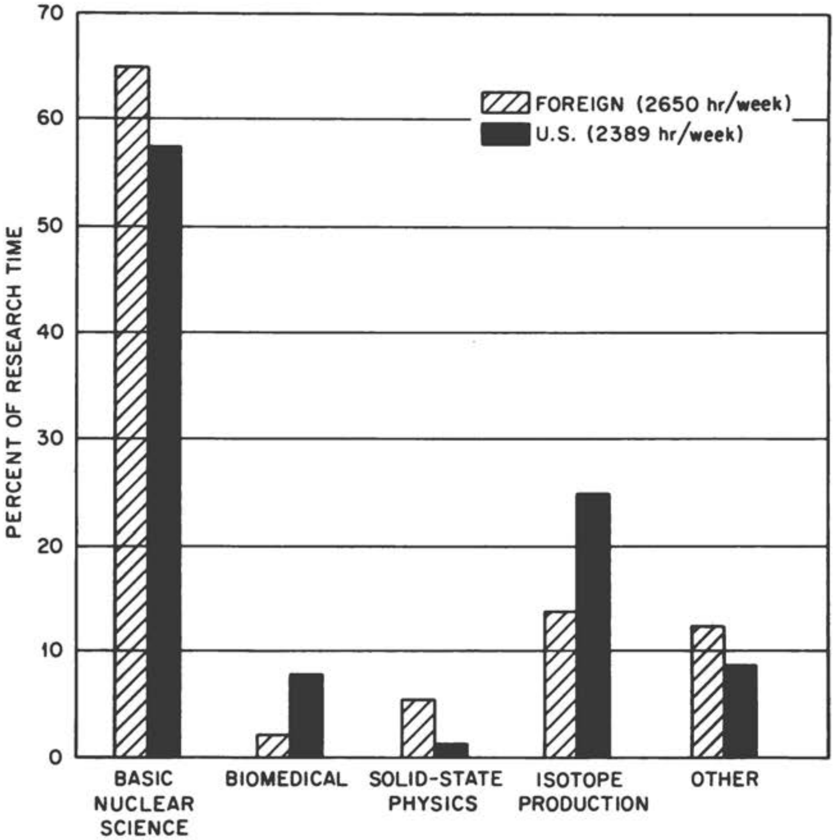

FIGURE 5 Cyclotron use. A graphical comparison between the U.S. and foreign cyclotron usage. While the vertical scale has units of percent, the total hours per week rate of accelerator usage is given in the legend.

FACILITIES

NEW FACILITIES

Facilities that became operational between 1970 and 1973 are listed in Table 2. As can be seen from this listing, approximately half the new facilities are oriented toward applied research. The five major new facilities devoted mainly to basic research are the Brookhaven National Laboratory double MP Tandem Van de Graaff, unique in that it is the highest energy (32-MeV protons) tandem presently operating; the Lawrence Berkeley Laboratory's Super-HILAC Accelerator, which has the unique capability of accelerating heavy-ion projectiles over the entire range of the periodic table to energies up to 8.5 MeV per nucleon; the Princeton AVF cyclotron (which includes an on-line isotope separator); the small T-11 tandem Van de Graaff at Ohio University, the last tandem facility to become operational; and the Los Alamos Meson Physics Facility (LAMPF), an 800-MeV proton linac internationally unique in its high energy and beam intensity.

SHUTDOWN OF OLD FACILITIES

The facilities shut down since 1969 are listed in Table 3. The rate is approximately five per year and does not differ greatly from previous years. The single-stage Van de Graaff continues to suffer the highest mortality.

GENERAL OBSERVATIONS

A comparison of the data in the 1969 and 1973 censuses clearly indicates that significant changes are taking place in basic nuclear research using particle accelerators. There is a marked shift toward research using heavier ions; the number of accelerators using projectiles heavier than ^{20}Ne more than tripled between 1969 (16) and 1973 (50). Low- and medium-energy facilities in universities are being replaced by the large regional or national facilities, organized under the user-group concept, such as the Los Alamos Meson Physics Facility (LAMPF), the Super-HILAC, the newly funded National Heavy Ion Laboratory at the Oak Ridge National Laboratory (a 25-MV tandem injecting into the existing ORIC cyclotron), the Indiana University separated sector cyclotron, and the Bates electron linac. There is also an increased emphasis on applied research using low-energy Van de Graaffs and AVF cyclotrons, as indicated in Figures 1 and 3.

One of the most notable changes is not immediately apparent from the 1973 census. Prior to 1969 the United States dominated in research using electrostatic accelerators and cyclotrons. However, since 1969 there has been a more vigorous growth abroad of accelerators dedicated to heavy-ion research. The ALICE facility at Saclay, France, has accelerated projectiles through ^{84}Kr for the past several years, and a cyclotron-injected cyclotron in Dubna, Russia, has been accelerating projectiles as heavy as ^{136}Xe. The UNILAC heavy-ion linear accelerator at Darmstadt, Germany, is just becoming operational and will accelerate ions up to uranium with energies generally in excess of 10 MeV per nucleon. A further example of the growth abroad is illustrated by the Pelletron, which represents a significant advance in high-precision, heavy-ion electrostatic accelerators; it was developed by a U.S. firm. Two Pelletrons, an 8-MV accelerator at the University of San Paulo, Brazil, and a 14-MV Pelletron at the Australian National University in Canberra, Australia, are now operational. Additional Pelletrons are now under construction for Japan and Israel. Although this U.S.-built accelerator represents an advance in technology, to date only the 25-MV tandem for Oak Ridge has been funded in this country. Thus the United States may lose its historically dominant position in low-energy charged-particle research.

GLOSSARY
DESCRIPTION OF ACCELERATORS

Abbreviation	*Identification and Energy Range*
RT	A relatively low accelerating voltage from a *rectified transformer* circuit. Typical energy range 0.1-0.5 MV. (Includes insulated core transformer types.)
e-RT	RT used to accelerate *electrons*.
CW	*Cockcroft-Walton* is a voltage multiplier device. This system is in use generally below 1 MV.
Dyn	*Dynamitron* is a potential-drop machine with a parellel-feed cascade generator usually available to approximately 4 MV.
VdG	The common electrostatic *Van de Graaff* accelerator is a potential-drop machine and typically has an energy range of 1-4 MV.
Marx Gen.	A *Marx generator* is a type of low-energy, potential-drop machine.
CN-VdG	Higher-energy VdG, 5.5 MV.
TVdG	The *tandem Van de Graaff* system typically accelerates protons to approximately 10-20 MeV.
EN-TVdG	$\approx$12-MeV TVdG.
FN-TVdG	$\approx$15-MeV TVdG.
MP-TVdG	$\approx$20-MeV TVdG.
T Dyn	*Tandem*-type (two-stage) *dynamitron* ($\approx$8 MeV).
AVF-Cyc	*Azimuthally varying-field cyclotron:* the most common orbit-type accelerators, typically in the range 20-100 MeV.

FF-Cyc	*Fixed-frequency cyclotron:* an early design with accelerating energy typically 10-20 MeV.
FM-Cyc	*Frequency-modulated cyclotron* or synchro-cyclotron: accelerates particles well into the relativistic range, approximately 400-700 MeV.
Cyclograaff	*Cyclotron* injector into a *tandem Van de Graaff* accelerates particles to the sum energy of the two systems.
Betatron	This early orbit-type *electron* accelerator produces electron beams typically in the energy range 10-30 MeV.
Synchrotron	High-energy orbit-type *electron* accelerator, approximately 70 MeV.
LINAC	*Linear accelerator* designed to provide a wide range of particles and energies.
HILAC	*Heavy-ion linear accelerator,* typically provides heavy ion energies of 10 MeV per nucleon.

AD HOC PANEL ON MANPOWER AND EDUCATION

L. Grodzins (Chairman)
Massachusetts Institute of Technology

Gordon L. Brownell
Massachusetts General Hospital

Robert A. Charpie
Cabot Corporation

Gregory R. Choppin
Florida State University

REPORT OF THE AD HOC PANEL ON MANPOWER AND EDUCATION

PREFACE

The data used in this report come mainly from three surveys. In 1973 both the American Institute of Physics (AIP) and the National Research Council (NRC) conducted extensive surveys. That of the AIP encompassed the entire membership of its constituent societies, respondents to the physics portion of the 1966, 1968, or 1970 National Register surveys who were not affiliated with any of these societies, and persons recently receiving BS, MS, and PhD degrees in physics and not included in the Register or society membership groups--in all some 70,000. The NRC Survey of Doctoral Scientists and Engineers, conducted by the Commission on Human Resources with support from the National Science Foundation (NSF), included PhD's in all sciences and engineering. Rather than surveying everyone, a stratified sample was taken. The sample included some 60,000 persons, about one fifth of the population, with heavier sampling (50 percent) of some minority groups, including women and foreign citizens.

The agreement between the AIP and NRC data on PhD physicists is generally good. A few discrepancies result from differences in definitions of categories. For example, the AIP reports, on the basis of an 85 percent response, 18,300 PhD's employed in physics in 1973; however, some 1700 of these were employed in biophysics (410), medical physics (400), chemical physics (470), and geophysics (460). These subfields are not regarded as physics subfields in the NRC survey, which finds 17,100 PhD's employed in physics. However, whether 16,600, 17,100, or 18,300 PhD's were employed in physics in 1973 is not the real issue, for even the highest of these numbers is not significantly larger than the number of PhD's employed in physics in 1968--17,600 (*American Science Manpower 1968*, NSF 69-38). The trends and findings in both sets of data are much the same and tend to reinforce one another, although absolute numbers often differ.

One major discrepancy that caused some concern was a difference of some 17 percent in the data on the number of physicists employed in federally funded research and development centers (i.e., national laboratories), the AIP indicating 29 percent, the NRC 12 percent. This discrepancy resulted largely from a difference in definition; many respondents to the NRC survey who were employed in national laboratories classified themselves as employed by academic or nonprofit institutions rather than as government employed (at federally funded research and development centers).

The third major source of data was a survey conducted by the Panel on Manpower and Education of the Committee on Nuclear Science. A questionnaire was sent to 200 professors of physics who had trained PhD's in nuclear physics. The responses of 100 of these thesis supervisors provided data on the present activity and the name of the employer of more than 1000 nuclear physicists. The principal findings of this survey were also in general agreement with those of the AIP and NRC.

Drawing on published sources, such as the *American Science Manpower* series, and these three recent surveys, the Panel developed a brief report on recent trends in the production, employment, and field migration of physics manpower in relation to other sciences and engineering and on nuclear physics in relation to other sciences and subfields of physics.

Because of statistical variability, response biases, and differing interpretations of definitions among the various sources on which this report is based, the Panel places an arbitrary 25 percent nonstatistical uncertainty on every survey-based number used here. Such uncertainties will not soften our conclusions, for the trends of importance are gross, and these trends are found in all sets of data regardless of source.

INTRODUCTION

The purpose of this report is to describe current trends in the production and employment of nuclear-physics PhD's. However, what is taking place in this subfield is but a part of broader events taking place in physics as a whole and, indeed, in most of science. The problems this subfield faces are similar to those that face most research-intensive, heavily academically based fields--stagnation in academic employment, the decline in employment in the federally funded research and development laboratories, and the severe economic pressures brought about by galloping inflation, a deepening recession, and changing missions, research emphases, and priorities in the federal funding of science.

The response to such pressures is generally to trade the future for the present--to postpone or stretch out programs, to do without needed equipment, to decrease technical and backup staff, and, finally, as economic constraints become increasingly severe or prolonged, to cut back on scientific personnel. This last stage has long since been reached in most institutions, as some of our data will show.

The number of physicists academically employed in all U.S. universities and colleges is the same in 1974-1975 as it was in 1968. (This statement is based on a yearly census. It has no statistical uncertainty and is not subject to doubt.) Although the number of professors is still increasing linearly, the number of associate professors has started to decline and the number of assistant professors has decreased 10 percent between 1973 and 1974. An additional fact is that the federally funded research and development laboratories employ less than 80 percent of the physical scientists they employed six years ago.

The static picture in academic hiring characterizes baccalaureate institutions as well as PhD-granting institutions; federal funding is not a significant factor for academic employment, which is tied to student enrollments.

Doctorate production still remains high relative to employment opportunities. Consequently, substantial migration among scientific disciplines and among subfields within disciplines has occurred. In this respect nuclear physics has displayed a particular strength, an ability to cope and to adapt, that sets it apart from many other physics subfields and, indeed, from other sciences, as we shall show in this report.

But this subfield, like all physics and all science, must address pressing questions. In a situation of aging college and university faculties, of increasing teaching loads and administrative responsibilities, and of continuing severe economic constraints:

Who will do the research needed as a foundation for progress in U.S. science and technology?

Where will the innovations, the breakthroughs, come from, if youth does not have a chance?

How can the resource of trained scientific manpower be most effectively maintained, employed, exploited--how avoid the waste and trammeling of the reservoir of talent and expertise that this country has invested so much to develop?

