Report by the Subcommittee on University

Research and Education in Nuclear Science

to the

DOE/NSF Nuclear Science Advisory Committee

October 1982

Subcommittee Membership

Stanley S. Hanna (Stanford University)

Ernest M. Henley (University of Washington)

John R. Huizenga, Chairman (University of Rochester)

Louis Rosen (Los Alamos National Laboratory)

Steven E. Vigdor (Indiana University)

Charge to the DOE/NSF Nuclear Science Advisory Committee Subcommittee on University Research and Education in Nuclear Science

I. The subcommittee will identify and analyze various research modes in Nuclear Science at Universities.

II. In its assessment the subcommittee should consider:

(a) The impact of these research modes on the education and training of nuclear scientists (undergraduate, graduate and postdoctoral students) as well as those in related fields for which expertise in nuclear science is essential. The factors that influence the supply of students and potential young scientsists for the field of Nuclear Science. The ways in which various research modes can be made more attractive to students.

(b) The impact of these research modes on the role and contributions of Universities to the national research program in Nuclear Science. The balance between research on small, intermediate and large facilities.

CONTENTS

		page
I.	Introduction	4
II.	Modes of Nuclear Research	7
	A. Small University Based Facilities	7
	B. Intermediate User Facilities Located on University Campuses	9
	C. University Research with User Facilities at National Laboratories	13
	D. Mixed-mode University Research	16
III.	Balance Among Various Nuclear Research Modes	19
	A. Continued Need for Small University Based Facilities	19
	B. Special Needs of University User Groups	21
IV.	Improvements of Nuclear Physics Education	24
V.	Future Manpower Needs in Nuclear Science	28
VI.	Recommendations	45

I. INTRODUCTION

The primary reason for keeping nuclear physics strong at universities is that it is at these institutions that the physicists who represent the future of the field are educated. It is taken for granted that both pure and applied research and development in nuclear science are vital to the short and long term interests of the United States. Visible, active centers of nuclear physics located at universities where students take their undergraduate and graduate education help to attract outstanding students to the discipline. Thus, such centers are crucial for maintaining the supply of those scientists of high quality necessary to keep the field strong.

To attract students to nuclear physics it is important to have nuclear physics taught to undergraduates by scientists who find this field to be an exciting one, i.e., nuclear physicists who are actively engaged in research. Without generating interest in nuclear physics at the undergraduate level, there is less chance of doing so in graduate school.

In order to train first-rate experimental scientists it is important that the students be exposed to the latest technology and to the sharpest and most clever and imaginative minds. Such physicists are more likely to be found at institutions where they have access to forefront facilities which allow them to pursue their ideas. If such facilities exist at, or close to, universities, it is likely that these physicists will migrate to these geographic locations.

Nuclear physics is an expensive experimental science. Some facilities are sufficiently expensive that they are and will be located at national research centers. However, some less expensive facilities are compatible with university operations. Because of the long range values of locating the latter facilities at universities, we believe that, when new facilities of an appropriate nature are funded, high priority must be given to locating them at universities. In nuclear science, a reasonable balance must be maintained between national and university facilities.

Nuclear physics is a vital and active branch of physics. Experimental nuclear physicists are among the more broadly trained physicists. Experiments carried out at university laboratories involve the student in all of its stages: design, development of equipment, execution, and analysis. Thus, the student is likely to receive broader training than in some other areas of physics. Graduates of such programs have opportunities for employment in many areas of physics and in other sciences both basic and applied.

When university nuclear physicists carry out experiments at national facilities located far from their home they often do a fair share of the equipment design and construction. To the extent that it is practical, such design and construction of experimental equipment at the home institution should be supported. The advantage is that nuclear physics becomes a more visible entity at the home university, and the work is likely to involve a larger number of students, faculty, and technicians. These activities make nuclear physics more attractive to prospective students.

In a university setting the relationship of theorists and experimentalists can be closer and more direct if experiments are carried out on location. Theorists are more likely to become deeply involved, and to suggest experiments in an environment where they are stimulated by experimental activity close at hand. The day-to-day interaction of experimentalists and theorists at universities is made more difficult if the former are gone for long periods of time in order to carry out their experiments at national facilities. There is a concomitant loss to students whose mentors are separated from the university for periods of time. Students who perform experiments at national facilities located elsewhere also lose the stimulus of the university environment and have to adjust to obtaining such stimulation in a less familiar environment. Furthermore, the interpretation of experimental findings is likely to be richer when the strong continuous interplay between experimental and theoretical physicist is not truncated by the former's absences. Improving and increasing the facilities at universities will ameliorate these problems but we must continue to seek ways to overcome them if graduate training must be carried out off campus.

Interdisciplinary arrangements available at universities favor cross fertilization. For all of the above reasons it is essential to keep universities as strong partners of the national laboratories in the national enterprise for nuclear science.

II. MODES OF NUCLEAR RESEARCH

With a strong and healthy university program in nuclear physics, the United States will have the variety of effort necessary to exploit the opportunities provided by our various accelerator facilities, and perhaps even more importantly, will attract and train the very best students who are the lifeblood of this and related fields. In order to maintain the proper role of the universities, their physical facilities for nuclear physics research must be kept at the forefront and support for undergraduate and graduate students must be provided. There have been significant losses in university nuclear physics programs. The committee believes that while these losses are not yet at a crisis level, further deterioration must be prevented and, in fact, reversed as each opportunity to do so presents itself. Nuclear physics research in universities in this decade is carried out in several different modes and it is the purpose of this section to discuss the strengths and weaknesses of these different research modes.

