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Outlook for US Physics

US physics research and education are in good shape but are having some growing pains, according to the recently-issued Pake report. There are problems in administration, manpower utilization, advanced degrees, applied research and, most of all, financial support. The current budget squeeze is too tight; expenditures should increase by at least 21% a year until 1970.

PHYSICS: SURVEY AND OUTLOOK, a report that assesses physics research and teaching in the United States and spells out requirements for future growth of the science, has been released by the National Academy of Sciences. The report is based on studies made during 1964 and 1965 by the Physics Survey Committee, an 18-member group working under the auspices of NAS's Committee on Science and Public Policy. The Physics Survey Committee was headed by George E. Pake, provost of Washington University in St. Louis and a member of the President's Science Advisory Committee.

Physics research in the United States is vigorous in all subfields, especially atomic and molecular physics, elementary-particle physics and solid-state physics, according to the survey. Research in plasma physics, astrophysics and nuclear physics, although considered vigorous, could be stronger if certain problems were solved. (For a detailed report on fusion research in the US, see PHYSICS TODAY, March 1966, page 60.)

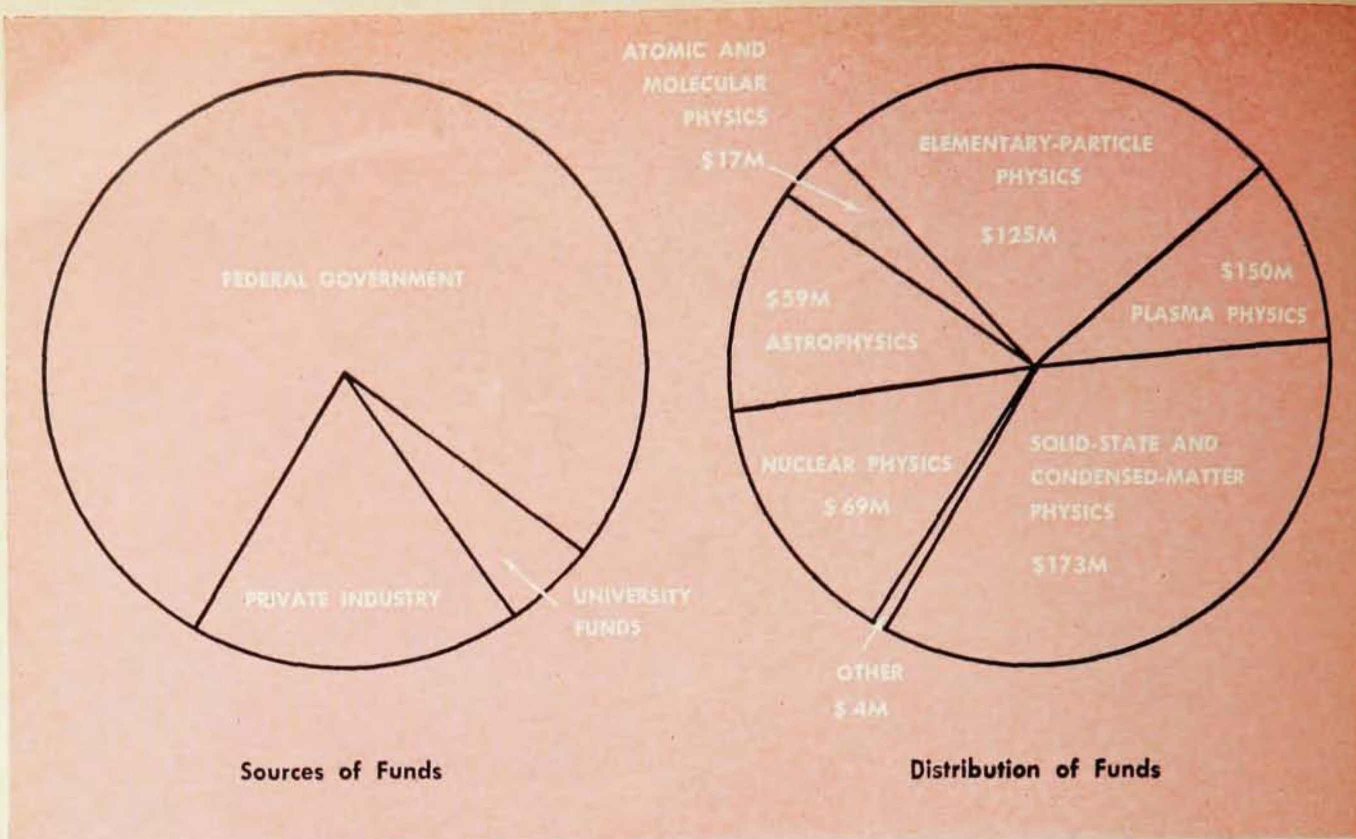
The Pake committee suggests that by 1969 the nation should be spending $1.1 billion on basic physics research, with $0.9 billion of this amount coming from the federal government. These figures are each 2.3 times the corresponding amounts spent in 1963. The report deplores the budget squeeze inflicted on physics during the past two years and emphasizes the importance of steady support from a variety of government agencies. The report also discusses the general problems of doing research and of teaching physics.

Subfields of physics

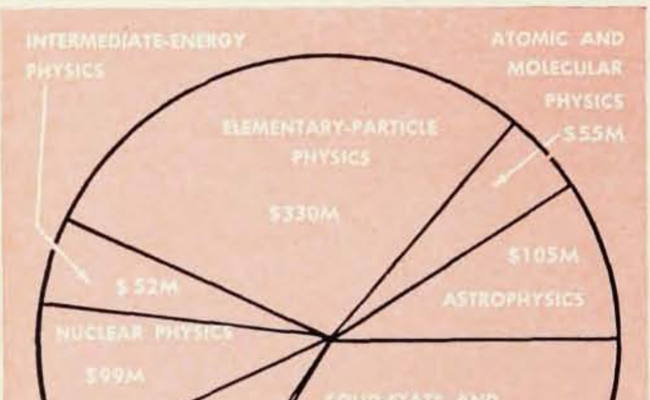
In organizing the survey, the committee limited itself to assessing basic research and teaching; it excluded applied research. Although there are almost as many ways of dividing the subject matter of physics as there are roads to Rome, the committee chose to separate the science into subfields dealing with identifiable kinds of matter. Thereby they obtained the following categories:

- astrophysics, space physics, cosmic radiation and gravitation
- atomic and molecular physics and quantum electronics
- elementary-particle physics
- nuclear physics
- plasma physics
- solid-state and condensed-matter physics.