DOCTORATE PRODUCTION, EMPLOYMENT, AND FIELD MIGRATION IN PHYSICS AND OTHER SCIENCES

DOCTORATE PRODUCTION

Figure 1 presents data on the annual production of doctorates in all natural sciences and in biosciences, physics, and engineering from 1920 to 1970. The patterns of growth are much the same, all showing a dip during World War II (compensated by a bulge in the early 1950's) then continued rapid growth until 1969-1970, at which time a downturn in all curves is apparent. Figure 2 shows the production of physics baccalaureate degrees from 1952 to 1971. Its ordinate is linear not logarithmic as in Figure 1. The number of BS degrees in physics leveled off in the early 1960's so that the reservoir from which the PhD's are drawn has been roughly constant, declining somewhat in recent years. First-year graduate enrollment in physics (Figure 3) had reached 50 percent of the BS class in the early 1960's but is now closer to 25 percent and tracking the BS decline. Total graduate enrollment, proportional to the integral of first-year enrollments, also has been declining rapidly (Figure 3). Figure 4 presents the distribution of graduate students in physics according to support and shows that most of the decline in graduate enrollments is attributable to a decline in federal support for fellowships and research assistantships between 1969 and 1973. Teaching assistantships, however, which are supported by the schools themselves, increased somewhat.

EMPLOYMENT OVERVIEW

Paralleling the decline in graduate enrollments was the decline in academic hiring. Figure 5 brings together for

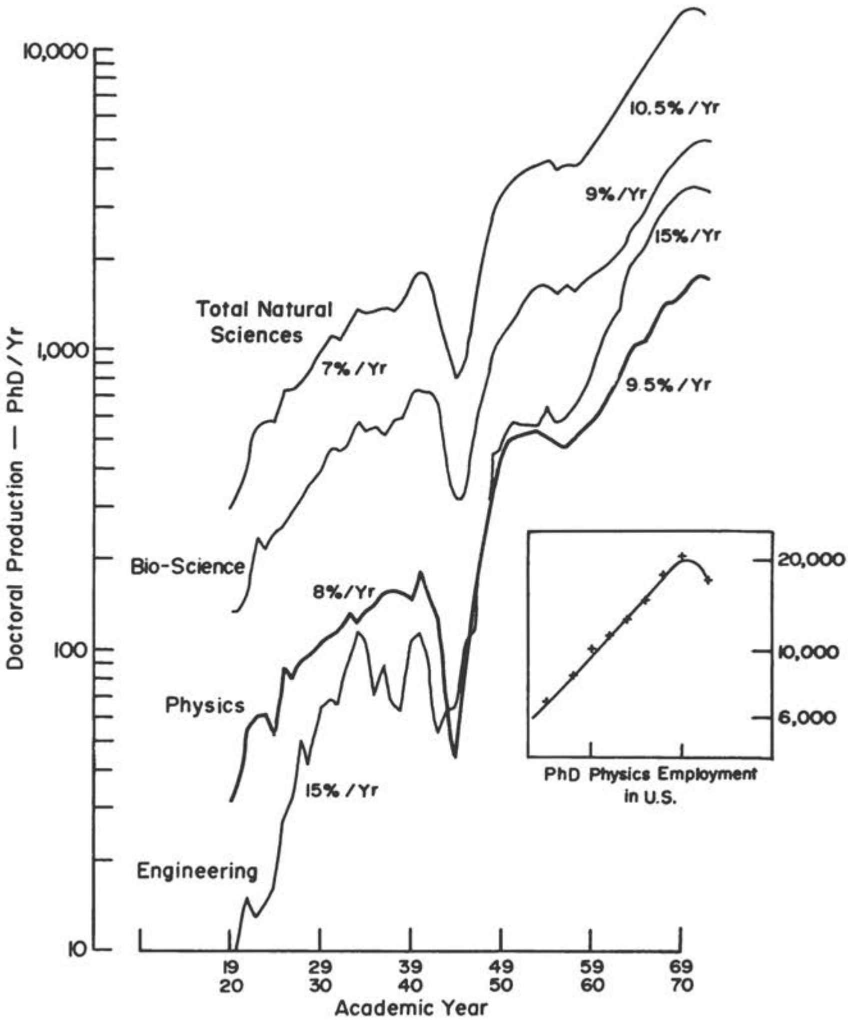

FIGURE 1 Doctoral production in various sciences from academic years 1919-1920 to 1969-1970. Source: NRC Doctorate Record File.

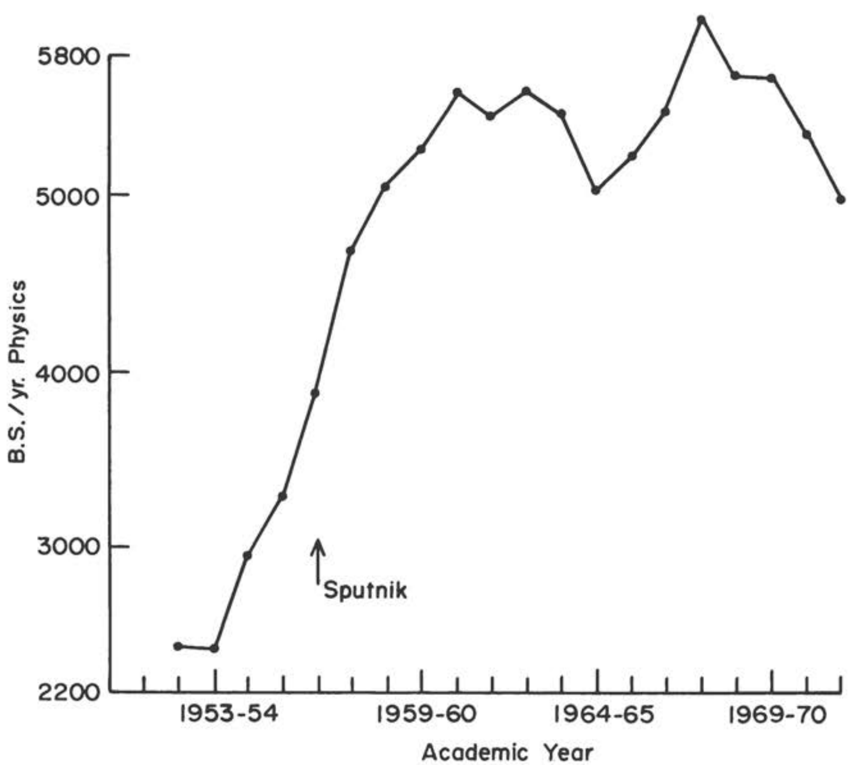

FIGURE 2 Baccalaureate graduates in physics from U.S. universities and colleges from 1952-1953 to 1971-1972 (sometimes called the anti-Sputnik graph, as some four years after Sputnik the number of physics BS's leveled off rather than continuing or increasing its rise, which would have been the case if Sputnik had inspired high school and first-year college students to become physicists). Source: AIP.

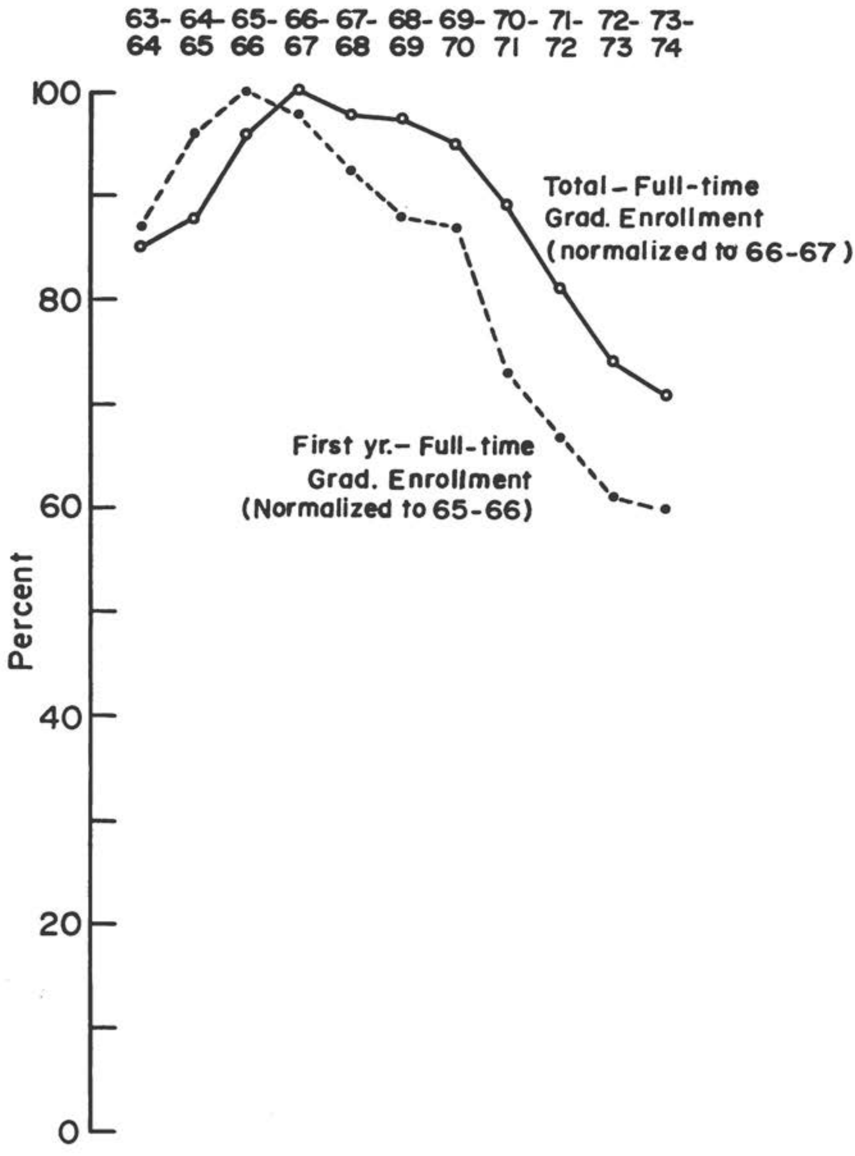

FIGURE 3 Full-time total and first-year graduate enrollments in PhD physics departments. Data prior to 1967-1968 are not based on matched departments as are data from 1967-1968 on. Source: NSF data supplied to L. Grodzins.

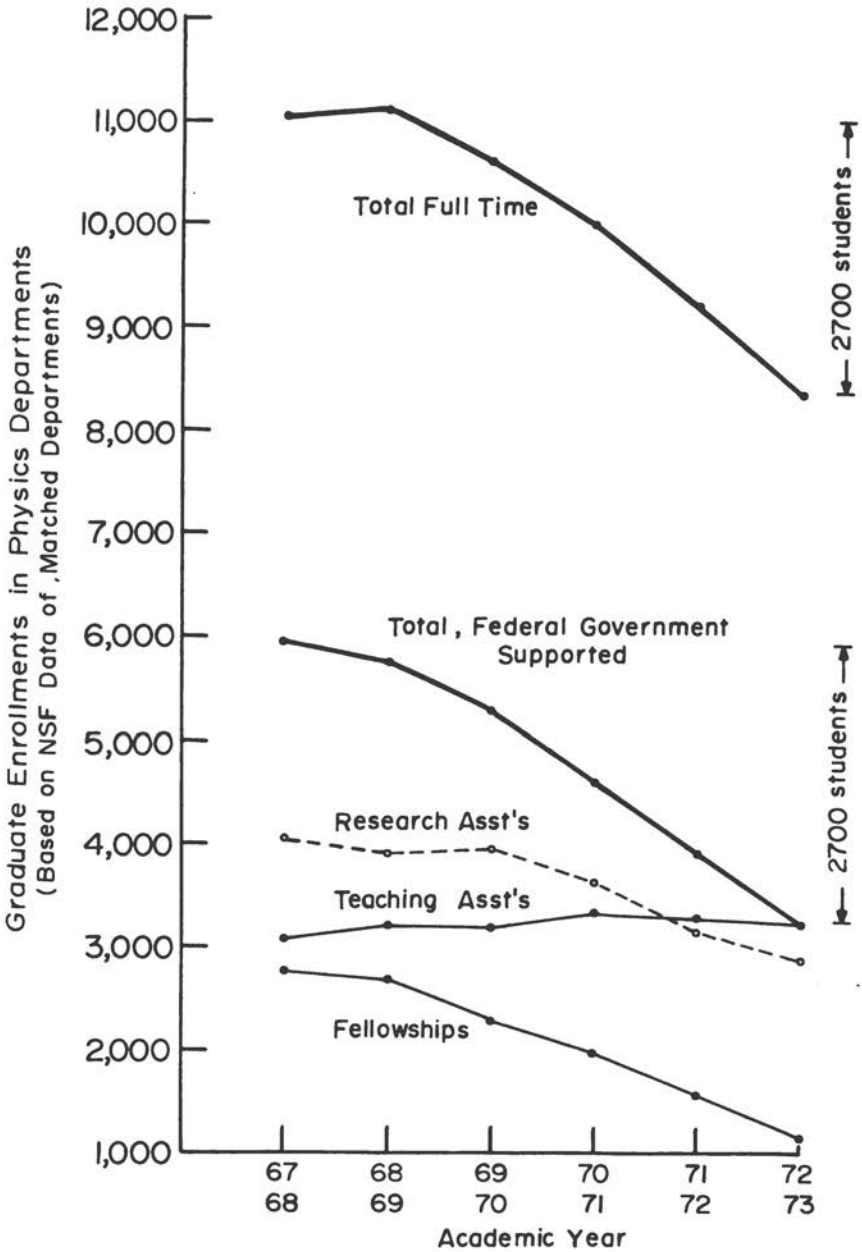

FIGURE 4 Graduate enrollments in physics departments for the years 1967-1968 to 1972-1973, separated according to support. Source: NSF data supplied to L. Grodzins.