IIA. Small University Based Facilities

Nuclear research programs carried out on small facilities at universities provide many valuable features and advantages for the training of graduate students and further development of postdoctoral candidates. Although used primarily by the university itself, these facilities are open to others, especially those at institutions nearby, who have no access to nuclear facilities of their own. In addition, the availability of these facilities to undergraduate students provides a very important source in the recruitment and early training of future nuclear scientists.

(1) In carrying out their doctoral research with these facilities, students can participate in and control all parts of their experiments. They

can contribute to the maintenance and improvement of the facility. They can operate and control directly the running of the accelerator for their research. The experiments are such that the students can plan and execute all parts of their experiments.

(2) This feature of research with a small facility in a university setting has a strong appeal for graduate students. As long as the experiments remain important and therefore interesting, nuclear physics can compete successfully with attractive and sometimes glamorous programs in solid state, low temperature physics, astrophysics and quantum electronics. Nuclear physics can also compete successfully with particle physics research for those students who are interested in subatomic physics but who do not wish to become part of a large team working at an outside facility.

(3) Nuclear research programs based on in-house facilities receive strong support from physics departments and university administrations which enables nuclear research to maintain a strong standing in these universities. It is obviously desirable to have as many people as possible, students and faculty alike, carry out their research at home. This enhances the graduate student and faculty involvement in the department and greatly strengthens the department. It provides the students with invaluable associations with the other areas of physics through their continued association with students and faculty in these fields and through colloquia, seminars, etc.

(4) The training received by students in a small facility laboratory is generally very broad and provides them with the experience and expertise to enter many different areas of physics and engineering in universities, government laboratories, or industry. The students receive training in instrumentation, computer technology and programming, design and execution of experiments and, of special importance, they take part and contribute to experiments other than their own.

(5) The University based facilities are in an excellent position to attract sizable numbers of promising undergraduates to participate in forefront research, especially from their own, but also from other colleges and universities (e.g., with summer stipends provided by the home institution or by national fellowship programs). Such research opportunities greatly enhance an undergraduate education, and increase the likelihood of bringing bright students into nuclear science research.

IIB. Intermediate User Facilities Located on University Campuses

There are a few national user facilities of intermediate size located on or near university campuses and closely associated with the Physics Departments of those universities: the Bates Linear Accelerator, operated by MIT; the Indiana University Cyclotron Facility; and the National Superconducting Cyclotron Laboratory now under construction at Michigan State University. These facilities potentially can combine the traditional advantages of both the larger national laboratory facilities and the smaller university laboratories in the training of nuclear scientists. Specifically, they can offer students the stimulation of participating in forefront research enabled by strong accelerator and other equipment development programs, and of interacting with a wide variety of active nuclear scientists, along with the possibility of a more broadly based training in experimental techniques than is easily accessible at the larger national laboratory facilities. At the same time, they can provide the university atmosphere and access to courses important for a student's general development. These intermediate facilities, since they are presently - and are likely to remain - few in number, have a substantial responsibility to the nuclear science community to live up to this potential in educational effectiveness, with its direct coupling to the production of high-quality research.

The most obvious limitations to the user facilities operated at universities arise from the size of the group (scientists, engineers, technicians, clerical support, etc.) needed to administrate and carry out research programs at such a facility. Few universities or physics departments are able or willing to build up sufficiently large nuclear science research groups, and one therefore expects only a few such facilities to exist. Where they do exist, their size is effectively limited by the ability of the faculty to handle the increased administrative and user-support burdens, in addition to normal teaching and research loads, while maintaining time to work closely with students. The load can be eased, and the efficiency of the laboratory efforts in both research and education thereby enhanced, by a number of measures: e.g., participation in laboratory operations by faculty from other departments (Chemistry, Biology, Medical Schools, etc.); university support in attracting and keeping a strong technical and scientific support crew; government funding for "research faculty" or for releasing selected faculty from teaching duties periodically. Under some circumstances it may be advantageous in vying for university support to operate user facilities as independent institutes within the university (e.g. SLAC), separated from the physics department; however, such separation should be undertaken with great caution, as it may also impede a profitable association of the laboratory's students and staff with researchers from other physics subfields.

These intermediate facilities have significantly larger operating budgets, more active technical development programs, and generally a greater variety of research possibilities, than the smaller university laboratories. These features, together with the advantages of carrying out research at a home facility, rather than in an outside user mode, enhance the opportunities for such laboratories to attract some of the best emerging nuclear scientists to universities - at junior faculty, research faculty, and post-doctoral levels - where they can interact with and help to train the next generation of students. Maintaining an influx of bright young nuclear scientists into university positions is essential to the future health of the field. Establishment of "research faculty" positions with funding agency support is an especially effective means for helping to maintain that influx. Universities, for their part, must support people in such research positions with clearly defined career ladders, strong association with the appropriate departments, and flexibility in allowing them access to graduate (and undergraduate) students.

The in-house students at university-run user laboratories benefit from the opportunity to interact with a wide variety of more senior scientists and from the breadth of choice in research projects available. While they are not able generally to participate actively in all aspects of an experimental investigation (including, for example, ion source and accelerator operation and development), as are students at some smaller laboratories, they often take part in a wider range of experiments early in their careers; they are thus exposed at the graduate level to more detection and analysis techniques, and probably to more points of view, than are their counterparts in most smaller research groups.