The Pake committee established a panel of outstanding physicists for each category and charged each panel to answer an identical list of questions. The committee's scheme meant that optics, fluid dynamics and acoustics had to be apportioned among the six listed categories. (To ensure that their fields were not slighted, the Optical Society of America and the Acoustical Society of America each considered the list of questions and gave independent answers to the committee.)



1963 FINANCIAL SUPPORT for basic physics as estimated by subfield panels. Total estimate was $497 million, estimated federal support $400 million. Latter figure is higher than government estimate (see figure 3) because panels included plant-construction costs and some solid-state support from engineering funds. —FIG. 1



1969 FINANCIAL SUPPORT for basic physics as recommended by the subfield panels. Total support would amount to $1.1 billion, of which the federal government would contribute $0.9 billion. In the 1963 chart (figure 1, above) intermediate-energy physics is presumably included with nuclear and elementary-particle physics. —FIG. 2

Aided by the panels of experts, the Pake committee evaluated the strengths and weaknesses of each subfield, enumerated the significant questions that physicists will to try to answer in the near future and recommended the amount of money and brainpower that should be expended in each subfield during the next three years. The report urges that new surveys be conducted every few years by new committees, not only to include new scientific developments but also to introduce into the study process the viewpoints of young physicists.

Two additional panels were convened after the survey began. The first, a group of theoretical physicists, read the reports of other panels to make sure that theoretical physics had been covered adequately. And a panel on intermediate-energy physics was formed after the committee found that neither the particle-physics nor nuclear-physics panels had considered the demands for research at intermediate energies. (It was learned meanwhile that AEC had introduced a new budget category for intermediate-energy physics.)

FINANCIAL SUPPORT IN 1969

In 1964, when the Pake committee and its panels first attempted a financial projection for 1969, their task seemed a straightforward one—simply to take 1964 figures and project them five years ahead.

However, although the 1967 federal budget was already being prepared, the committee could obtain figures only on expenditures through fiscal year 1963 (see figure 1). (With the understatement characteristic of many physicists, the committee remarked that a physics survey would be a lot easier if better fiscal and sociological data were available on physics and physicists.)

What the panels and committee finally recommended is shown in figure 2. Most subfields would gain in support by roughly the same proportion as the growth in overall support. But federal support of atomic and molecular physics would roughly triple according to the recommendations, whereas astrophysics and plasma-physics support would be somewhat less than doubled.

The committee recommended a growth rate that would make the 1969 level at least 2.3 times that of 1963. In addition there should be a "contingency allowance" of about 10% to "allow for the unpredictable developments in physics and the 1969 needs associated with them," according to the committee. This allowance would bring the growth factor up to 2.5 for the 1963–1969 interval —still considerably smaller than the factor of 2.8 that characterized the four-year interval from 1959 to 1963. The committee's growth factor of 2.5 for the six years corresponds to a growth rate of about 16% compounded annually.

Since two years of the 1963–1969 interval had already elapsed when the Pake committee was compiling its report in mid-1965, the committee had to assess whether the federal government had indeed been increasing its support by 16% each year. The most favorable assumptions indicated that support for fiscal year 1964 had increased by no more than 6% from 1963. For fiscal year 1965, the committee's only indication of the financial level was the growth rate for academic-research support. This support increased by only 6.3% from 1964.

The report points out that growth rates as low as these "scarcely cover the annual increase in the cost of doing research, which several of the panels took to be at least 5%." The growth rates for the past two years "thus correspond to little or no real growth in basic physics activity. Certain fields, such as nuclear physics, have actually experienced a decrease in operating funds." Therefore to catch up to the projected 1969 figure, the average annual growth rate (compounded annually) from 1966 through 1969 will have to be not 16%, but 21%.

Throughout the report the committee remarks that there is no justification for fears that physics research is growing without bound. In fact the committee feels that when and if the factors influencing the growth rate are mitigated by "achieving a uniformly high level of excellent quality in US physics," physics activity "will correspondingly tend to plateau."

PAST, PRESENT AND FUTURE SUPPORT

In the United States about $20 billion is spent each year for scientific research and development, according to the Pake report, but of this less than $2 billion goes for basic research. Not all of the research funds come from Washington, of course. The federal government spends about $1.5 billion each year for basic research, physics and astronomy together getting some $400 million.

Support trends

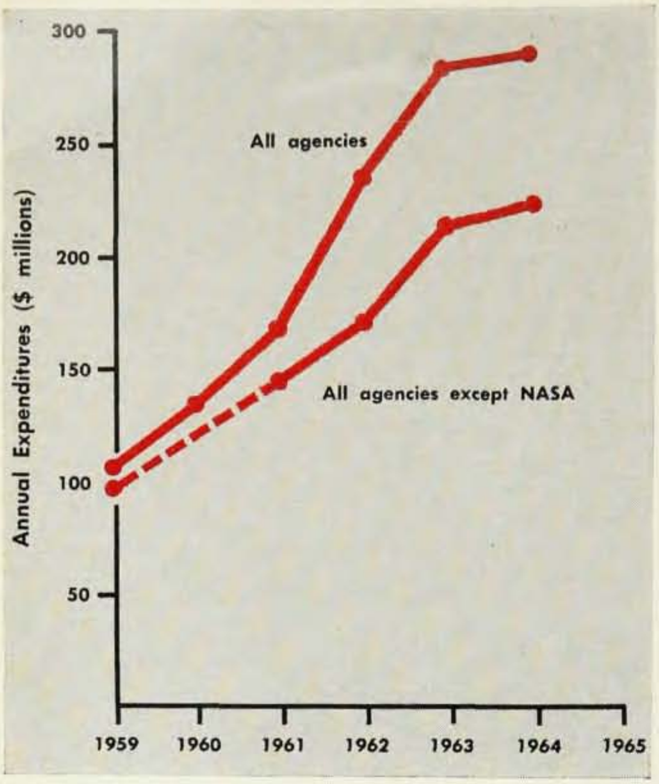
Figures 3 and 4 show that federal support for physics and astronomy grew by at least 20% a

Comment from Kistiakowsky

"The central issue facing federal science-budget planners is that, unless the total science budgets resume the rapid growth that characterized the period prior to fiscal year 1964, a painful choice must be made. The choice is between (a) preserving the growth of general academic research . . . and (b) new commitments to large scientific projects, most of which, in terms of dollars, are in physical field sciences (space, atmosphere, solid earth and oceans and in medium-energy and high-energy nuclear physics."