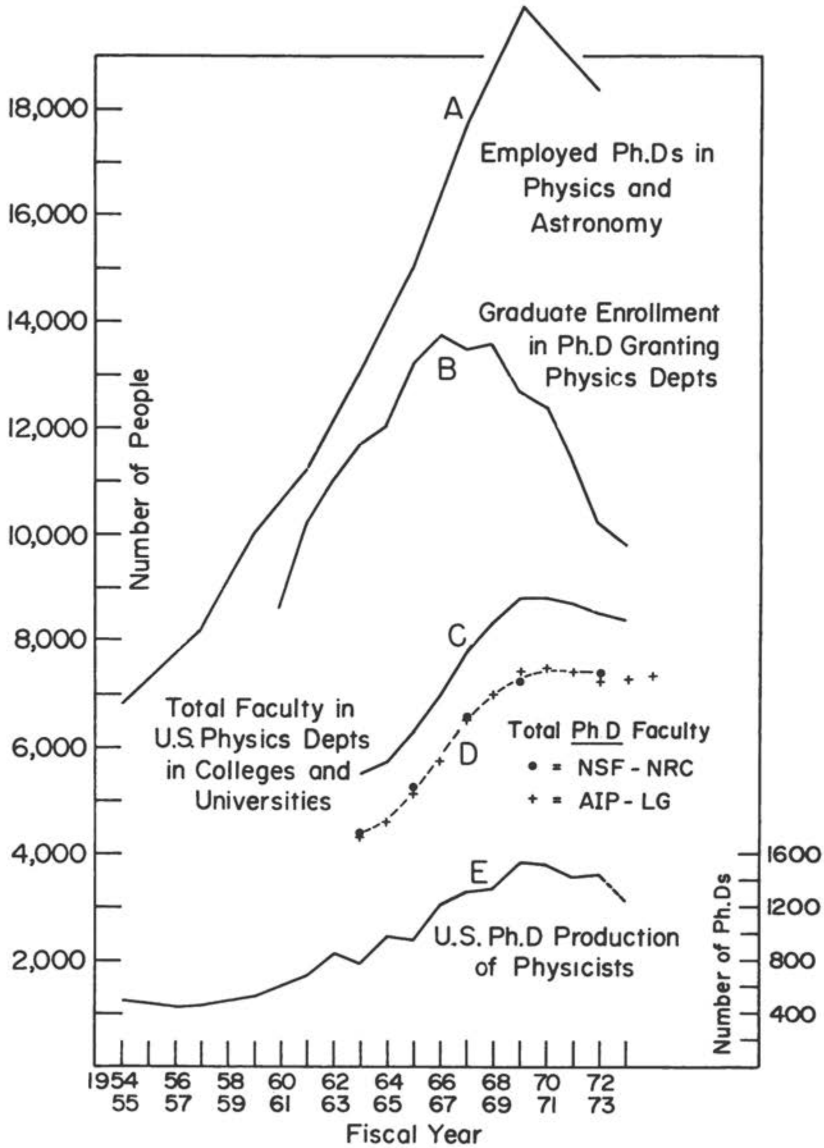

FIGURE 5 Comparative data on the production and employment of PhD physicists. Sources: NRC Doctorate Record File and Survey of Doctoral Scientists and Engineers; AIP data and survey; NSF *American Science Manpower* series; AIP *Directory of Physics and Astronomy Faculties*, published annually by AIP since 1962; and data assembled by L. Grodzins.

comparison data on graduate enrollments in PhD physics departments (curve B), total faculty employment in college and university physics departments (curve C), total employed PhD's in physics (curve A), and production of PhD's in physics (curve E) from 1954 to 1973. These data show that after a steady growth--approximately 8 percent per year--in employment of PhD physicists, a sharp drop occurred after 1969; the number of PhD physicists employed in 1973 was about the same as in 1968, some 17,000. The number of faculty in physics departments in colleges and universities was almost the same in 1973-1974 (and 1974-1975) as in 1967-1968. As curve C shows, the peak was reached during 1969-1970. Curve D, and also Figure 6, indicates that the number of PhD's on physics faculties has actually increased slightly since 1967-1968, for almost every new faculty member who was hired had a PhD, whereas many who left the faculties of colleges and universities did not. Thus the employment situation in academia has been much like that of the entire physics community.

Curves C and D go to the heart of the problem: *Academia, which employs 50 percent of the physicists and where 60 percent of the research is done, has not grown.* The acute effects of this stagnation were further amplified by the high percentages of the academically employed holding tenure. Thus the current situation in academia is characterized by a decline in the number of new faculty hirings, an increase in the number of tenured professors in response to pressures for promotion of the most desired faculty, and an increasing average age of physics faculties (about 0.5 years per calendar year).

About as many physicists received their PhD's from 1969 to 1973 as from 1960 to 1968 (or during the 20 years from 1930 to 1959). Although PhD production began to decline after 1972 (see curve E in Figure 5), the yearly production still greatly exceeds the number that can be absorbed at present by traditional physics occupations (i.e., teaching and basic research). The national laboratories, which next to the universities are most heavily engaged in basic research, cannot compensate for the lack of employment opportunities in academia; in fact, substantial decreases in size of scientific staff (thus in scientific man-years) have occurred in these laboratories. Data from the Atomic Energy Commission (AEC)* indicate at least a 20 percent decrease in scientific man-years in national laboratory programs in low- and medium-energy physics

*Now the Energy Research and Development Administration.

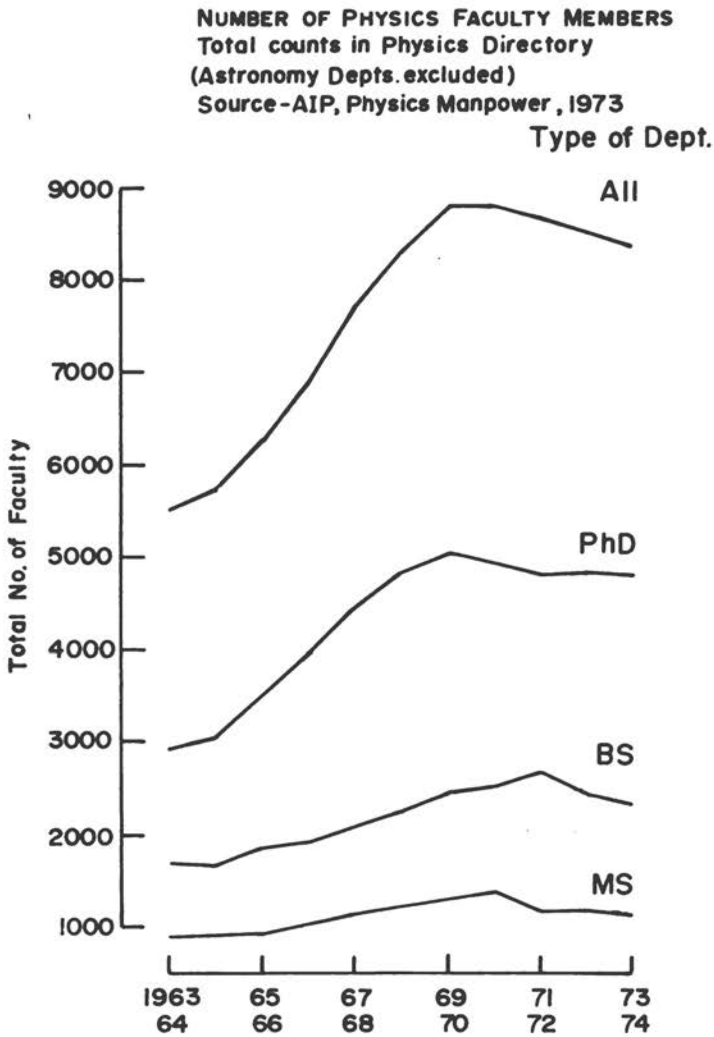

FIGURE 6 Number of physics faculty members, not including astronomy departments, based on total counts in AIP *Directory of Physics and Astronomy Faculties*. Source: AIP *Physics Manpower, 1973*.

research between 1969 and fiscal year 1975. By the late 1970's, the production of physics PhD's in U.S. universities will probably be well below 1000 per year, more than 25 percent of whom will be foreign citizens. Yet even this number might not be fully absorbed into traditional physics occupations.

ACADEMIA

The data presented in Figures 7, 8, and 9 provide additional details on the employment situation in academia. Figures 7 and 8 compare the growth patterns for various faculty ranks in physics departments in BS-granting (Figure 7) and PhD-granting (Figure 8) institutions from 1962 to 1974. The continuous increase in the number of professors, the plateauing in the number of associate professors (though occurring later in the BS than the PhD institutions), the marked decline in the number of assistant professors, and a continuing decrease in instructors and lecturers characterize both types of institution.

Figure 9, derived from a name-by-name matching of physics faculties (in the *Directory of Physics and Astronomy Faculties*, issued annually by the AIP since 1962-1963), presents an input-output diagram of faculty changes in PhD-granting departments between academic years 1972-1973 and 1973-1974. The main findings from the data in Figure 9 and similar flow charts from 1965 to 1975 are the following:

1. A rapid turnover in the junior faculty ranks. The mean length of time for the average faculty member to hold an instructorship is about two years, an assistant professorship, between three and four years, an associate professorship, between seven and eight years.
2. A sharp decline in the number of new hirings. In fall 1968, between 1100 and 1200 new faculty were hired by some 700 physics departments; most such hiring represented expansion of staff, not just the filling of vacancies created by retirement and the like. In fall 1973, only half that number was hired, most for the replacement of junior faculty. About one fourth as many associate professors were hired from outside academia in 1973 as in 1968.
3. A constant probability of promotion since 1965, defined as the ratio of the number promoted to the total number who left a particular faculty rank in a given year.

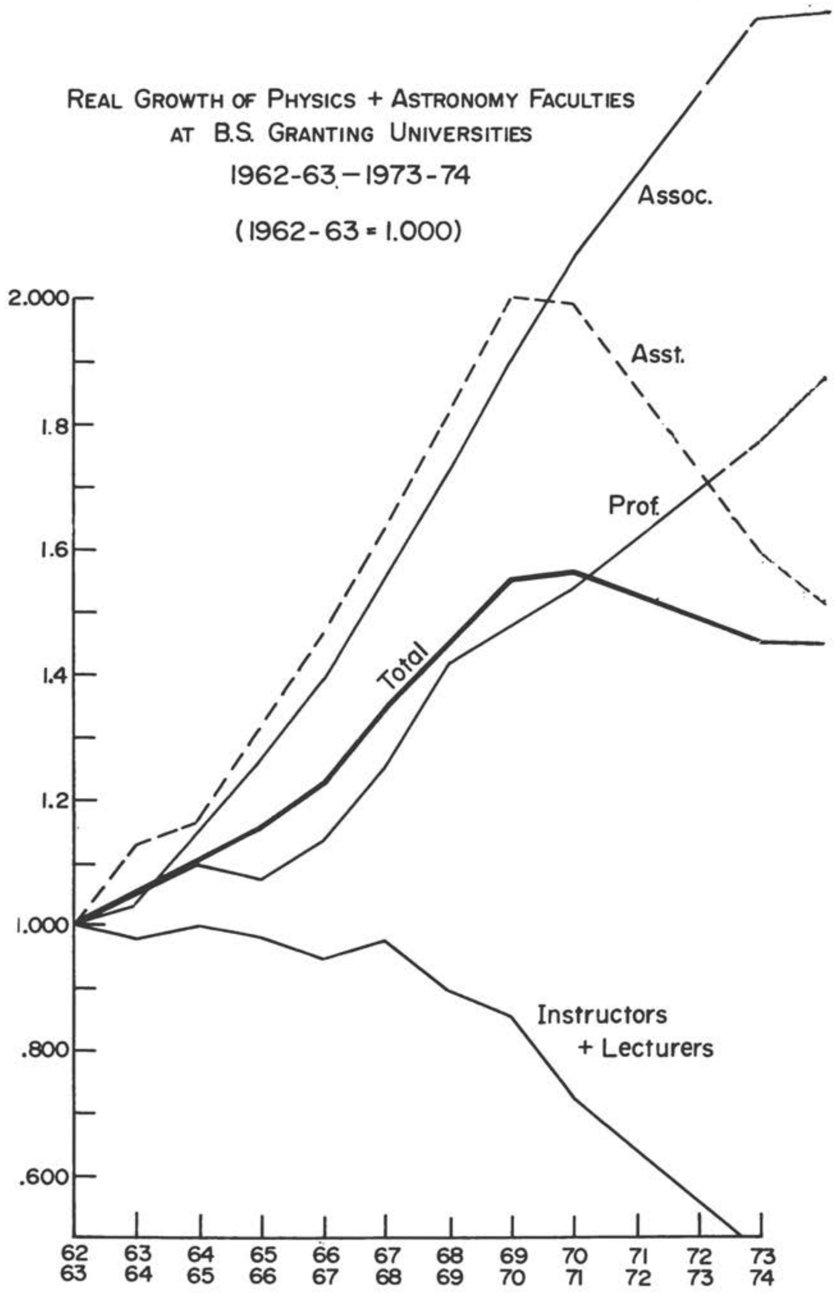

FIGURE 7 Growth of physics and astronomy faculties in institutions granting up to a BS in physics. Source: AIP Directories of Physics and Astronomy Faculties.