On the other hand, the intense competition for beam time at user facilities, and the pressure to use such time with maximum efficiency, introduce the danger that students may end up more as observers in large consortia, or as custodians of one small segment of the equipment, than as prime movers behind their own thesis research. Even the perception that such a danger exists damages our ability to attract the brightest, most creative students. It is imperative that research advisers (both inside and outside users), directors, and Program Advisory Committees (PAC's) at user facilities encourage students to participate actively in all aspects of proposed research, including the planning and defense of the proposal. Toward this end, user laboratory directors should investigate mechanisms for supplementing normal PAC beam-time allocations with the purpose of allowing students somewhat more leeway to make and find their own mistakes.

In addition to their obvious service to outside user groups participating in experiments, there are a number of ways in which the university-run user facilities should be encouraged to serve the long-term needs of the nuclear science community, especially of smaller university laboratories and nuclear research groups. (1) There are typically vigorous ongoing accelerator development and upgrade projects at these facilities. Encouragement of student participation in aspects of these projects, with degrees awarded for nuclear science research specializing in accelerator technology, can help to replenish the vanishing breed of "machine physicists," who are essential to progress in experimental nuclear and particle physics. The shortage of such physicists is especially acute in university research groups, and makes significant upgrade or accelerator construction projects at small laboratories very difficult.
(2) The vigorous ongoing equipment development projects referred to above are often more than can be reasonably handled by the staff at the user facility. Specific substantial equipment development -e.g., of ion sources, magnetic spectrographs, polarized targets, complex detection apparatus - can sometimes be "farmed out" to outside university user groups to the mutual benefit of all concerned. This sort of cooperation can help to meet the desired goals of the user facility, while bringing more research funds to the outside group, and providing them with an on-site "presence" at the home institution. (3) User facilities at universities are especially well equipped to serve as host

institutions for outside user students, affording them the same exposure to a wide variety of experimental research as is available to in-house students. Cooperative agreements among universities, e.g., allowing courses taken at the user institution to count for credit, and supporting occasional faculty leaves to user laboratories at which students reside, could help to make this a viable and mutually beneficial policy.

IIC. University Research with User Facilities at National Laboratories

The evolution of the user mode of research in nuclear and particle physics seems, in retrospect, to have been almost inevitable. As the avenues of research have led to a requirement for higher and higher energies per nucleon as well as better beam quality, cost and complexity have increased such that, very often, these are too high to be borne or justified unless there is widespread use such as the user mode permits.

As with all choices, the user mode gives rise to advantages and disadvantages. Some of these are discussed below.

In order to work at the frontier of nuclear science, it is becoming ever more necessary to utilize large, complex and expensive facilities. Where such a facility is one of a kind, it provides unique as well as forefront research opportunities. Very small university groups, which would normally be far below criticality, can participate in the most exciting research by collaborating with researchers from other institutions, including the one where the facility is based.

In the user mode the capital and operating costs per user become much more affordable than they would otherwise be, because the method of operation permits the use of a given facility by many researchers, on a wide variety of problems, the complexity of which has also increased with time. That is to say, the preparation and analysis of an experiment have gotten longer in time, so that the relative fraction of time occupied in facility use is less than in the past, and the facility thus must involve a larger number of people than was the case formerly, if it is to be cost effective.

This capacity for multiple use and the special opportunities offered at user facilities tend to attract users from a large geographical area, typically the entire United States, and often from Western Europe, the Near and Far East, and Australia. Thus the influence of the facility is similarly expanded, often to become worldwide in extent. Scientific activity may be stimulated over a very large region.

Related to the increasing complexity of experimentation and of research machines is the requirement that a competent staff be recruited and retained at the user facility. Such a specialized group is difficult to acquire and keep and requires its own special needs for management and professional accomplishment.

A Program Advisory Committee (PAC) is a universal and necessary characteristic of a user facility. The PAC consists of several, typically five to twenty, researchers of high competence in the research capabilities of the facility. It meets to evaluate research proposals submitted to the facility, and performs this evaluation on several bases: appropriateness and timeliness of the proposed research, demand on resources at the facility, competence of the proposers to do the proposed work, technical and budgetary feasibility, and similar considerations.

PAC operation is a kind of prompt, personalized, and visible peer review. Its relation to education lies in the opportunity provided students and beginning scientists to observe the dynamics of interactions among their senior colleagues; thus the student is given instruction not only in scientific matters, but in the techniques of presentation, persuasion, and politics, which enter into the process of undertaking and accomplishing a successful research program (assuming that PAC operations are open to some extent, as many are) at a large facility.

If the PAC serves its role, there is a large measure of assurance that research undertaken at the facility will lie, as it should, in the areas of greatest importance to the progress of the field. On the other hand, the point is sometimes made that PAC's tend to make for conservative, "bread and butter" experiments, perhaps not always yielding the best science.

The user mode offers some disadvantages. One of the most crucial of these, one which appears to be widespread in the user community, is a lack of appreciation of the user-traveler by his colleagues who stay at home and occupy themselves with other kinds of research, the sort which is often called "table-top" physics. Multiple authorship of papers is sometimes regarded as evidence that none of the participants worked hard enough to deserve credit for the paper. This view, though naive, is not uncommon within many universities, some of whose faculty participate in user-mode research. It works hardship particularly on the junior faculty participant in matters of promotion, tenure, and salary increments. Other disadvantages are that a student may find it more difficult to be involved in all phases of an experiment, especially the very sophisticated instrumentation.