These are the words of George B. Kistiakowsky, chairman of the National Academy of Sciences' Committee on Science and Public Policy. The quote is from a letter transmitting to the academy the report of the Pake committee. Kistiakowsky praised the efforts of the committee and noted that "the report estimates educational manpower needs in physics (and research funds required to keep this manpower scientifically competent) to overcome the threatened shortages. The Committee on Science and Public Policy strongly endorses these recommendations."

However, Kistiakowsky remarked that the report has a few shortcomings: (1) It is "rather conservative and cautious" in evaluating the "contributions of basic physics to technology—civilian and military—and to the progress of other basic sciences." (2) ". . . the report suffers occasionally from compromises that are unavoidable when some members of a group believe in the overriding importance of preserving the opportunities for individual creativeness in research and for trc:ning of graduate students on their own research problems, while others are committed to group efforts of 'supercritical' size, usually associated with centralized and costly research facilities essential for some frontier types of research." (3) The analysis of recent federal support of basic physics was extremely difficult, primarily because NASA recently changed its budget classification schemes. (4) The report has not attempted to identify relative priorities for federal support in case the budget does not grow at the recommended rate. But Kistiakowsky feels that despite its shortcomings the report is very successful as a pioneer effort.



BASIC PHYSICS RESEARCH expenditures by the federal government from 1959 through 1964. The growth factor for all agencies was 2.8; for all agencies except NASA it was 2.1. These factors correspond to growth rates of 29% and 20% respectively, compounded annually. —FIG. 3

BASIC ASTRONOMY RESEARCH expenditures by the federal government from 1959 through 1965. In 1963 NASA changed its reporting methods, so the upper curve shows a sudden rise at that point. The lower curve essentially shows support for ground-based astronomy. —FIG. 4

year from fiscal year 1959 through fiscal year 1963. Interpretation of the data is complicated because NASA, in midspace, changed its method of reporting budget figures. Some of the funds once assigned to engineering are now assigned to the research to which they actually contributed. For example, the rocket booster for the Orbiting Astronomical Observatory is now considered an astronomy expense instead of an engineering expense. This effect shows up in the top curve of figure 4, where there is a remarkable leap between fiscal years 1962 and 1963. The lower curve essentially shows funds spent on ground-based astronomy.

Federal support of basic physics grew from $102 million in fiscal year 1959 to $288 million in 1963—a growth factor of 2.8, corresponding to a growth rate of 29% compounded annually. Meanwhile federal support of astronomy grew from $6 million to $140 million. Considering physics and astronomy together, federal support almost quadrupled in that four-year period. The increase corresponds to a growth of 41% a year compounded annually. Ignoring NASA's contributions the growth factor is considerably smaller—it is 2.1 both for physics by itself and for physics plus astronomy.

Up and down

The steady upward climb of the support curves levels off sharply in fiscal year 1964, when federal support for physics was $293 million—only $5 million more than the preceding year. The amount for all basic physics research in fiscal year 1965 can only be estimated. The staff that prepares the National Science Foundation's annual compendium, *Federal Funds for Research, Development and Other Scientific Activities*, estimates that physics received $329 million, but the Pake committee feels that this estimate is far too high. The report cites a 6.3% increase for academic research in 1965 as a more realistic estimate for total support.

Vicissitudes in research funding, whether upward or downward, can have serious effects, the report remarks. When the trend is downward, small projects and individual researchers are more likely to be affected than large facilities. Similarly, newly trained physicists often have trouble getting funds because agencies tend to continue supporting established researchers. Bookkeeping methods can also aggravate the situation during a cutback; some government agencies separately fund "equipment" and "materials and services" categories, and budget cuts are applied to categories arbitrarily without considering the technical content of individual programs.

Of the $400 million of federal money poured into basic physics and astronomy, more than half went to university-motivated research (this included major portions of the programs at such national laboratories as Brookhaven and Argonne). The volume supplied to each subfield appears in the table at right.

How should physics be supported?

Two methods of distributing federal funds to universities are project grants and institutional grants. A project grant goes to a university for research by a particular faculty member, who is often a well established scientist. Institutional grants may involve several departments and may be connected with a large experimental facility. According to the report, such grants tend to be flexible, and they can support promising physicists who are relatively unknown.

The Pake committee feels that each specialty should have a variety of support schemes. At the present time the committee does not think there should be more extensive institutional grants at the expense of project grants. The committee notes that trouble arises if there is a sudden large increase in one kind of support. In solid-state physics, for example, most US research is concentrated in a few university materials-science laboratories. If a researcher is at one of these centers, chances are he will have little difficulty finding support. At other universities, however, researchers must seek their own contracts, and the search is much too seldom successful.

Large grants are often needed, the report notes, because a "critical size" is required for significant research in many physics fields. Sometimes the size is controlled by a single expensive facility, such as an accelerator or telescope. Even when such apparatus is not required, as the solid-state physics panel remarks, "the possibilities of mutual stimulation are greatly increased if a critical size is reached. Experimenters learn from each other, theorists have contact with other theorists, and a strong coupling can develop between theorists and experimenters." Researchers can also benefit from collaboration with specialists in other fields. Such collaboration accounts for the success of interdisciplinary laboratories, but it also aggravates the problems faced by other universities.

Which specialty costs more?