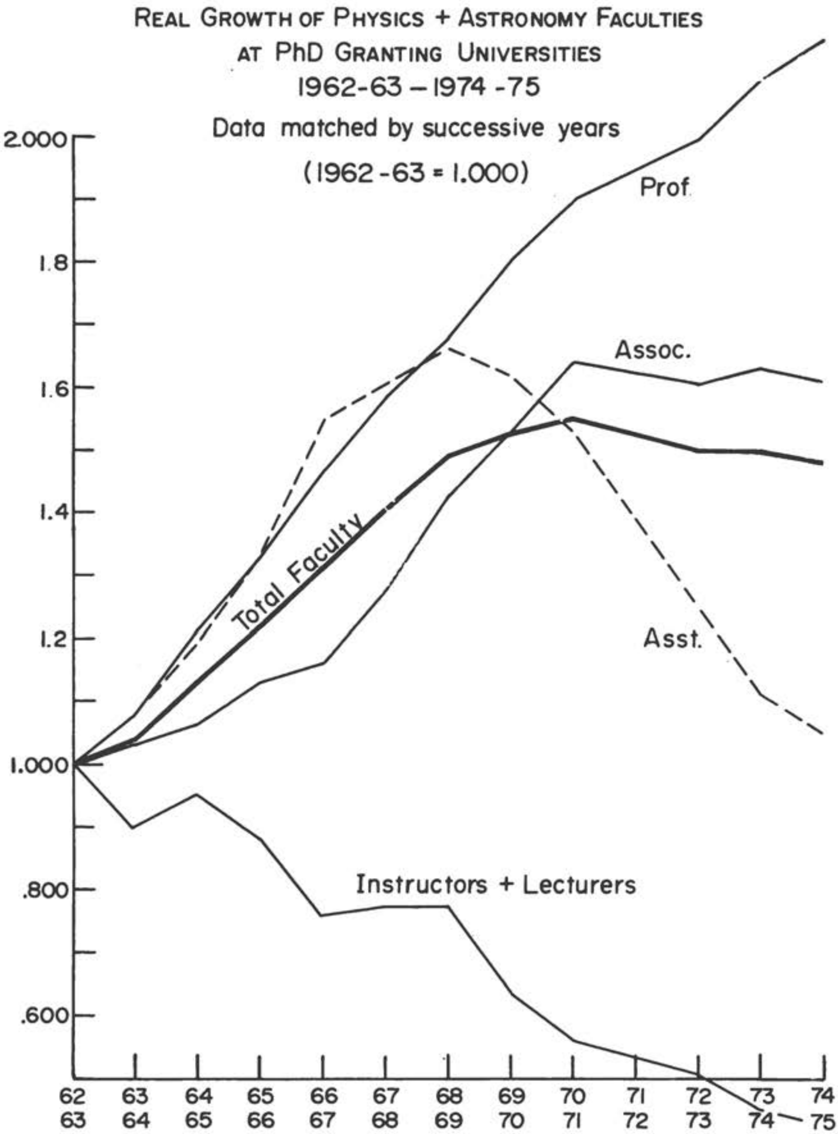

FIGURE 8 Growth of physics and astronomy faculties in institutions granting the PhD in physics. Source: AIP Directories of Physics and Astronomy Faculties.

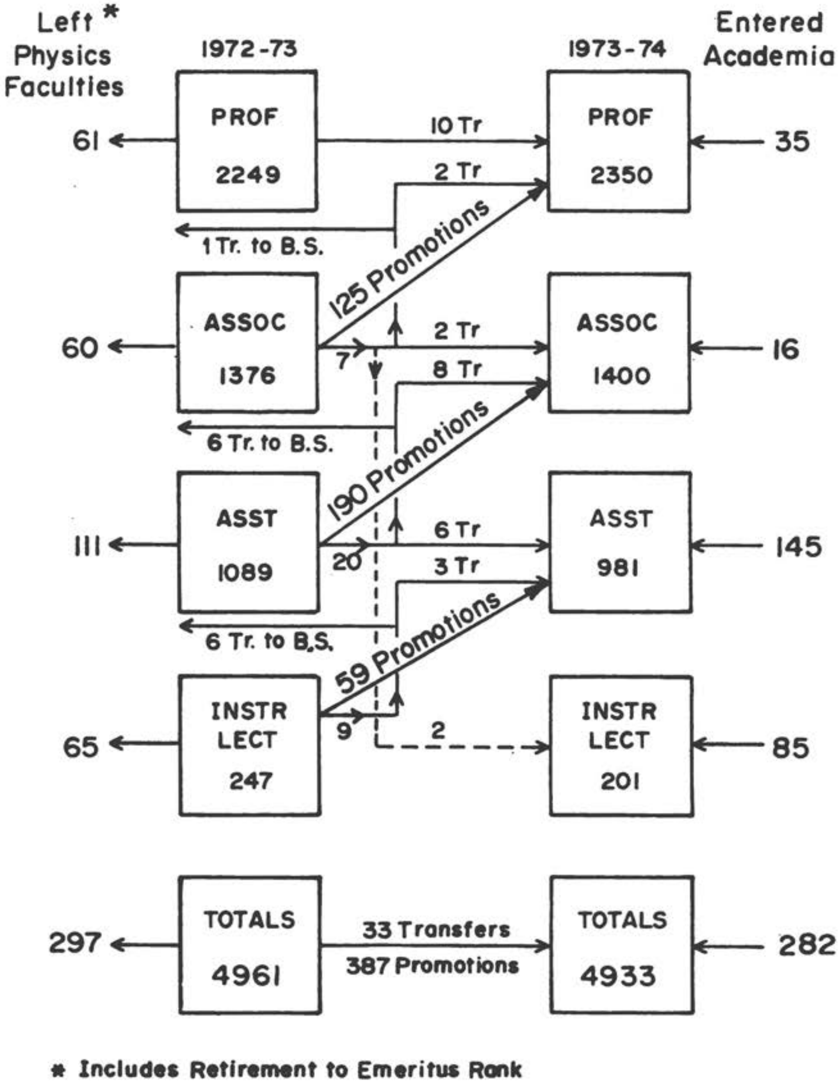

FIGURE 9 Faculty migration in physics PhD-granting departments (176 schools included). Source: AIP Directories of Physics and Astronomy Faculties.

Although probabilities vary widely among institutions and depend strongly on time, the averages do not vary greatly between PhD-granting and BS-granting institutions, being one out of two for promotion from assistant to associate professor and three out of four for promotion from associate to full professor. Obviously, such high average probabilities for promotion cannot be sustained if faculty sizes do not grow.

To summarize, the number of professors is still increasing linearly; the number of associate professors has leveled off; the number of assistant professors in 1974 was the same as in 1963, showing a sharp (50 percent) decrease since 1968; and the number of postdoctoral appointments in physics dropped 10 percent from 1973 to 1974 [shown by data (not documented here) from the NSF].

4. Low likelihood that a physicist who does not obtain tenure in the department in which he begins working will remain in academia. In the mid-1960's the probability, for all PhD-granting institutions, that an assistant professor who was not promoted would find a faculty position in another school was about two out of five (among the ten most prestigious schools the odds were three out of four); by the early 1970's these odds had dropped to one in ten for all PhD-granting schools (and one in four for the ten most prestigious schools). Those physicists who are not promoted to tenure are generally in their mid-30's, have little experience outside universities and basic research, and have close personal ties to the place where they have been working. It is difficult for this talented group who have seldom suffered failure to find suitable employment in traditional physics jobs.

FIELD SWITCHING

The high rate of production of PhD's in physics during a period of decline in employment of PhD's resulted in a substantial exodus of physicists from traditional areas of physics and even from physics itself. Each physicist has had to plot his own course through largely uncharted border areas between scientific fields to obtain a position of intellectual equity with his original expectations. Although there are many examples of aborted careers, lost ambitions, and underemployed talents, the overwhelming proportion of physicists who have faced the employment crisis of the past few years have found such positions. A major purpose of this report is to describe this successful interfield migration.

Physics, of course, is not the only field that is experiencing such migration and field switching. Figure 10 compares the outward with the inward migration of the broad fields of science, including engineering; migration to the nonsciences is included in these figures. Chemistry, physics, social sciences, and biosciences currently are experiencing a greater outward migration of PhD's they produce into other fields than an inward migration of PhD's from other fields. Psychology and engineering have an approximately equal number entering and leaving; mathematica sciences and earth sciences have greater numbers of PhD's entering than leaving. Figure 11 compares the inward with outward migration for the subfields of engineering; those subfields of greater inward than outward migration are nuclear engineering, operations research, electronics, and aerospace engineering.

There is substantial interaction between physics and engineering. The flow between the fine fields of these disciplines is shown in Tables 1 and 2, which indicate the number of scientists and engineers who have switched to a field of employment different from that of their PhD. (The data, from the NRC Survey of Doctoral Scientists and Engineers in 1973, although listed to the nearest person have large nonstatistical errors. All numbers should be assigned 25 percent uncertainties. Numbers under 20 should be considered to have uncertainties of a factor of 2.) The data show that the flow of engineering PhD's into elementary-particle and nuclear physics (Table 1, column 3) is zero; however, the flow of nuclear-physics PhD's into engineering (Table 2, column 5) constitutes 12 percent of the total switching from physics to engineering.

Figure 12 is a comparison of the primary work activities of persons who have remained in the field of their PhD and those who have switched to another field of science or to engineering. For example, those who obtained a PhD in physics and are employed in physics are more heavily engaged in teaching (by a factor of 2) and basic research (by a factor of 3) and less involved in management (by a factor of 2.5) and industrial work (by a factor of 2) than is the case for those PhD's from physics who are now employed outside of physics. This trend is characteristic of management activities in all fields of science; that is to say, those who switch fields tend more often to be employed in management positions than those who remain in the field

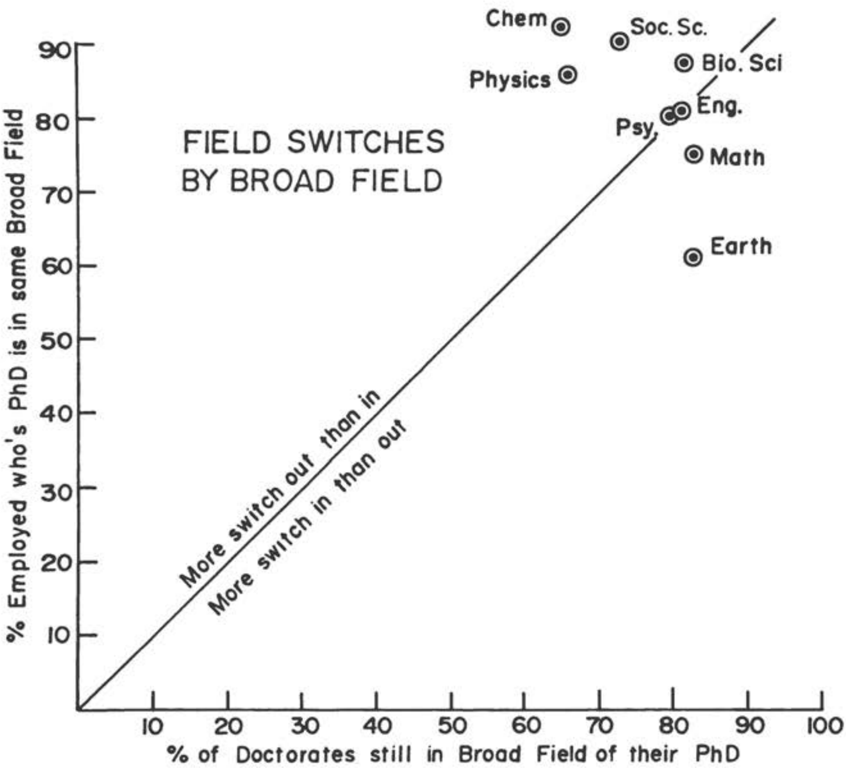

FIGURE 10 Outward versus inward migration for various sciences. Source: NRC 1973 Survey of Doctoral Scientists and Engineers.