For the reason that absences from the home campus are sometimes frequent, or as for students, fairly extended, there tends to be a loss of association, sometimes even an alienation, from the home campus. These absences may lead to personal inconvenience or problems; the latter are a fact of the user's life. The user's interactions are sometimes more with peers than with home colleagues. The user mode certainly makes faculty less visible at their home institution, which may be seen as limiting their contribution to intellectual activities at home. However, their frequent visits to a large, interdisciplinary laboratory can also be a valuable learning experience for them and thereby make their interaction with colleagues and students at home more intellectually invigorating to all concerned.

For students there may be a lack of opportunity for continuing learning opportunity at the user facility, depending upon its relative remoteness from a university, for example, or on university policy even if the facility is not remote. If there is such a shortfall, it can usually be remedied without difficulty through the devices of short courses, special lectures, and the like. But the effort must be made and the necessary resources expended.

In the past, perhaps more than at present, there has sometimes been the objection made that user facilities take funding away from local research projects. This objection does not appear justified, in the long-range view, in the light of the evolution of the nature of research in nuclear science toward higher energies and more complex facilities. Offsetting the objection is the fact that large facilities are required for forefront research, which is necessary to keep the disciplines alive. Another factor is the increased opportunity for outstanding research at the frontiers of science through the large array of amenities offered at user facilities. The numerous user groups at the several user facilities throughout the United States demonstrate that aggressive fund-seeking still works. In fact, user participation at user facilities may actually be an advantage in fund-seeking.

IID. Mixed-Mode University Research

The mixed-mode operation of nuclear research has the advantage of making available to university groups the best large forefront accelerator facilities while at the same time these groups can retain, to a large extent, contact with their home facility, department and university.

This mode of research allows students to have close associations with their peers and faculty in an informal university atmosphere, a factor that can be a positive aspect in a student's early training. The availability of courses and seminars on campus enhance the opportunities for early scientific development of both undergraduate and graduate students. The opportunities for interaction between experimentalists and theorists are certainly enriched in a university setting. Essentially all aspects of a student's early growth and development are supported by the university environment. In the first two or three years of graduate study, students are usually required to meet course schedules, examination requirements and, in many cases, teaching assistantship obligations. Insofar that early participation in research is an important part of advanced training, this aspect of graduate study can be more easily integrated with other university responsibilities when an on-site nuclear accelerator is available.

Students from universities with home facilities have a better opportunity early in their careers to participate actively in all phases of an investigation than students limited to large user's facilities. With home facilities, students obtain early training in mounting and running experiments in a less "pressured" environment than at a large user facility. Furthermore, the mixed-mode operation allows the possibility for preliminary test runs at the smaller home facility, as well as follow-up runs, to complement experiments performed at large user accelerators. The research experience gained at a large user's facility can serve to enhance the research program at one's home facility, and in most cases serves to counteract any possible disadvantages arising from the manpower drain from the home facility. The mixed-mode operation of nuclear research allows groups to extend home-based experimental programs into areas, for example, of energy and angular momentum, that are accessible only at a larger user facility with its range of projectiles and energies. Hence, this mode of research offers the possible complementarity of experiments carried out at both home and user's facilities.

Students with early experience gained at their home facility are better prepared to take advantage of the more complex equipment and forefront beams available at large user's facilities. The exposure of advanced students to the variety of techniques and research opportunities at a large user's facility is a real advantage of the mixed-mode operation over research carried out solely at a small university facility. In many respects the best features of both the latter two research modes are incorporated into the mixed-mode operation while many of the accompanying disadvantages are minimized.

The availability of a home accelerator facility ensures the nuclear science user group of the necessary visibility on campus needed to appeal to both quality graduate and undergraduate students. Furthermore, the opportunity during graduate training to conduct experiments at a large forefront user facility serves as an additional enticement to study nuclear science. Hence, the mixed-mode method of performing research in nuclear science at universities has a number of significant advantages both for carrying on forefront research and training of students.

It is obvious that funding of the mixed-mode operation may become difficult if the home-based facility does not in its own right retain its vitality for forefront research. Many of the benefits of mixed-mode operation can be realized if major new accelerator facilities are located on or near university campuses whenever it is consistent with efficient operation of such facilities. We feel that priority should be given to such locations.

III. BALANCE AMONG VARIOUS NUCLEAR RESEARCH MODES

Forefront nuclear research at universities is carried out in several operational modes as described in section II. In this section arguments are presented for the continued need for small university-based facilities and, in addition, for the special needs of university user groups.

IIIA. Continued Need for Small University Based Facilities

Nuclear research carried out on small university facilities still plays a vital role in nuclear physics. In a recent issue of Physical Review C approximately one-half of the articles reported work that was done at such university laboratories or that was involved with the physics addressed by these laboratories. The research ranges over most of the areas of nuclear physics and is limited only by the energy and type of probe available in these facilities. We mention here only a few examples of the important research that is now actively pursued or will be carried out with these facilities.