Not suprisingly, the subfield panels found that in the cost of doing research there are considerable variations from one subfield to another and from one physicist to another. Several of the panels ventured an estimate of the research cost per PhD physicist per year. The figures range from $21 000 for atomic and molecular physics to about $160 000 for particle physics. The plasma-physics panel remarked that the cost per PhD researcher varies substantially with individual projects. The panel's guess, based on the fusion program, is about $100 000.

The solid-state physics panel asked many laboratories what their research costs were. Among other things, the panel found that the cost per PhD physicist in a government laboratory was more than twice the cost in a university laboratory. At a university with a strong solid-state research program the average annual support per PhD physicist (from government, university and other sources) was $36 000. At industrial and nonprofit laboratories the figure was $57 000. At government laboratories (including laboratories controlled by the government but actually operated by a company or university) the cost was $83 000. The solid-state panel arrived at an average cost of $56 000 per PhD physicist per year.

Federal Support of University-motivated Research

Physics subfields	*Federal funds* (*millions of dollars*)	*University portion*
Astrophysics	49	25
Atomic and molecular physics	15	11
Elementary-particle physics	125	100
Nuclear structure	69	36
Plasma physics	43	8
Solid state and condensed matter	95	36
Theoretical physics	4	4
Total	400	220

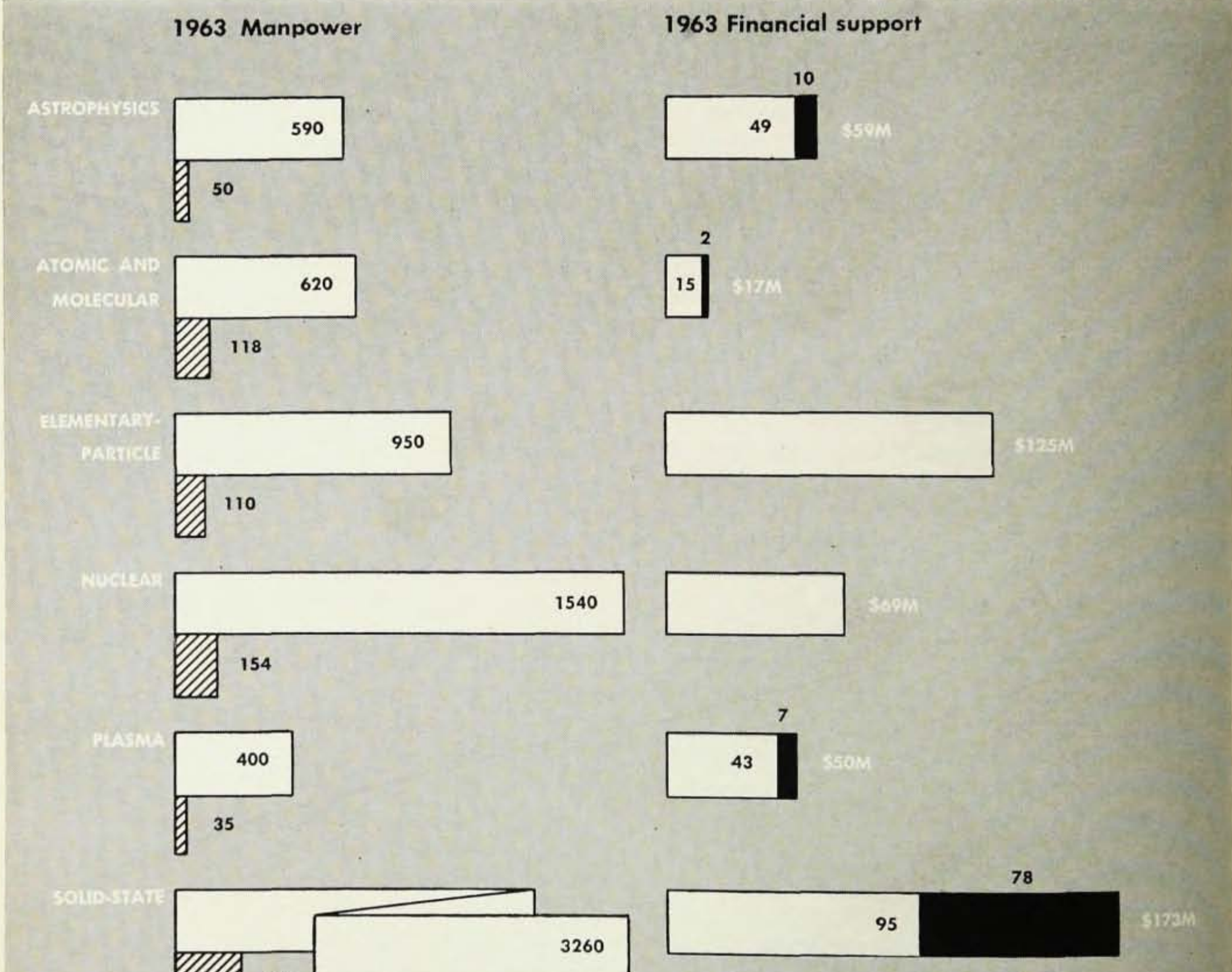
PHYSICS MANPOWER

By 1969 there should be more than 11 000 PhD physicists doing basic research, according to estimates made by the subfield panels. Many of these physicists will combine their research with teaching, and the Pake committee believes that, including these researchers, there will be about 12 000 physics teachers (with master's or doctor's degrees) in colleges and universities.

To arrive at the research-manpower estimates for 1969 each panel first estimated, for its subfield, the total number of physicists in 1963, the number of physicists who held PhD's that year, and the number of new PhD degrees granted. Then the panels predicted the number of PhD physicists that would be working in 1969 and the number of new PhD degrees to be granted then. (See figures 5 and 6.)

The 1963 estimates by all six panels added up to 15 150 physicists in all, 7360 physicists with PhD's and 693 PhD degrees granted. (AIP's 1964 statistical handbook, *Physics Education, Employment and Financial Support*, gives figures that differ considerably: in 1962, according to the publication, there were 21 273 physicists in all and 9080 PhD's. And there were 851 new PhD's granted in 1963, according to an AIP survey. "These discrepancies," the Pake report says, "are to be expected. For example, a physicist who specialized in nuclear physics as a graduate student but who is now engaged in nuclear engineering or in full-time teaching will count himself . . . as a nuclear physicist, but he will not be claimed by the nuclear-physics panel.")