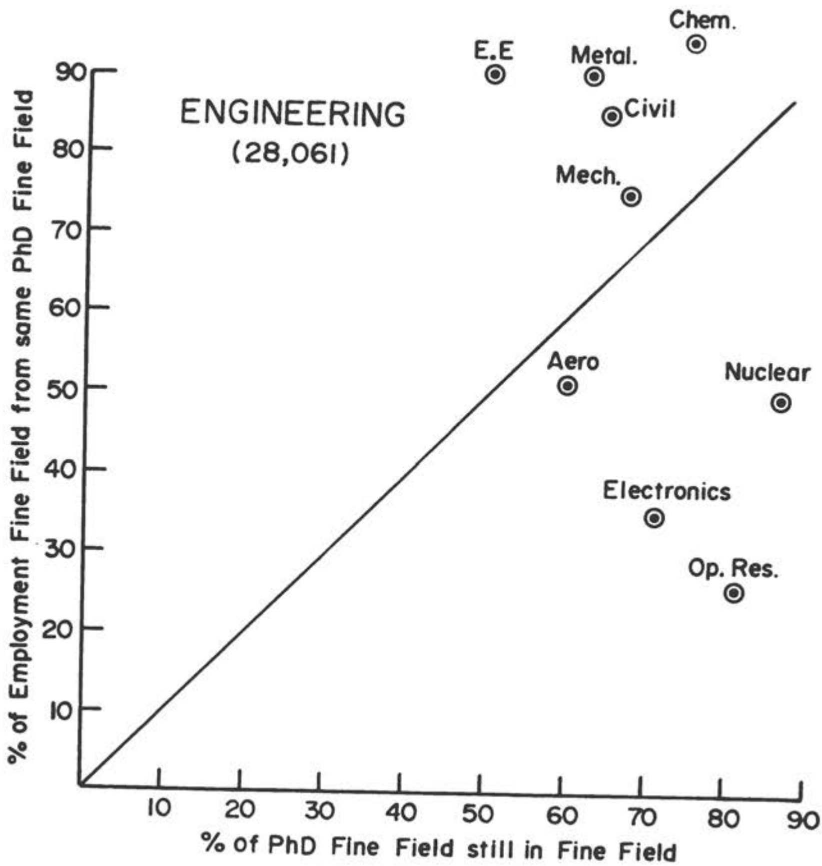

FIGURE 11 Outward and inward migration among subfields in engineering. Source: NRC 1973 Survey of Doctoral Scientists and Engineers.

TABLE 1 Engineering PhD's in Physics

Engineering Subfield of PhD	Physics Subfield of Employment: Astronomy	Atomic and Molecular	Elementary Particles and Nuclear	Thermal	Acoustics	Fluids and Plasma	Optics	Solid State	General and Other	All Physics Subfields
Aerospace	11				11	96	15		47	180
Chemical				7	9	9	8	6	11	50
Electrical	40				55	54	64	60	13	314
Electronics	12	5			7		30	33	10	100
Engineering mechanics					18	18			47	83
Engineering physics	5					23		25	11	102
Mechanical				20	33	72		10		145
Civil										
Ceramic										
Industrial										118
Nuclear										
Metallurgical										
Materials science										
General and other					31	4		11	21	75
All engineering subfields	68	9	0	43	164	273	144	203	152	

TABLE 2 Physics PhD's in Engineering

Engineering Subfield of Employment	Physics Subfield of PhD									
	Astronomy	Atomic and Molecular	Electron and Magnetism	Elementary Particle	Nuclear	Solid State	Fluids and Plasma	Mechanics Acoustics Optics Therm	General and Other	All Physics Subfields
Aerospace	8			1	7	5			22	55
Biomedical		5			8	19	23		21	96
Electrical		21		23	32	52			59	198
Electronic	10	65	71	45	2	156	25	7	252	633
Nuclear				41	120	20	14	11	99	305
Engineering physics		43		9	43	161	39	30	193	518
Mechanical		10	29		6	1	8		25	79
Metallurgy		12				37			2	51
Operations research		15	10	18	32	65	14	30	54	250
Materials science		2			11	158			19	190
General		42		6		17	11	18	31	125
Other		4		2	52	33	22		41	159
Chemical										
Ceramics										
Industrial										
Engineering mechanics										
Petroleum										
Sanitary										
All engineering subfields	18	228	121	155	327	741	155	104	982	2756

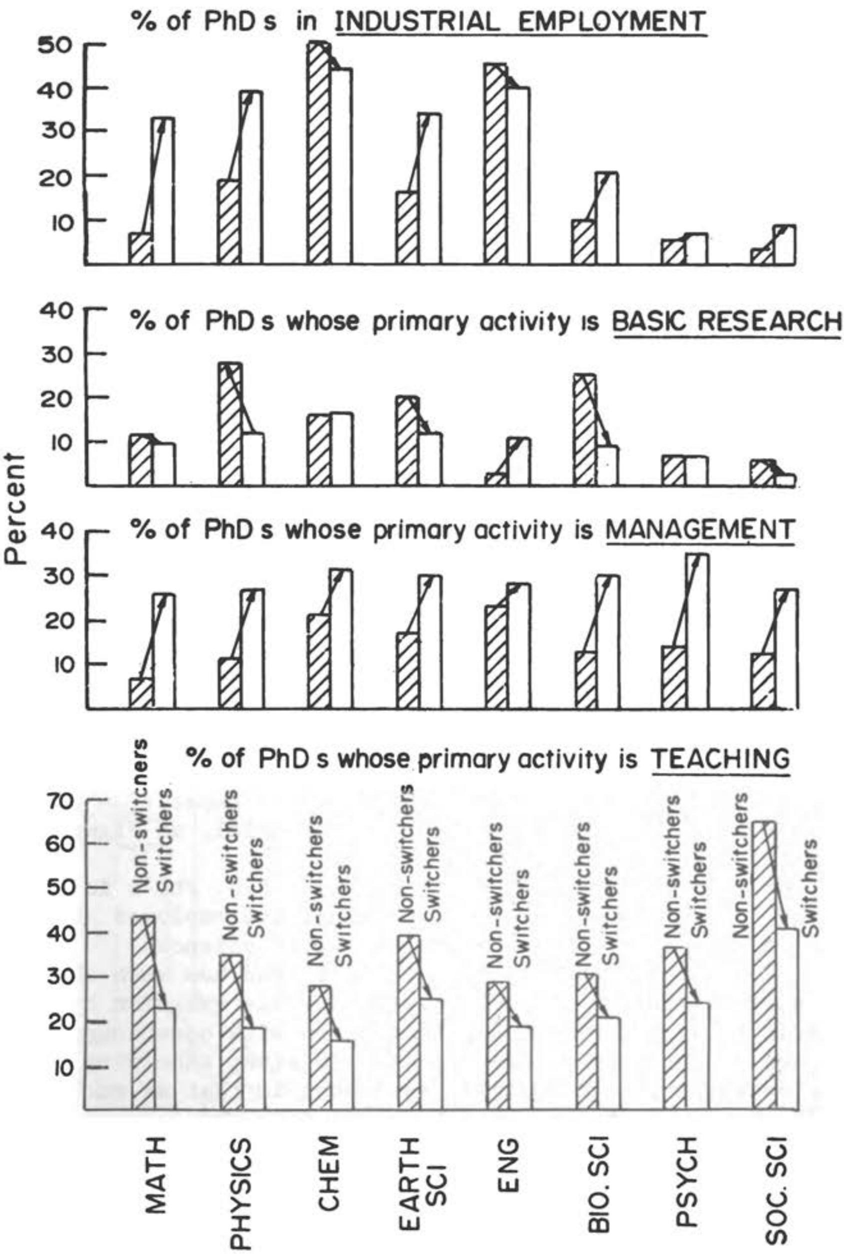

FIGURE 12 Comparison of degree of involvement in various work activities between those who have remained in the field of their PhD and those who are employed in a field different from that of the PhD. Source: NRC Survey of Doctoral Scientists and Engineers.

of their PhD. In all fields except chemistry and engineering, applied industrial work is more frequent among field switchers than among nonswitchers. The only gross anomaly in the trends is in engineering; those who have switched from engineering fields (mainly into physics) are more heavily engaged in basic research activities than those who did not switch.

Figure 13 shows the fields of employment of 7115 persons who received a PhD in physics from 1968 to 1972. More than one fourth (27 percent) were employed in fields other than physics. Of these 1931 PhD's, nearly two fifths (38 percent) went into engineering; 17 percent went into employment fields having no physical-science content, and 16 percent went into earth-science fields.

Twelve percent of those who entered physics employment during this interval had received their PhD's in other fields, principally (64 percent of the 732 entering physics from other fields); 13 and 12 percent, respectively, had received their PhD's in non-physical-science fields and in chemistry.

Figure 14 shows the employment sectors in 1973 for the 23,000 persons who had received doctorates in physics from 1930 through June 1972. It also shows the PhD origins of the 17,000 who were employed in physics in 1973, 2400 of whom entered from other fields, chiefly engineering and chemistry. Inward migration, especially from chemistry, has decreased sharply in recent years, but competition from engineering fields continues to be substantial, as Figure 13 shows.

Figure 14 also indicates that 1200 U.S. PhD's in physics, half of whom are U.S. citizens, are employed abroad, and that some 1000 physics PhD's have left science.

How much field migration is real, and how much is only name switching? The Panel studied this question by comparing survey response questionnaires with questionnaires returned by the same people immediately after receiving their doctorate. Our initial assessment is that as much as 80 percent of the recent migrations into physics may be *pro forma*, for example, engineering PhD's whose PhD thesis work really was physics and who subsequently found employment in physics without actually changing fields. However, about 80 percent of those who said that they had left physics and were working in other fields clearly did switch--nuclear-structure physicists now doing development work in medical technology, plasma physicists now working in oceanography, high-energy physicists now in operations research, physicists from a variety of subfields now working in computer sciences.

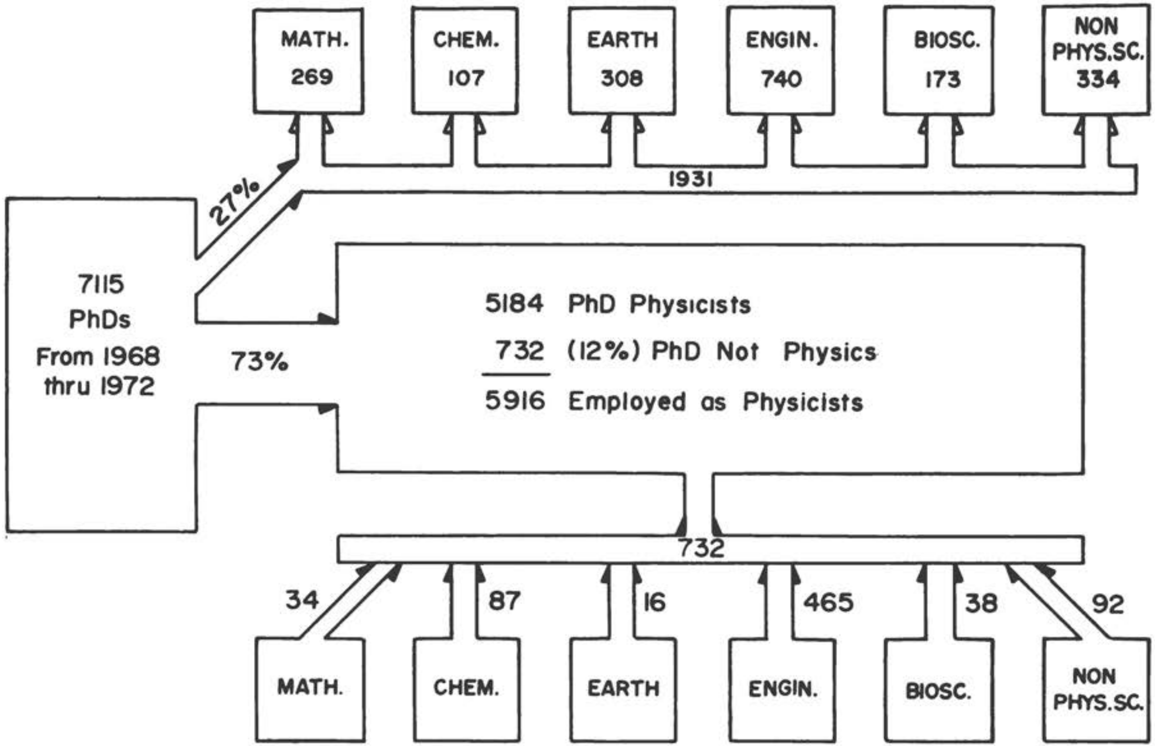

FIGURE 13 Flow of 1968 through 1972 PhD's in physics into physics and nonphysics employment, and the flow into physics of PhD's received during this same interval in fields other than physics. The figure does not include data on those not employed in sciences, unemployed, and working abroad. Source: NRC Survey of Doctoral Scientists and Engineers.