In the area of nuclear structure there continues to be a real need to measure properties of nuclear levels. This research is now more selective than in the past and is usually motivated by the desire to test new or refined theories or calculations of nuclear structure. An example is the great revival of interest in nuclear properties that has been stimulated by the IBA theory. Another example is the renewed interest in the high-spin, stretched states because of their simple shell-model configurations. Yet another example, is the measurement of the properties of the high-spin, collective states and fission isomers that can be produced in some "small" facilities. These measurements rely heavily on methods still being developed at these facilities. Of special interest are the magnetic and electric moments of these states.

The measurement of nuclear moments continues to be an important area of investigation. Measurements of moments of short-lived radioactive species are still scarce, as are those of excited states in certain lifetime regions. Very few reliable electric quadrupole moments have been obtained. There is still a need to develop better methods for all these measurements. These studies are ideal for the small facilities.

An interesting outcome of research at intermediate energies or with the use of new probes, pions, etc., has been a rekindling of interest in nuclear phenomena long studied at low energies. Thus, studies of giant resonances, analogue states, spin-flip modes, isospin splitting, and isovector modes are now being intensively pursued. The small facilities are still making vital contributions to these studies.

In the past few years polarized beams of high intensity and good polarization have become available. These beams have opened a new dimension in the study of nuclear reactions and properties. These studies are far from complete and will need to be pursued for some time to come.

Similarly, despite the fact that they are an historic probe of nuclear physics, fast neutron beams, both polarized and unpolarized, have only recently come into their own as probes in many areas of nuclear physics. Examples are the study of polarized fast neutron capture and scattering.

A very active area of research with the small facilities is the study of the properties of the weak forces. Parity nonconservation in nuclear transitions and scatterings has been and is continuing to be used to elucidate the structure of the weak non-leptonic forces. Indeed, nuclear processes offer a unique tool for such exploitations. Beta decay from both polarized and unpolarized nuclei has been used to search for second-class weak currents and to learn more about weak semi-leptonic force.

As a final example we cite the study of nuclear symmetries. Recently time reversal invariance has come under close scrutiny and is being tested in polarized reactions and in electromagnetic transitions. Isospin invariance remains an active subject, as mentioned above. The search for parity non-conservation has been and is continuing to be carried out primarily on the small facilities.

Many of these experiments on the weak force and on symmetry have been made possible by the availability of good polarized beams. With the advent of a new generation of greatly improved polarized ion sources we can expect these studies to continue and to lead to new investigations.

Nuclear science laboratories have contributed significantly to the research and training of students in other sciences outside physics including astronomy, chemistry, nuclear medicine, biology, geology and archaeology as well as to other subfields within physics including particle physics, astrophysics, atomic physics, condensed matter physics and materials science.

IIIB. Special Needs of University User Groups

Until the onset of the last decade most research in nuclear science was carried out by people using their own in-house facilities either at universities or at national laboratories. This situation has been and is very different from that in high energy particle physics where the requirement of very large accelerators dictates that all available machine funds be allocated to a very limited number of facilities of optimal performance as measured by a few parameters as, for example, beam energy and intensity. Although research problems in nuclear science require a much larger and diverse arsenal of projectiles with a wide range of "optimal" energies, research requirements and funding trends in nuclear science over the last few years are moving the nuclear science community to extensive use of large national and regional facilities. The increasing complexity and cost of accelerators in both medium energy physics and intermediate to high energy heavy-ion physics necessitates that only a very few existing nuclear science groups (particularly those at universities) can expect to have such a facility. Hence, most groups working in these areas of nuclear science are now, or will be in the near future, working in the user mode of operation.

With large numbers of university based nuclear scientists doing research in the user mode, it is important to examine the structure and operation of these groups on campuses. In order to attract an adequate supply of future nuclear scientists, both in quality and in quantity, it is essential for a user group to have a highly visible program on campus (this is essential for attracting undergraduate as well as graduate students). The funding level, at least for major groups, needs to be sufficient to allow the group to engage in a wide spectrum of activities in their home laboratory. In addition to having elaborate data analysis capabilities, user groups can be much more effective in training students if other activities, such as detector development, are also carried out on campus.

Therefore, in order to provide a wide breadth of experience for students and research associates in a number of leading universities, it is important to support a number of successful user groups with some highly visible facilities at their home institutions. This approach implies also a wider distribution of the experimental development funds to user groups in order to increase their vitality. The development of dynamic capabilities of the user mode of operation requires a greater degree of interdependence between the outside user groups and the host accelerator facilities. Clearly the particle beams only exist at the accelerators but this does not mean that most of the development of detectors, experimental equipment and data reduction facilities have to be concentrated also at the same sites. The diversification of the latter efforts is important not only for the development of stronger user groups but especially for the broader training of new young nuclear scientists. One advantage of involving the user groups in the development of experimental instruments is to produce a better balance between equipment and accelerator development. The latter development projects tend to dominate at large accelerator laboratories and the placement of the main part of the equipment development with university user groups will, in the long run, strengthen nuclear science. Such a division of effort will more nearly parallel that in high energy particle physics.

Insofar that major university user groups must spend extended periods of time away from campus, it is important to fund advanced research positions in a number of these groups. This allows needed flexibility for meeting teaching schedules and other university responsibilities as well as greatly improving overall group efficiency at an off-site national laboratory. In addition, the quality of the educational experience for students is greatly enhanced when more senior members are present during the experiment, which necessarily in the user mode is run under considerably more pressure than at a small university based facility. The addition of senior research scientists to university groups will put these groups on a more equal footing with competing groups at national laboratories.