The panels' total estimates for 1969 amounted to 11 470 PhD physicists and 1205 new PhD degrees. (The 1964 AIP handbook's figures are, respectively, 16 000 and 1150.) Will the supply of physicists, then, exceed the demand in 1969? The Pake committee did not try to estimate the demand but referred to a prediction made by the Bureau of Labor Statistics. According to this prediction, there will be a serious shortage of physi-



1963 MANPOWER AND MONEY by subfields, as estimated by the subfield panels. Graph at left shows number of PhD's in each subfield (white bars) and number of new PhD degrees granted annually (shaded bars). Graph at right shows federal support for each subfield (white) and nonfederal support (black) in millions of dollars. —FIG. 5

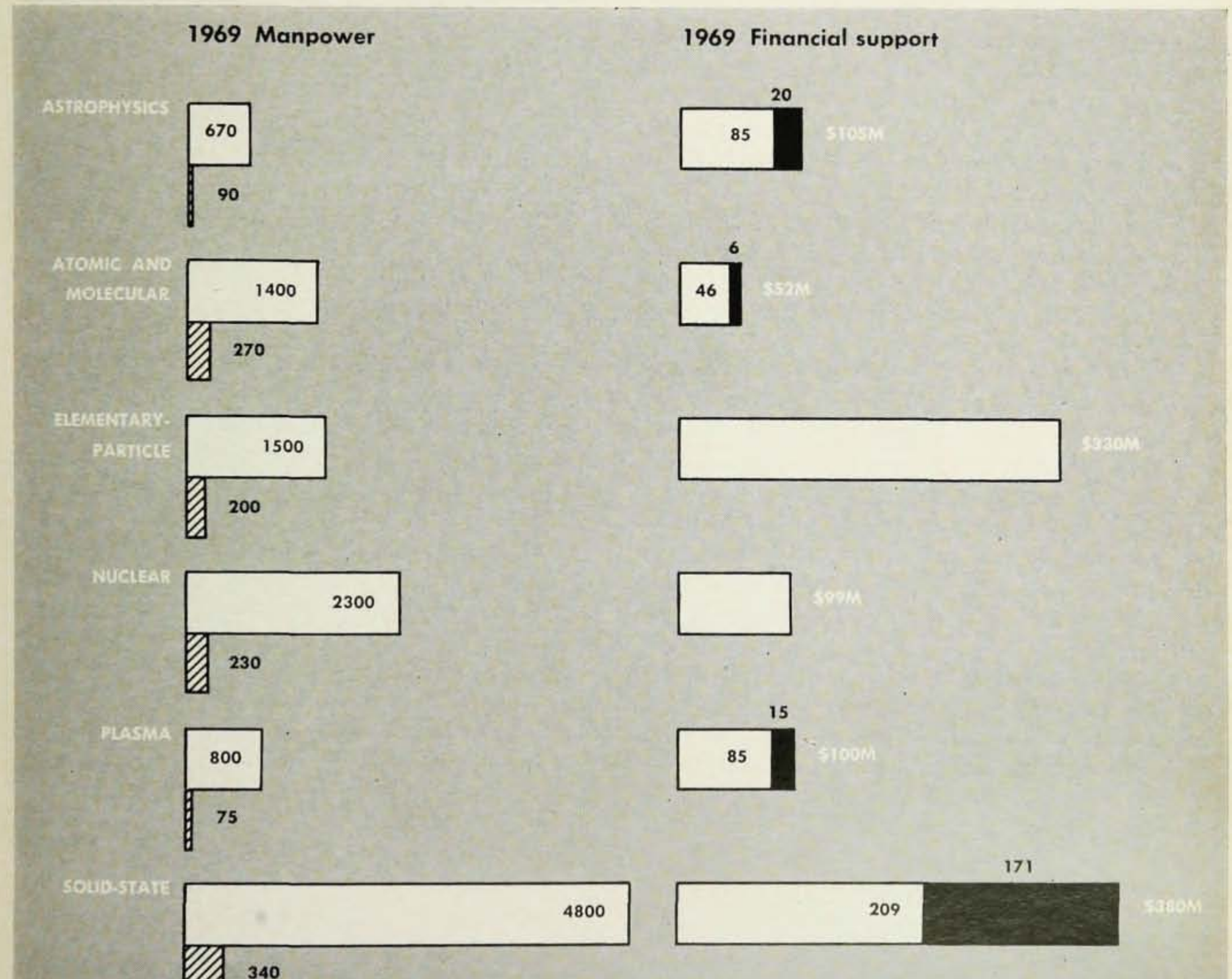
cists everywhere except at nonprofit laboratories. The universities will do best in meeting their needs, getting 75% to 80% of their demand. Industry will get slightly more than half its demand and government somewhat less than half.

Critics have occasionally expressed concern that too many of the nation's engineers and technicians (already in short supply) will be drawn away from other fields by some particularly large physics facility. The committee feels that this concern has little justification.

How many teachers in 1969?

To predict academic manpower and financial needs for 1969, the Pake committee first constructed a manpower model for 1963 based on the number of physics students and on faculty-to-student ratios. According to the model there were 5700 faculty physicists. Since the actual figure was about 7000, the committee computed a correction factor. Then using the same model for 1969, and assuming that the number of physics students would grow in proportion to the overall college enrollment and that the error in its estimate would be proportional to the 1963 error, the committee predicted that there would be 11 200 to 12 000 physicists at universities in 1969.

The committee made a second, independent estimate for 1969. Using the estimated physics-degree production given in AIP's statistical hand-



1969 MANPOWER AND MONEY by subfields, as projected by the subfield panels. The graphs are like those in figure 5, showing, for each subfield, the number of PhD's, new PhD degrees granted annually, and federal and nonfederal support. "M" stands for "million." The scales used in figures 5 and 6 differ because of space limitations. —FIG. 6

book for 1964, and assuming that the same proportion of new degree recipients would go into university employment, the committee concluded that there will be 12 000 master's and doctor's-level physicists at universities in 1969. Even though the two methods of estimating faculty numbers were different, the results were remarkably similar.