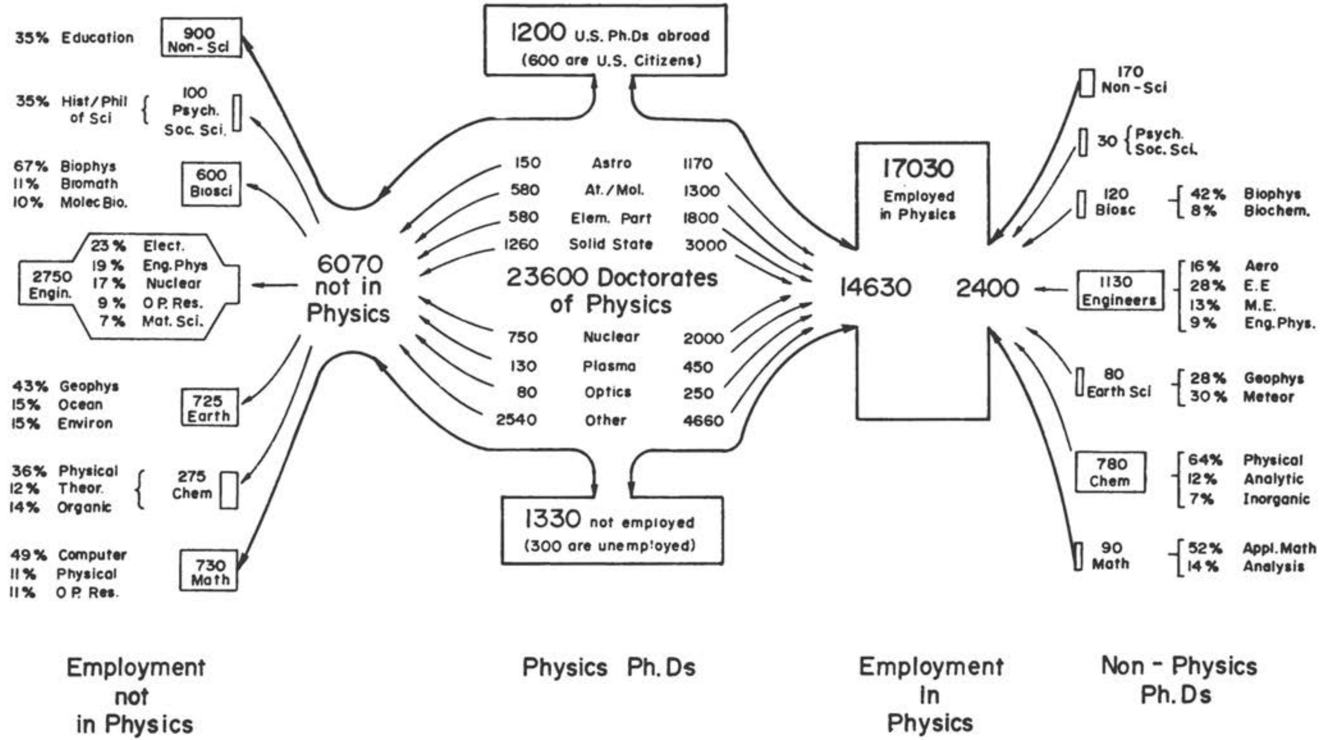

FIGURE 14 Physics employment 1973. Source: NRC Survey of Doctoral Scientists and Engineers; also AIP survey data and panel data.

The 20 percent of apparent-but-not-real switchers are principally those who did nonphysics theses under physics department auspices. (The *pro forma* field switchers are not factored out of Figure 14.)

MISMATCH BETWEEN TRAINING AND OPPORTUNITY

The Doctorate Record File provides comprehensive data on the subfield of thesis work; the 1973 NRC survey correlates that information with data on the primary work activity and employment sector.

In Figure 15 the distribution of subfields of physics theses is compared with the distribution of subfields of employment in applied research and industry. It is not surprising to find that 12 percent of all PhD physicists did their theses in elementary-particle physics, which is not a subfield of work reported by those respondents in industry. Conversely, optics is one of the major fields of physicists in industry but is the field of thesis study of only a small percentage of physics PhD's.

The correlation between thesis subfields and subfields of employment in universities is shown dramatically in Figure 16. The thesis distribution is for the five-year period, 1969-1973, obtained from the Doctorate Record File. The correlation is essentially complete; the correlation function $r = 0.94$. The comparison between thesis subfields and the subfields in industry (indicated by crosses in Figure 16) shows no correlation. Indeed, if one excludes the point for solid-state physics, there is a slight anticorrelation.

The conclusions of Figure 15 and 16 apply to most fields of science. Students are trained in the research interest of the university faculties. There is little correspondence between the distribution of such fields and the distribution of fields represented by scientists engaged in applied research and employed by industry. Yet it is largely to applied research and to industry that one must look for growth in employment of scientists in the coming decades.

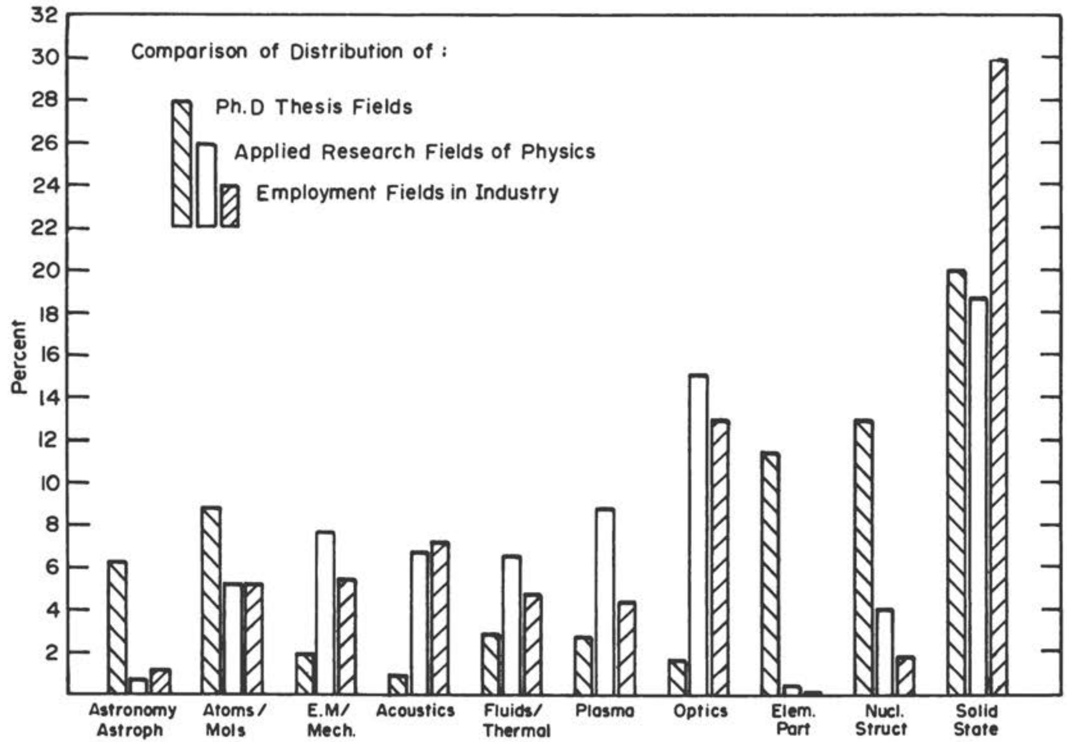

FIGURE 15 Comparison of distribution of subfields of PhD theses with distribution of subfields reported as most closely related to their work by physicists engaged in applied research and physicists employed by industry. Source: NRC Survey of Doctoral Scientists and Engineers.

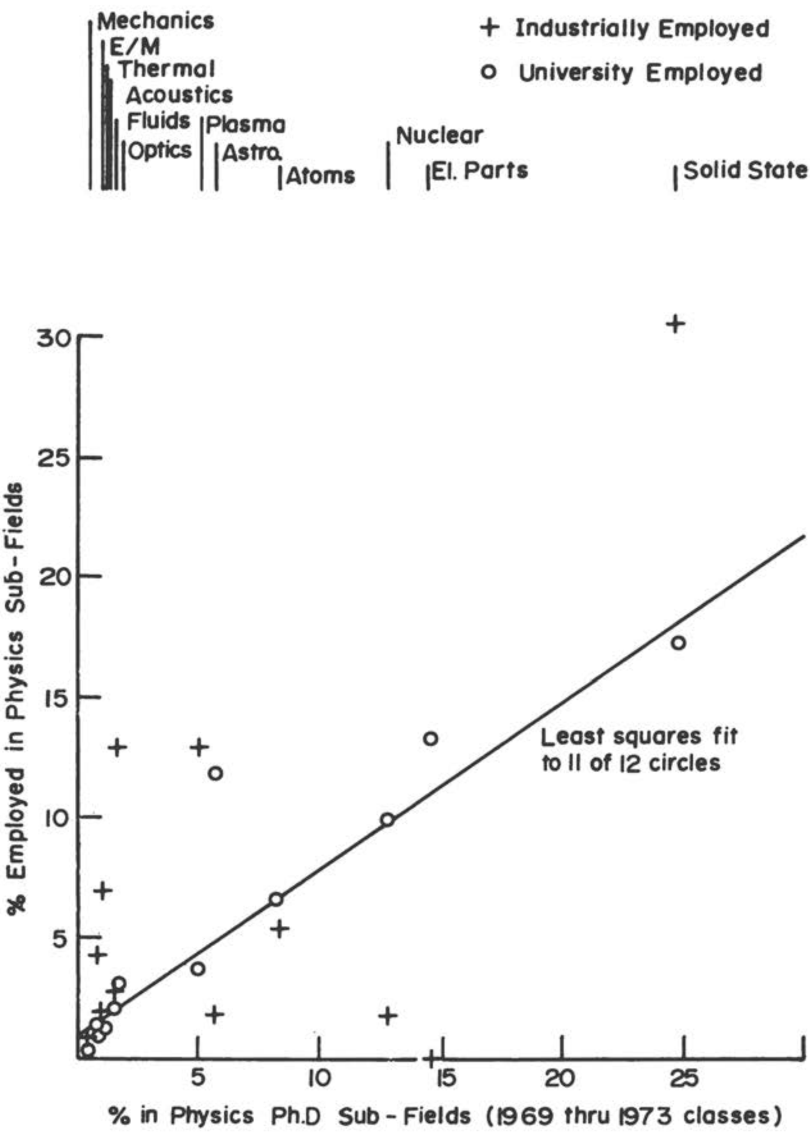

FIGURE 16 Correlation between subfields of PhD and subfields of employment.

EMPLOYMENT TRENDS IN NUCLEAR PHYSICS

TRENDS

The employment patterns in different subfields of physics differ. Emerging fields (quantum optics) and rejuvenated fields (acoustics) continue to grow, while the more traditional fields tend to show substantial outward migration. Nuclear physics, with some 70 percent of its population employed in academic institutions or in national laboratories, neither of which has grown, and with some 85 percent engaged in basic research or teaching, has had more outward mobility than any other subfield of physics.

The capability of nuclear physicists to adapt and apply their knowledge and expertise to a variety of contexts and problems is a special strength of this subfield. More than 70 percent of those who obtained PhD's in nuclear physics are not currently working in this subfield; in fact, the number of nuclear-physics PhD's who remain in nuclear physics has decreased by some 25 percent in recent years. We shall briefly discuss these trends and their implications.

The production of doctorates in nuclear physics since 1968-1969 has declined only slightly in relation to PhD production in other physics subfields. Nuclear-physics PhD's constituted slightly more than one tenth (11 to 12 percent) of the total annual PhD physics output from 1968 to 1972, as Figure 17 shows. (Data from the 1973 NRC survey indicate that nuclear-physics PhD's comprised 13.5 percent of all employed physics PhD's.)

The Panel's survey of professors who have trained PhD's in nuclear physics yielded the data in Figure 18 on the employment in 1973 of 540 PhD's in this subfield who received their degrees between 1960 and 1973. A striking finding is the large number of those graduates since 1970

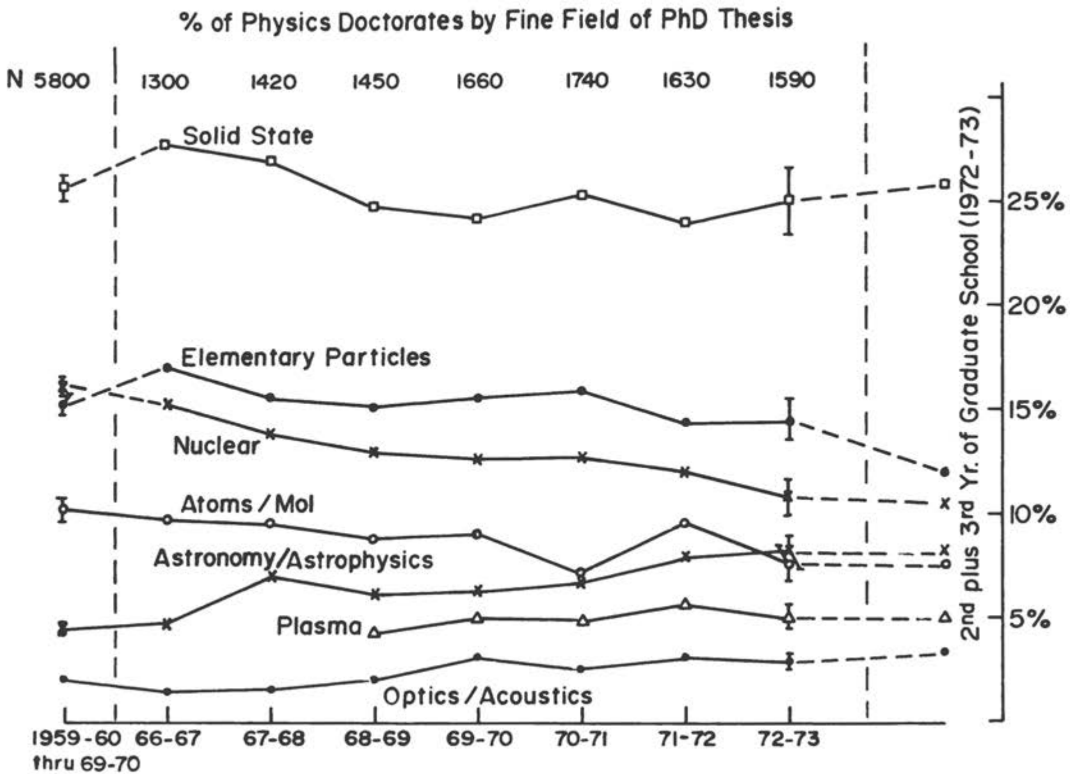

FIGURE 17 Distribution of physics PhD thesis majors by year. Sources: NRC Doctorate Record File; data for the distribution of research fields of graduate students during the year 1972-1973 were provided by the AIP.