Another sizeable research cost unique to the user mode operation is for travel. Funding in this area is a vital part of the overall budget and must be adequate to meet the rising costs of travel expenses.

IV. IMPROVEMENTS OF NUCLEAR PHYSICS EDUCATION

It is well known that (1) exciting discoveries attract students to a field. Other factors which are described in this report include (2) the exposure to outstanding teachers, courses, and laboratory programs, (3) funding patterns, (4) grants, fellowships and assistantships, (5) the opportunity to develop independent research programs, and (6) the broad applicability of the training to existing sciences.

These features apply to nuclear physics. Examples of exciting recent discoveries are Gamow-Teller transitions and other giant resonances (including the breathing mode), dynamic symmetries, e.g. the interacting boson approximation, high angular momentum (spin) states, parity nonconservation in nuclei, and the importance of exchange currents and excited nucleon [e.g. $\Delta(1236)$] degrees of freedom in nuclei.

As pointed out earlier in this report, the attraction of students of high quality to nuclear physics is optimized if the conditions outlined in (1) to (6) are satisfied. At the undergraduate level the presence of a number of outstanding research nuclear physicists at a given university is bound to attract students to nuclear physics through their exposure to courses taught by these individuals. Furthermore, courses taught by nuclear physicists are likely to include some nuclear physics, which will further enhance the attractiveness of the field to students. The presence of nuclear physicists on the faculty also results in the development of meaningful laboratory courses which include nuclear experiments. We have not been able to study systematically the influence of such laboratory courses on career choices, but we know of students who definitely were influenced by them. Similarly, meaningful participation of undergraduates in research programs has been proven to be effective in developing students' interest in nuclear physics. Again, we have not carried out a study to show the effect of such participation in career choices, but we know several outstanding researchers who were attracted to nuclear physics through such exposure. Clearly, it is much easier to make such opportunities available to students at universities which have nuclear research laboratories on site or close by. Until recently the National Science Foundation had programs to encourage undergraduate research participation, but these funds have disappeared. To compensate for this loss, many laboratories have used research contract funds to attract students in summer or year long research programs.

At the graduate level, there are a number of improvements which can be made. New modern texts on nuclear physics are required. Revitalization of university nuclear programs and the attendant increase in good students would create the motivation and pressure for producing texts that are abreast of the forefront developments in the field. Additional fellowships and assistantships clearly would be helpful to graduate programs. Research participation just prior to entering graduate school is bound to affect a student's career choice. Clearly, if a student is to be trained to be a leader in nuclear physics research, it is essential that he/she be exposed to modern instrumentation. He or she should be able to participate in the design, construction, and upkeep of modern nuclear physics equipment.

A "home" research laboratory generally allows graduate students to participate in all phases of an experiment and ultimately to plan their own experiment under the guidance of a faculty member. It is under such circumstances, in a well equipped laboratory, that a student is best able to show her or his abilities. An outstanding student finds such an opportunity attractive if first rate research can be carried out. At a user facility, it is more difficult to bring out the student's talents since she or he participates in only one or a few phases of an experiment.

Two recent surveys allow us to draw some interesting conclusions. The NRC survey of Ph.D. recipients in nuclear physics shows that the percentage of nuclear physics students who have received their Ph.D.'s at institutions which have or have had home facilities during the period 1972-1980 has remained roughly constant at 50-55% with a maximum deviation of ~5%. On the other hand, if the group of universities is reduced to those which still have home-based accelerators[1)] the percentage of Ph.D.'s produced in nuclear physics at these institutions has increased from about 36 to 50% over the same period with fluctuations of > 5%. We believe that this difference is correlated directly with the better funding of these laboratories.

Although research facilities are funded primarily for the scientific research they produce, graduate student training is also an important by-product of all research facilities. The number of students trained at the larger national facilities is not proportionate to their increased cost. This is evident in the Manpower Report[2)] recently submitted to NSAC, showing that universities with home-based facilities had approximately 50% of the graduate student population engaged in nuclear physics research, but received less than approximately 20% of the total operating funds. Another way of stating this figure is that the operating funds per graduate student were ten times as high at LAMPF and Bevalac and four times as high at intermediate size facilities as those at small university facilities. [See Table 1].

1)Cal Tech, Colorado, FSU, Illinois, Kentucky, Notre Dame, Ohio State, Ohio University, Pennsylvania, Pittsburgh, Princeton, Rochester, Rutgers, Stanford, Stony Brook, Texas A & M, TUNL, Washington, Wisconsin and Yale.

2)Census of Basic Nuclear Scientists in the U.S. (11/81), F. Ajzenberg-Selove, P. D. Parker, and J. Cerny (Chairman).