The estimates indicate that despite increased enrollment and current shortages of physicists at some institutions, the situation will be no worse in 1969 than it was in 1963 unless inadequate financial support makes it impossible to train all of those who qualify for PhD training.

Money for faculties in 1969

Having estimated the number of academic physicists in 1969, the committee estimated the 1969 cost of supporting faculty research. Then, to check on the panel projections for 1969, the committee compared its projected academic-research growth with that of all physics.

The committee assumed that all faculty researchers supported in 1963 would continue to receive funds, but that the total amount should be scaled upward from \$220 million in 1963 to \$275 million in 1969. The increase is to cover an assumed rise in research costs. (Retirements will be negligible, the committee feels.)

Meanwhile, according to the report, some 3000 new PhD's will probably enter academic life, and all of them should be supported. To estimate the expense of supporting these men the committee turned to the panel estimates of research costs per PhD physicist. The average annual support per faculty investigator in 1963, the committee estimated, was \$60 000. By 1969, the committee believes, the support will rise to \$75 000 per faculty investigator. (The report remarks that this is a conservative estimate; it cites the solid-state panel's estimate that recently the cost of research has been rising 5% to 7% each year.) Multiplying cost per man by the number of men, the committee calculated that \$225 million would be needed to finance the research of new faculty PhD's.

Thus the net projection for federal support of academic physics in fiscal year 1969 is \$500 million. This amount represents a growth factor of 2.27 over the period 1964 to 1969, in good agreement with the growth factor of 2.3 plus 10% recommended by the subfield panels for all basic physics research.

HOW WELL ARE WE DOING?

After the panel reports were in, the Pake Committee assessed the nation's relative strength in each of the six subfields. It rated US research physically fit in all the subfields, but it felt that three of them could be improved. The report notes:

"There have been many spectacular advances and contributions in all of these major subfields. Those that display most vigor and progress at this time are atomic and molecular physics, elementary-particle physics and solid-state physics. The remaining subfields also possess vigor and show progress, but the panels have emphasized certain problems that hinder development somewhat: for plasma physics inadequate representation in university physics departments is a problem; for astrophysics there is a pressing need for more observational facilities; in nuclear physics theoretical and experimental efforts are not in good balance."

Astrophysics

"Our strength in observational astrophysics with optical telescopes has been long established with the 200-in. telescope on Mount Palomar, but we have many more bright astrophysicists and astronomers than have access to the two US telescopes most suited for frontier research. Our relative strength will be altered with the implementation of plans for construction of several large telescopes in the Soviet Union. Any nation can, by placing a large telescope in the Southern Hemisphere, assume leadership in the observational astronomy of stellar evolution and cosmology, because the Magellanic Clouds are the nearest of all external galaxies. The United States has taken the initiative in the expensive but highly promising field of space-based optical and x-ray astronomy.

"In radioastronomy the United States now has an impressive group of major radio telescopes, but the US position is not preëminent. Even the new instruments nearing completion at the California Institute of Technology and the National Radio Astronomy Observatory are inferior to existing instruments in Australia and the Soviet Union and to large new cross-type arrays nearing completion near Sidney and Moscow. The US position in space physics and cosmic radiation is good, with some question whether present conditions permit further strengthening of that position. Research on gravitation is at present not a large sector of research, but the US effort is of very high quality and is being increasingly recognized."

Atomic and molecular physics

"In the broad field of atomic and molecular physics and quantum electronics, the US position

Recommendations to Universities and Physicists

The many problems attending the growth of physics in the United States will not all be solved by increased money and manpower. The Pake committee urges physicists to "give increasing attention to the solution of a number of administrative and organizational problems" by the following techniques:

"Better utilization of available physicists, and improvement in content and techniques of teaching, in order to maintain instruction of the highest quality for our increasing number of students.

"Increased incorporation of research and teaching programs in new fields of physics into regular university departmental programs.

"Providing incentives for more students to pursue studies and careers in applied physics.

"Critical examination of the postgraduate degree structure in the face of changing and expanding needs, with special attention to strengthening the master's degree in physics. If it cannot be enhanced, a new intermediate degree should be considered.

"Achievement of optimum relations between universities and national facilities. Physics departments (and their university administrations) must plan carefully for the 'users' mode of participating in research and graduate education at shared facilities such as major accelerators or telescopes. There should be minimum disruption of the student's educational experience and of participation by the faculty member in on-campus teaching programs.

"Careful projection of support required to operate a new facility when the authorization to construct it is under consideration.

"Efforts to help colleges, junior colleges, and secondary schools cope with shortages of physics teachers.

"Development of effective means of informing the public of the goals and accomplishments of physics."

is generally strong and leads the world in several of the major subdivisions of the field. United States physicists initiated the study of radiofrequency and microwave spectroscopy of atoms and molecules and continue to lead in this field. Quantum electronics had its primary origin in the United States as an outgrowth of microwave spectroscopy, and a large fraction of the world's activity is in this country. Although the resurgence of interest in atomic collisions [after] World War II was led by British scientists, the US position in this large field is now very strong. Our theoretical work in the entire field of atomic and molecular physics is broadly based and of very high quality. The field of optical spectroscopy is relatively weak in this country. Although the United States now enjoys a position of strength in atomic and molecular physics, the US effort is rather modest and it will be essential to provide for a substantial growth rate if we are to maintain our present position in the field and provide trained atomic physicists needed in other branches of pure and applied physics. The US activity in the more applied aspects of atomic and molecular physics, which includes much of quantum electronics, is extensive, and the outlook for its adequate growth appears good."

Elementary-particle physics

"The present position of the United States in elementary-particle physics is very strong, but the outstanding Western European laboratory, the European Center for Nuclear Research, is certainly competitive. Furthermore, present Russian competence, together with their commitment and progress in constructing the world's largest accelerator, serves notice that there will be a continuing high level of activity in this field in the Soviet Union. The United States now stands at a point of critical decision as to whether it will undertake the next logical steps in this area of research rapidly enough to prevent the dissipation of its existing strength."