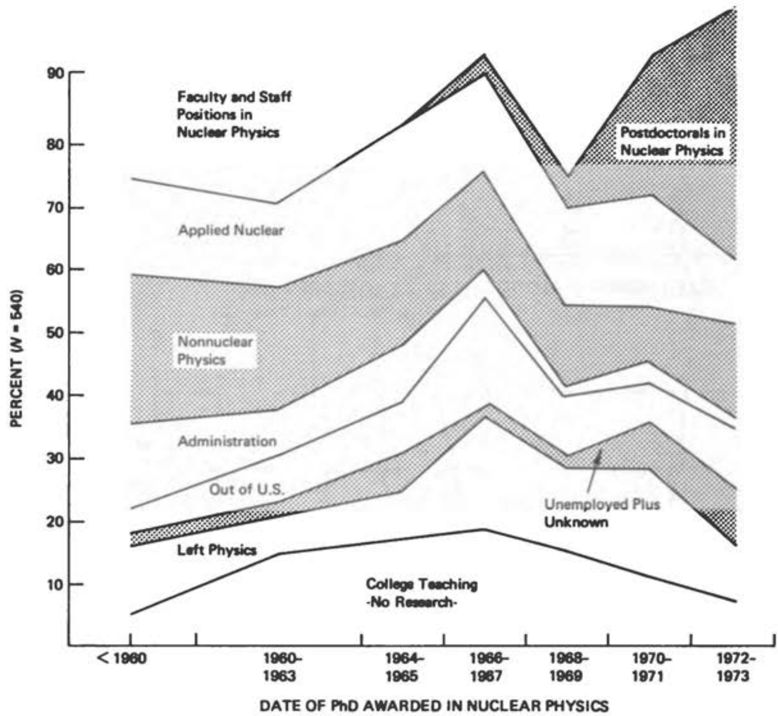

FIGURE 18 Employment fate of 540 recently graduated nuclear physics PhD's. Source: Survey of Panel on Manpower and Education, L. Grodzins, Chairman.

who continue to hold postdoctoral appointments (evidence of the "holding pattern" discussed in the 1971 report of the Physics Survey Committee, *Physics in Perspective*). A substantial proportion of the annual PhD output of nuclear physicists has migrated to nonnuclear physics subfields; the largest percentages are doctorates from the 1964-1970 classes who failed to find tenured positions in academia.

Figure 19, based on the NRC survey, gives an overall flowchart on the employment of nuclear-physics PhD's. Equivalent percentages remained in nuclear physics (30 percent) and migrated to other physics subfields (31 percent). One fourth migrated to other fields, principally engineering. Only 4 percent left science altogether, and less than 1 percent was unemployed and seeking employment.

This figure also shows that nuclear physics receives a substantial influx from other physics subfields. Of the nearly 1300 PhD's employed in nuclear physics in 1973, more

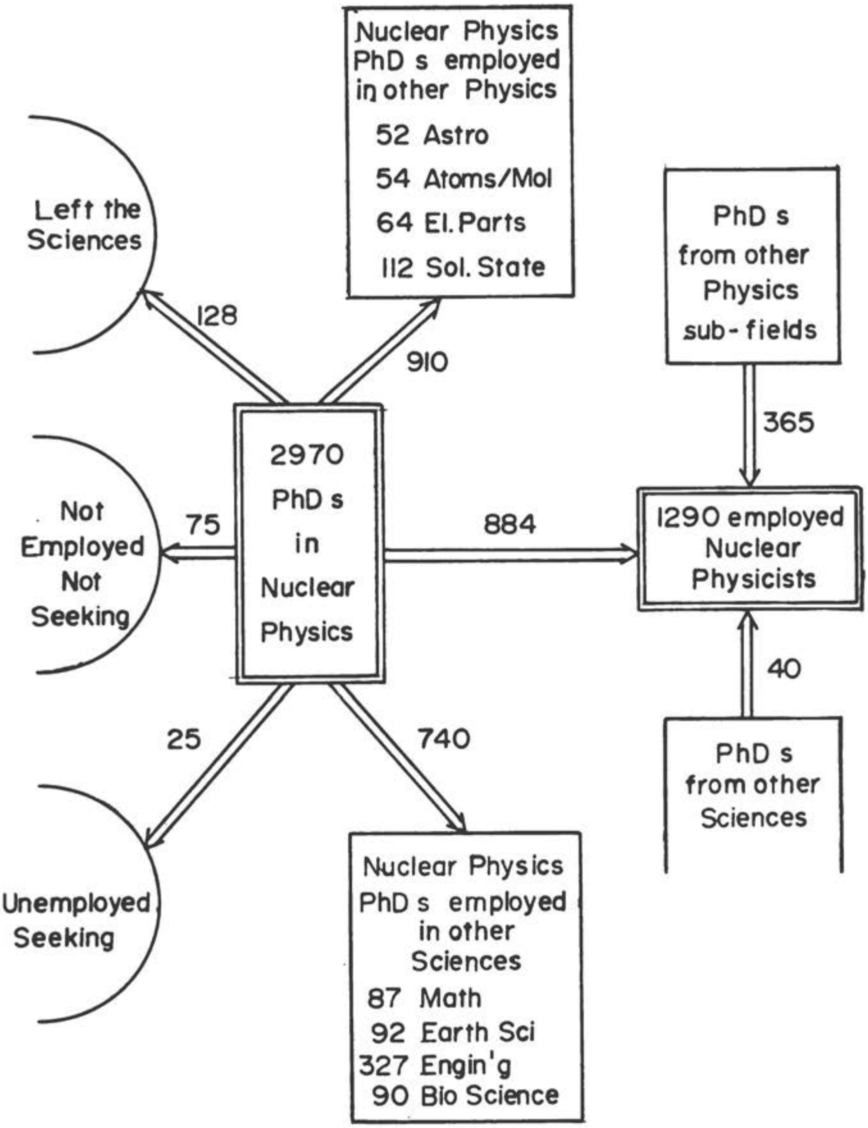

FIGURE 19 Employment of nuclear-physics PhD's and the flow of PhD's from other subfields and other sciences into nuclear-physics employment. Source: NRC Survey of Doctoral Scientists and Engineers.

than one fourth received their highest academic degrees in other physics subfields.

Table 3 is a matrix showing the flow between the subfield of PhD and subfield of employment in physics; nuclear-physics PhD's who switched from physics to other fields have been excluded. The percentages in the rows labeled H indicate those who received PhD degrees in a particular subfield; those in the rows opposite V indicate the percentages employed in a given subfield. When we look at the cell in which the nuclear structure row and column intersect, we find that only 45 percent of those who received PhD degrees in nuclear physics, and are still in physics, were employed in this subfield in 1973; however, of those employed in nuclear physics in 1973, 71 percent had obtained their PhD's in this subfield.

Figure 20 provides yet another perspective on nuclear-physics employment. Here, the "university" category includes those in national laboratories who claimed to be employed in academia. For two sectors of employment, university and industrial, and for four types of principal work activities, basic and applied research, teaching, and management, the bars of the graph show the involvement of six groups: nuclear-physics PhD's employed in nuclear physics, other PhD's employed in nuclear physics, nuclear-physics PhD's employed in other physics subfields, all employed nuclear-physics PhD's, and nuclear-physics PhD's employed in neither nuclear physics (group E) nor physics (group F). The most striking conclusion from these comparisons is that as the nuclear-physics PhD's migrate further away from nuclear physics, the less likely they are to be employed in a university or to be working in basic research and the more likely they are to be in management and to be in industry.

The figure shows that university employment is substantially greater than industrial for all six groups, and that it is greatest for nuclear-physics and other PhD's working in this subfield, the percentages for these two groups being equal. Industrial employment is greatest among nuclear-physics PhD's not employed in nuclear physics or even in physics. Basic research involvement is greatest for the nuclear-physics PhD's employed in nuclear physics, as might be expected, and declines progressively for the other five groups, being least among the two groups not employed in this subfield or in physics. These groups both show the heaviest involvement in applied research and management. The nuclear-physics PhD's not employed in

TABLE 3 Comparison of the Distribution of Physics PhD's among Subfields of Doctorate and among Subfields of Employment

Employment Fine Fields

Ph.D. Fine Fields		ASTR/ PHYS	ASTRO NOMY	ASTRO PHYS	A/M	ACQUS & EM	F & PL	OPTICS	ELEM PART	NUCL STRUC	SOLID STATE	GEN	OTHER
		14,633 100 100	3.5	6.8	6.4	4.8	6.1	6	10.2	8.5	18.5	14.1	13.0
ASTRONOMY	H												
	V	3.1	67	31				1					
ASTROPHYSICS	H		8	78	2		5					5	
	V	4.3	12	45	1		3					1	
ATOMS/MOL	H			4	42	3	3	11	2	3	6	16	6
	V	9.1	1	5	61	6	4	16	1	3	3	10	4
ACOUSTICS & EM	H					56		8			10	20	8
	V	2.1				24		3			1	3	1
FLUIDS & PLASMAS	H			2	4	7	61	6				12	7
	V	4.5		2	3	7	45	5				4	3
OPTICS	H				6			74			8	3	8
	V	1.8			2			22			1		
ELEM PART	H			3	1	3	2	2	64	2	1	14	8
	V	12.3	2	6	2	8	4	4	72	3		12	7
NUCL STRUCT	H			3	3	3	5	3	3	45	3	15	15
	V	13.5	2	5	6	7	11	6	4	71	4	14	16
SOLID STATE	H			1	2	4	2	5			64	13	8
	V	20.3	3	2	5	16	5	17		1	70	19	12
GENERAL	H			4	6	7	5	6	9	7	18	18	19
	V	8.4	2	4	8	13	7	8	8	7	8	11	12
OTHER	H		1	6	4	5	6	5	5	7	11	21	29
	V	16.5	8	16	11	15	15	13	8	13	10	24	36

H = Horizontal percents. V = Vertical percents.

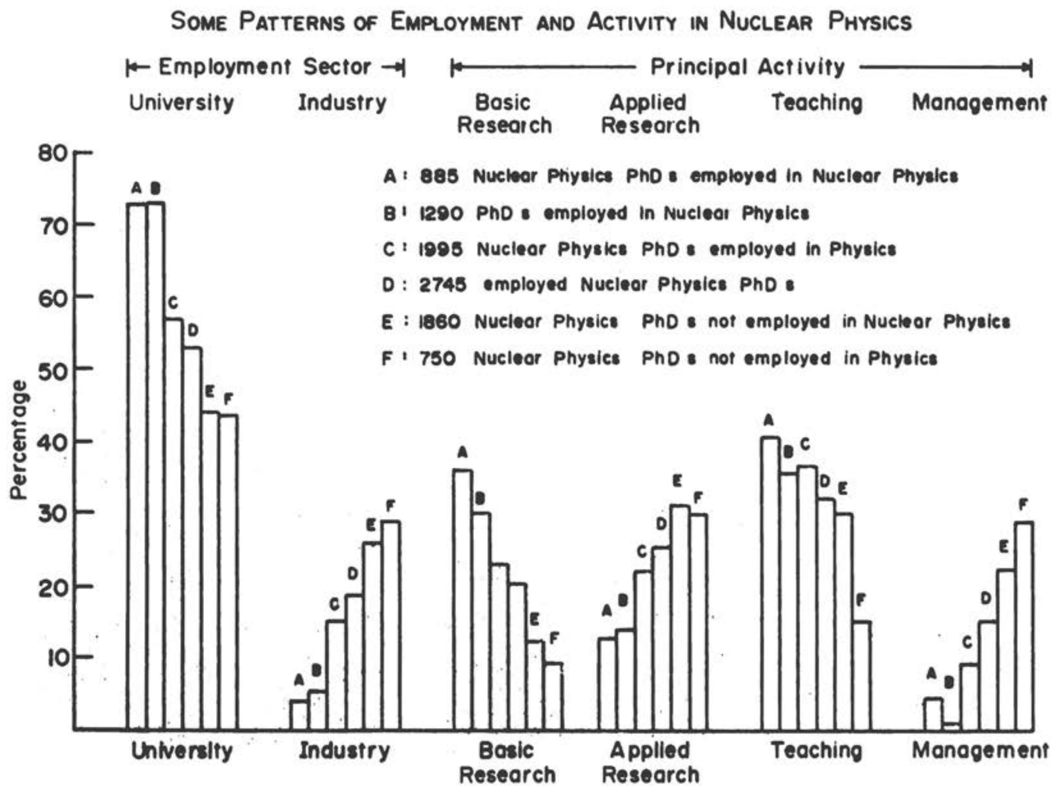

FIGURE 20 Type of employment and principal work activities of six PhD groups having degrees in nuclear physics or employed in this subfield. Source: NRC Survey of Doctoral Scientists and Engineers.

nuclear physics also have substantial teaching responsibilities, as in fact do all the groups except those nuclear-physics PhD's no longer employed in physics.