Table 1

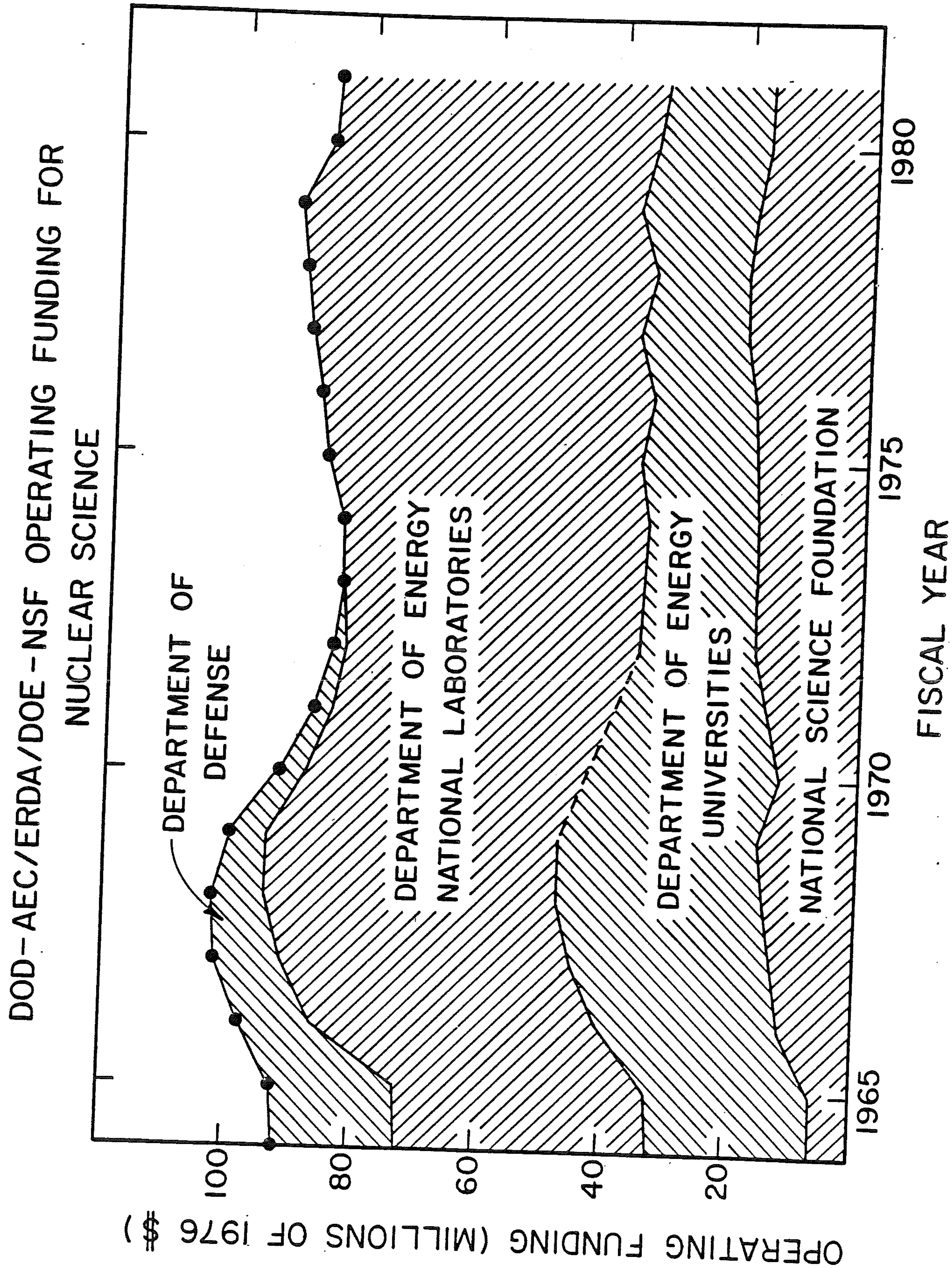
	Number of Grad. Students[2)]	%	FY '81 Oper. Funds (1000)	Oper. Funds/ # Grad Students
Home Based Laboratories[1)]	123	50	18,000	150
LAMPF and Bevalac	31	13	47,000	1500
ANL,BNL,IUCF, LBL(SH),MIT,MSU,ORNL	52	21	31,000	600
Other	39	16	?	

V. FUTURE MANPOWER NEEDS IN NUCLEAR SCIENCE

The deliberations of this subcommittee have been stimulated largely by concern about the trends established throughout the past decade in federal funding of basic nuclear science research in the U.S. and in the education of young nuclear scientists. Some relevant aspects of these trends are illustrated in Figs. 1-3. As seen in Fig. 1, a rapid rise in overall operating funds (in constant 1976 dollars) for nuclear science research in the late 1960's was eradicated by a sharp drop during the early 1970's (during this period there was a large increase in construction funds for LAMPF). From 1973 through 1978 the overall operating funding for nuclear science then increased slowly, followed by a downturn in 1979-80, when corrected for inflation via the Consumer Price Index (which, however, significantly underestimates the effective inflation rate relevant to high technology research). As important as the trends in overall support level is the qualitative change which occurred during the 1970's in the balance between funding of nuclear research facilities sited at national laboratories vs. universities. Following a dramatic drop in funding for universities after 1968 the small funding increases of the middle 1970's went essentially completely into operation of national laboratories, especially of the large new facilities at Los Alamos and Berkeley, while the sum of NSF and DOE support for university-based laboratories remained nearly constant. Furthermore, a substantial fraction of that support has been channeled in recent years into a few relatively large user facilities sited at universities. As a result of inflationary pressures, a large number of smaller university-based facilities have lost their federal funding, as illustrated in Fig. 2. In 1982 there are a factor of three fewer active nuclear research facilities at universities than there were in 1969. At a number of the small university laboratories which remain operational, funding is presently marginal, and the faculty and staff

Figure 1

Operating funds (in constant 1976 dollars) in nuclear science for the last fifteen year period. Data from the Report of the National Science Foundation Subcommittee (D. A. Bromley, Chairman) to Review NSF Supported Nuclear Science Laboratories (1979) and Peter Parker, private communication (1982).