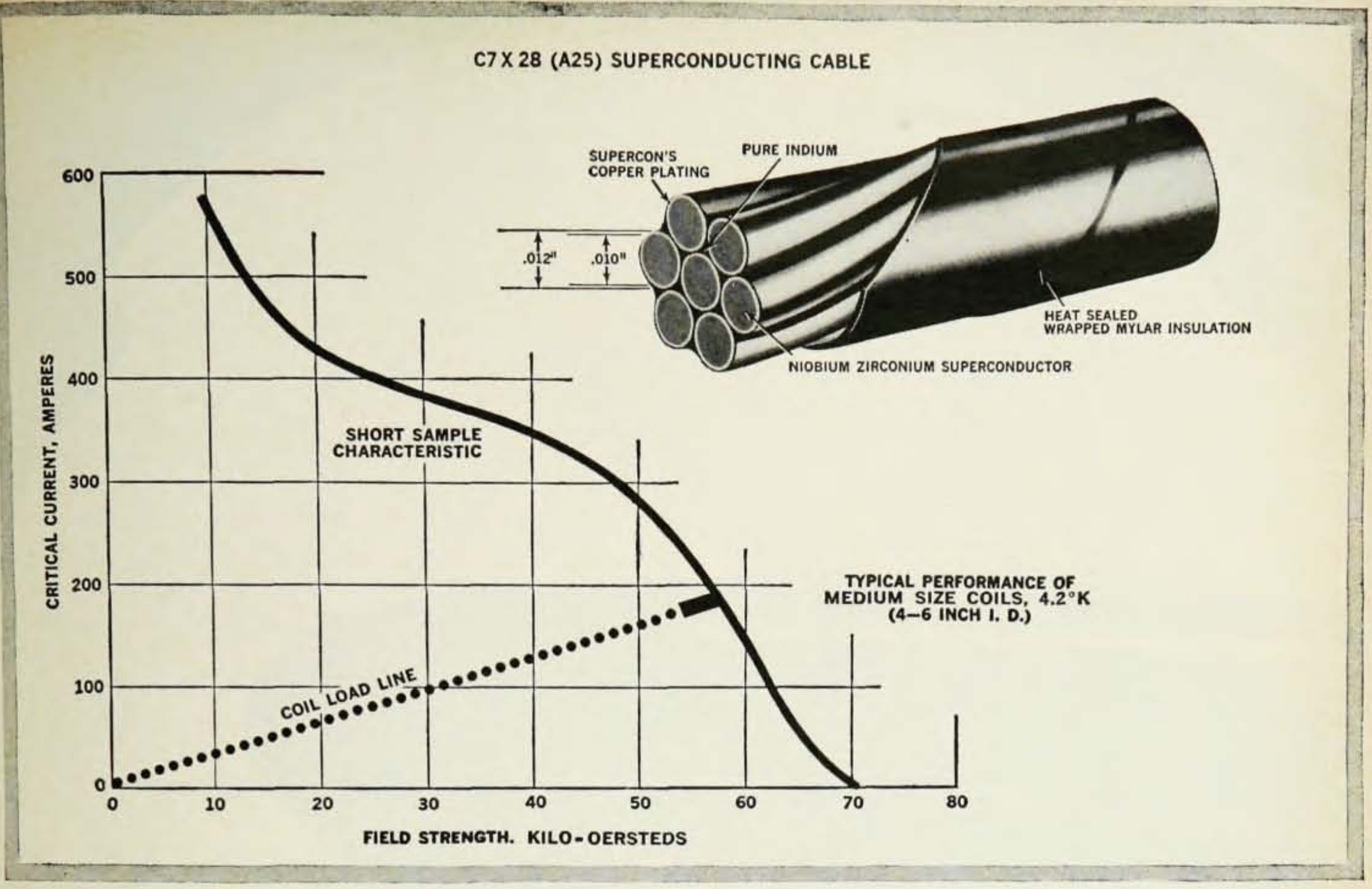
Nuclear physics

"The United States has widespread and good experimental facilities in [nuclear physics]. However, exploitation of these facilities has been adversely affected by the recently imposed limitation—indeed, reduction—of operating funds. Moreover, too few young theoretical physicists are entering the field in this country, in contrast to the strong theoretical groups abroad.

"It has been recognized that accelerators of intermediate energy (between 100 and 1000 MeV) will also be important tools in nuclear physics. Both in this country and abroad, plans are under discussion to upgrade existing accelerators in this range (now primarily used for elementary-particle physics) or to construct a new high-intensity facility. Our relative position in this emerging field will depend on the implementation of these plans."

Plasma physics

"Pressure to achieve applied goals—utilization of nuclear fusion, together with space and military research—has resulted in an explosive increase in US plasma-research activity since the 1950's. A high price was paid for this rapid growth. Relative to the total effort, too little attention was directed toward achieving basic understanding, and our universities have too little concern in the field. Though awareness of this deficiency is



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SUPERCON'S COPPER PLATING
PURE INDIUM
.012"
.010"
HEAT SEALED WRAPPED MYLAR INSULATION
NIOBIUM ZIRCONIUM SUPERCONDUCTOR
CRITICAL CURRENT, AMPERES
600
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100
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SHORT SAMPLE CHARACTERISTIC
TYPICAL PERFORMANCE OF MEDIUM SIZE COILS, 4.2°K (4–6 INCH I. D.)
COIL LOAD LINE
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FIELD STRENGTH. KILO-OERSTEDS


Re-entry Wake

growing and research of increasingly high quality is being done, at the present time some parts of the US plasma-research effort do not compare advantageously with the effort elsewhere. In particular, the United States is clearly behind in the quality of education for advanced plasma research. Since plasma research bears an obvious and intimate relationship to coming important scientific and technological developments, weakness in this field should be a matter of national concern, and steps should be taken to establish more quality plasma-physics graduate programs in university physics departments."

Solid-state and condensed-matter physics

"The United States has unique strength in [solid-state physics] as exemplified by the fundamental advances in semiconductors and superconductivity made primarily in this country. This strength is in part a direct result of a close dependence of American industrial and defense technology on basic solid-state physics. Faltering federal support and the limitation of industrial support to a few large laboratories make the present situation precarious. In particular, industry based on the use of structural materials has not given enough backing to this area. Continuing broad federal and industrial support is essential for maintaining US excellence in basic solid-state physics."