Figures 21, 22, and 23 offer a more detailed picture of type of employer and primary work activity for three groups: those persons who received PhD's in nuclear physics and are employed in this subfield or in physics (Figure 21); those persons with a PhD who are employed in nuclear physics (Figure 22); and those persons with a PhD in nuclear physics who are not employed in nuclear physics (Figure 23).

SUMMARY

Nuclear physics is a strong and vigorous subfield whose doctorates can and do apply their expertise in a variety of other physics subfields and other fields of science and engineering. Although outward migration substantially exceeds inward migration, the subfield has an influx of doctorates from other physics subfields, chiefly solid-state physics and elementary-particle physics, and from fields outside physics. Nuclear physics continues to be heavily concentrated in universities and its doctorates engaged principally in teaching and basic research; however, there are indications of growing industrial employment and increasing work in applied research and management activities. With decreasing numbers of postdoctoral opportunities and a static employment situation in academia, further shifts in these directions are likely throughout the 1970's and early 1980's. Many of the best graduates already are turning away from the academic research track to take immediate postgraduate jobs in applied research in industry or government or teaching jobs in colleges.

Nuclear physics, like most other physics subfields and many other sciences, is an aging field where employment opportunities for the young physicist are much less--by a factor of 3 or so--than they were in the early 1960's. Graduate-student enrollments have decreased by almost 50 percent from their peak in 1965. The number of postdoctorates has also decreased. We must come to grips with those key questions with which we began this report: Who will do the basic research? How do we maintain a strong fundamental research capability in this field which is so closely related to many of the critical problems this nation is attempting to solve? How do we ensure that nuclear physics remains vigorous and productive?

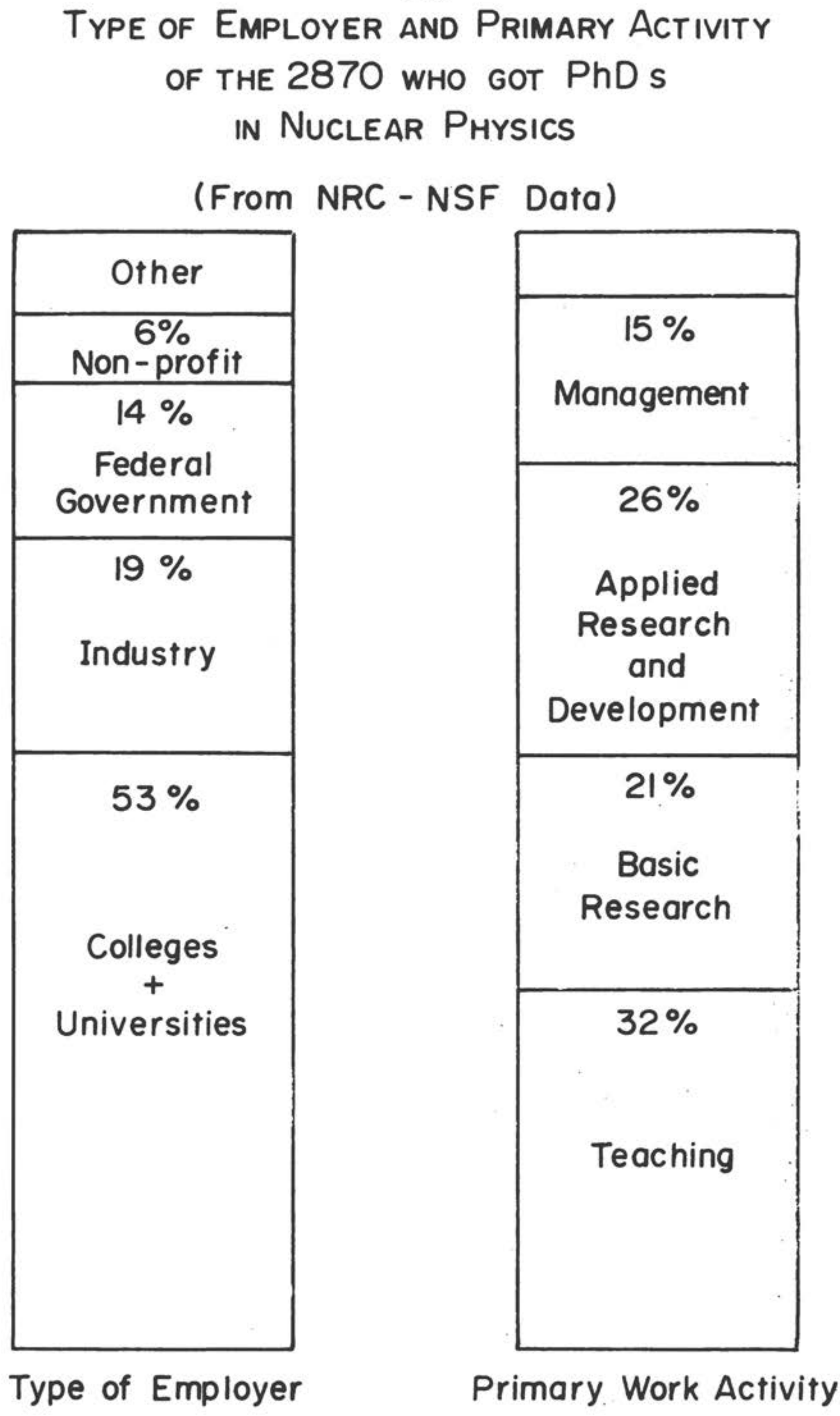

FIGURE 21 Type of employer and primary activity of 2870 physicists who received PhD's in nuclear physics. Source: NRC Survey of Doctoral Scientists and Engineers.

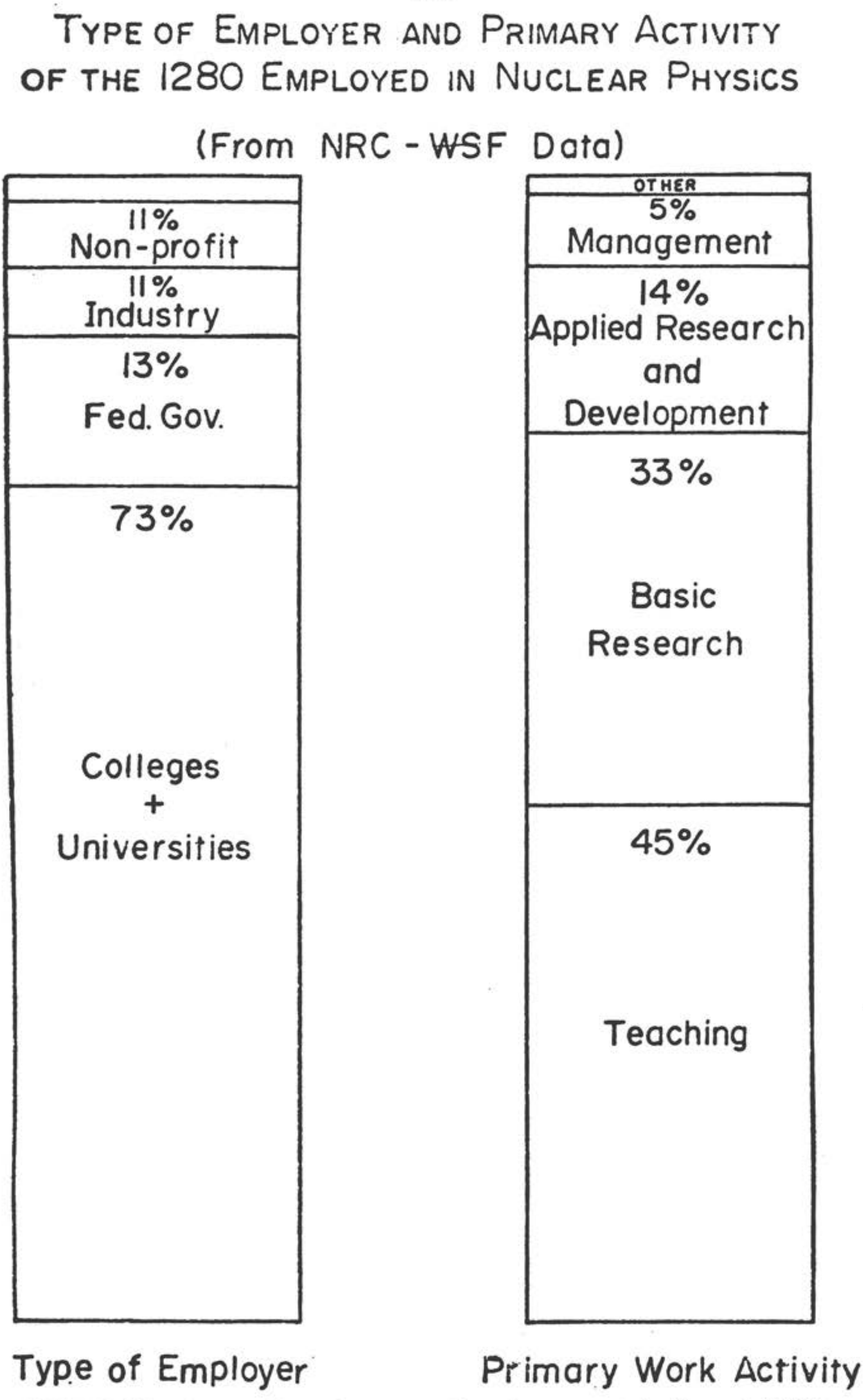

FIGURE 22 Type of employer and primary activity of 1280 PhD's employed in nuclear physics. Source: NRC Survey of Doctoral Scientists and Engineers.

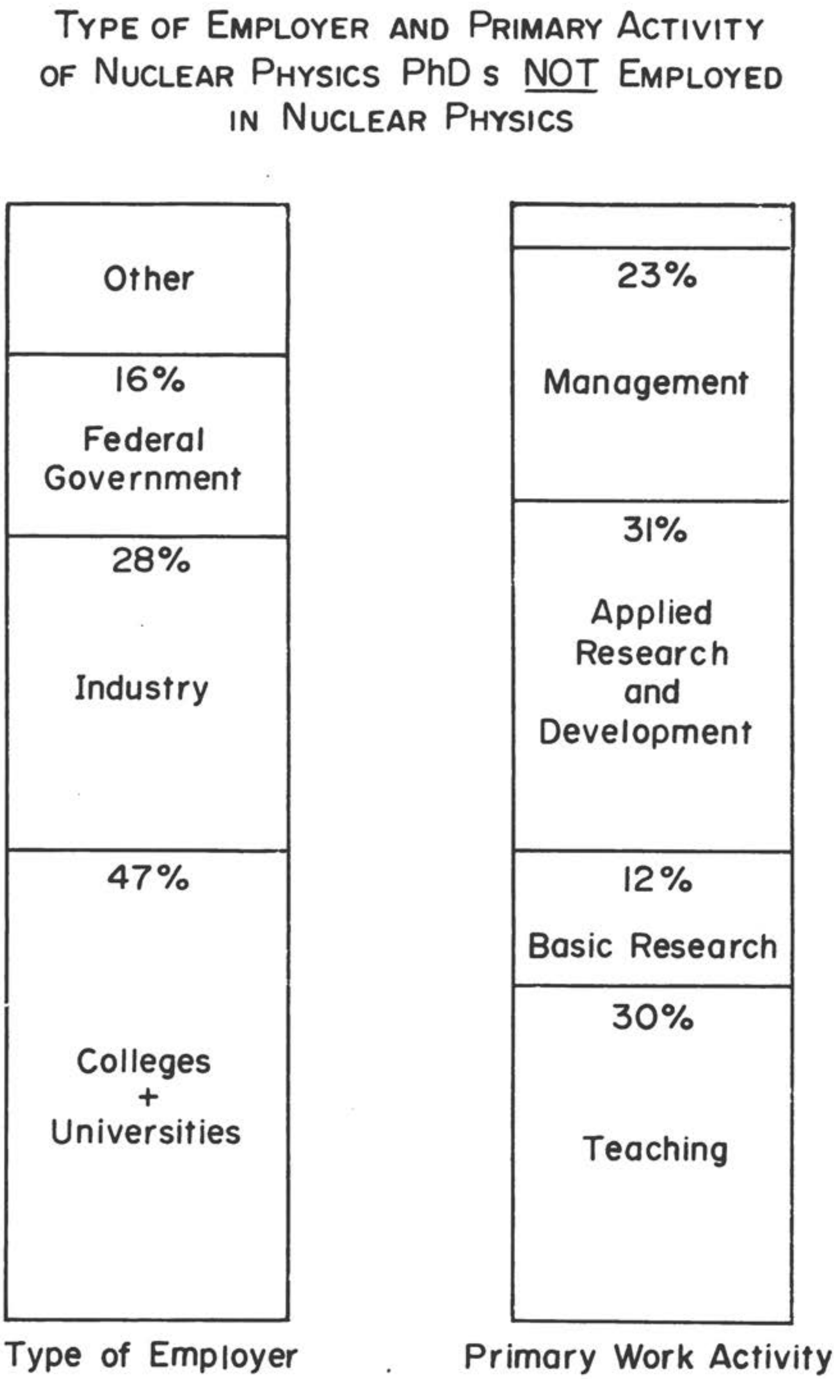

FIGURE 23 Type of employer and primary work activity of 1860 nuclear-physics PhD's *not* employed in nuclear physics. Source: NRC Survey of Doctoral Scientists and Engineers.