PHYSICS GROWTH CAUSES PROBLEMS

Although the Pake committee found that physics is in good shape in the United States and that we have made many spectacular advances and contributions, our very success has created difficulties.

Money is the root

The most serious problem facing all physics research is the budget squeeze that began two years ago. In its report, the Pake committee remarks that physicists have always been able to think of more new projects than they could get money for. "But today, for the first time in the history of physics in the United States, budgetary limitations threaten our ability to sustain productive continuing activity in many segments of physics."

There is an anomalous situation in several subfields: existing facilities are getting too little money to carry out their research programs while large sums are being spent on the construction of new facilities. Part of the difficulty is that future operating costs are underestimated when construction plans are first made (new instruments seem to inspire new techniques, and the extrapolation of expenses becomes difficult). The Pake committee urges that better estimates of future operating costs be made. Even though the committee objects to the money shortage at existing facilities, the report says, "We do not intend to imply . . . that satisfaction of all reasonable operating requirements using present tools should take absolute priority over creation of new facilities."

Physics Survey Committee

George E. Pake, Washington University, chairman
L. H. Aller, University of California, Los Angeles
Samuel K. Allison, University of Chicago (deceased)
Harvey Brooks, Harvard University
Geoffrey F. Chew, University of California, Berkeley
Henry A. Fairbank, Duke University
E. L. Goldwasser, University of Illinois
Vernon W. Hughes, Yale University
Clyde A. Hutchison Jr., University of Chicago
R. Bruce Lindsay, Brown University
Edward P. Ney, University of Minnesota
W. K. H. Panofsky, Stanford University
David Pines, University of Illinois
Emanuel R. Piore, IBM Corporation
Richard F. Post, Lawrence Radiation Laboratory, Livermore, Calif.
Roman Smoluchowski, Princeton University
C. H. Townes, Massachusetts Institute of Technology
Eugene P. Wigner, Princeton University
Lewis Slack, National Academy of Sciences, secretary

University issues

The university has a vital role in the continued development of physics in the United States, but it is time to consider the role of doctoral and postdoctoral research, the subjects covered by departments, the general disrepute of applied physics on campus and the quality of physics courses being offered.

The Pake committee urges that the master's degree be strengthened. If it cannot be improved, the committee proposes serious consideration of a new advanced degree in physics intermediate between the master's and the PhD. This degree would have substantially the same course requirements as the present PhD but a lesser requirement for independent original research. As an alternative to independent research, a student training to be a college teacher might develop new curriculum materials, and a student preparing for industrial work might serve as a junior member of a research team for six months to a year. The intermediate degree should be given prestige commensurate with the accomplishments it requires.

To earn a PhD now takes an average of almost 5½ years from the time undergraduate work is completed and it may soon take six years, according to the committee. At the end of his apprenticeship the journeyman physicist frequently chooses to prolong his study by taking a postdoctoral fellowship. In the academic year 1959–1960 there were 412 postdoctoral fellows in US physics departments. Five years later there were 900.

The Pake committee fears that postdoctorals may be curtailed for two reasons: (1) curtailment is an easy way to cut support, and (2) postdoctorals delay PhD's from becoming college teachers, according to one school of thought, and thus intensify the shortage of physics faculty. The committee argues that the extra time spent in postdoctoral study better prepares the physicist for teaching and research, and that much of the postdoctoral fellow's time is spent teaching younger graduate students how to do research.

Another important problem discussed by the report is that many physics departments completely ignore some subjects, particularly if they are considered applied physics. Fields like plasma, solid-state and space physics are frequently not studied at all, or else they are relegated to one of the engineering departments. Many "major" physics departments scarcely get involved in solid-state physics. In plasma physics, nearly 70% of the doctorates are obtained in departments other than physics (these departments range from electrical engineering and astronomy to applied physics and nuclear engineering).

The isolation of certain subjects damages physics as a whole, according to the committee, for the following reasons: (1) It hinders the development of given subfields because the basic aspects are underemphasized. (2) Since students are often discouraged from an interest in applied physics, they avoid these subfields. (3) The various subfields of physics become isolated from each other and so do the physicists. The committee offers a remedy: university physics departments should try to achieve a broad coverage of physics, and they should demonstrate to students that physics need not be "pure" to present exciting intellectual challenges.

Problems at four-year colleges are somewhat different from those at universities, the report notes. Most departments are understaffed in both quality and quantity. The result is twofold: the colleges are no longer outstanding sources of future physicists, and many colleges do not offer good courses to nonscience majors. Only 20% of American college students study physics at any level, and the committee doubts that this percentage will increase in the next five years. The report remarks that "there is an urgent need for the ablest physicists to put energy and effort into these courses [for nonscience students in the liberal arts] if the communication gap . . . is to be reduced."

Although the interactions between physics and society are growing stronger, the layman's understanding of the aims and content of physics remains weak. The committeee has not dealt with this problem at length but feels that somebody should—particularly the universities and physicists themselves.

Big facilities, big problems

Large-scale facilities have become increasingly important in fields like astronomy, space physics and particle physics; new machines for nuclear-structure physics may also soon be big enough to require joint operation by several institutions. Such big facilities have created problems involving their cost, location, construction and use.

Since equipment is so expensive, the limited number of facilities that can be built leads to a great deal of competition when a location is to be chosen. And once a facility is completed there is competition for machine time among qualified scientists. Frequently a university professor needs to run a long experiment at a facility far from his home campus. The Pake committee feels that university administrations should make special efforts to relieve professors of campus duties for extended periods if they need to do research at a distant facility.

Despite the importance of scientific apparatus to scientific research, the committee says that equipment designers do not get enough recognition from the academic physics community. The committee urges that designers and other technical personnel at physics facilities get involved in university educational processes. At the same time, users of such facilities should get involved in the technical work.

Future large centers ought to be operated as "national facilities," the report says, with policy control "in the hands of the funding agency working together with a nationally representative group having expertise in technical, scientific and educational problems." □

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