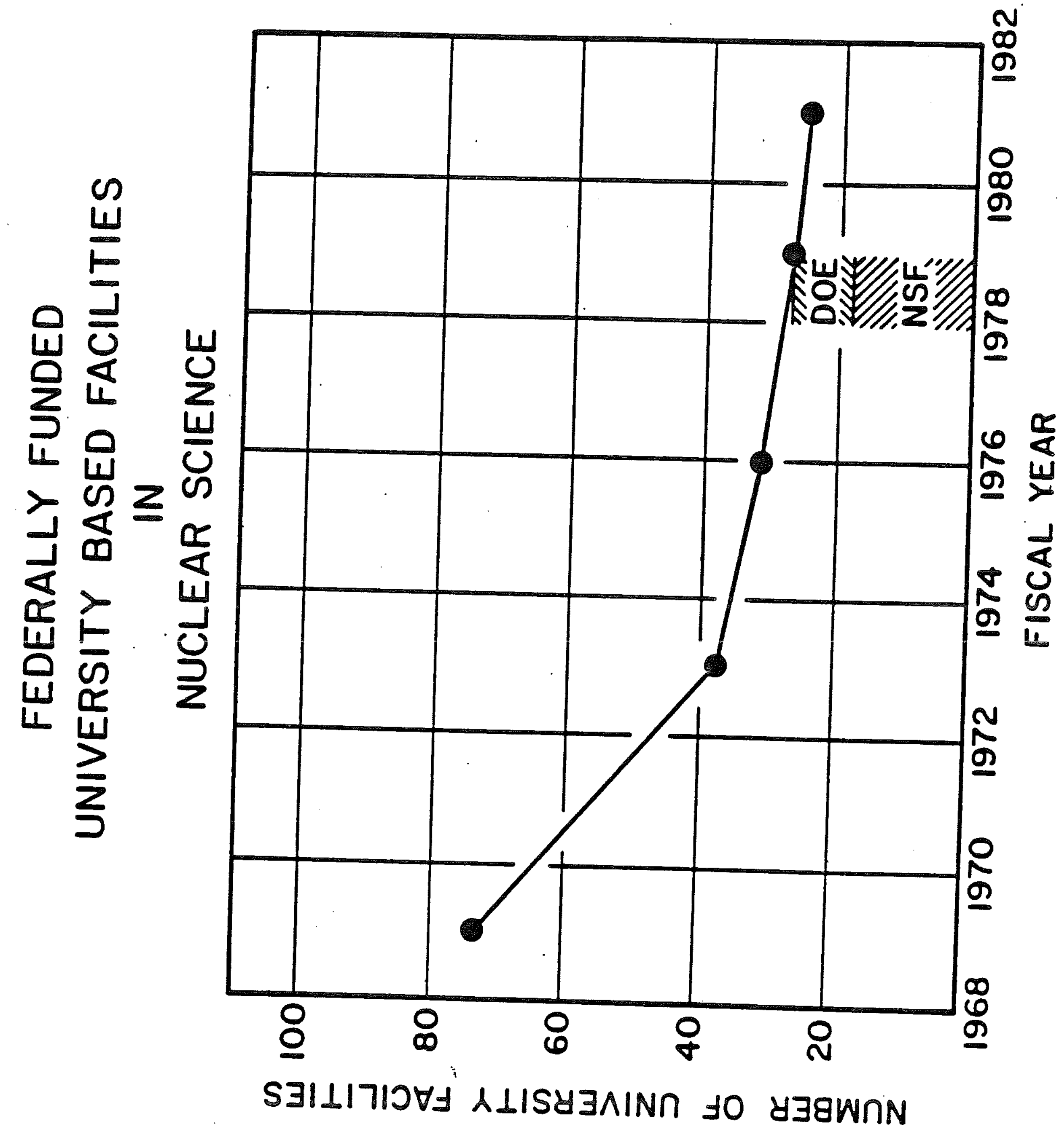


DOD-AEC/ERDA/DOE-NSF OPERATING FUNDING FOR NUCLEAR SCIENCE
DEPARTMENT OF DEFENSE
DEPARTMENT OF ENERGY NATIONAL LABORATORIES
DEPARTMENT OF ENERGY UNIVERSITIES
NATIONAL SCIENCE FOUNDATION
OPERATING FUNDING (MILLIONS OF 1976 $)
100
80
60
40
20
1965
1970
1975
1980
FISCAL YEAR

Fig. 1

Figure 2

Number of university based facilities in nuclear science. Data from the Report of the National Science Foundation Subcommittee (D. A. Bromley, Chairman) to Review NSF Supported Nuclear Science Laboratories (1979) and Peter Parker, private communication (1982).



FEDERALLY FUNDED
UNIVERSITY BASED FACILITIES
IN
NUCLEAR SCIENCE
NUMBER OF UNIVERSITY FACILITIES
100
80
60
40
20
1968
1970
1972
1974
1976
1978
1980
1982
FISCAL YEAR
DOE
NSF

Fig. 2

Figure 3

Number of Ph.D. degrees award from 1965 to 1980. From the 1980 Census of Basic Nuclear Scientists in the U.S., F. Ajzenberg-Selove, D. D. Parker and J. Cerny (Chairman).

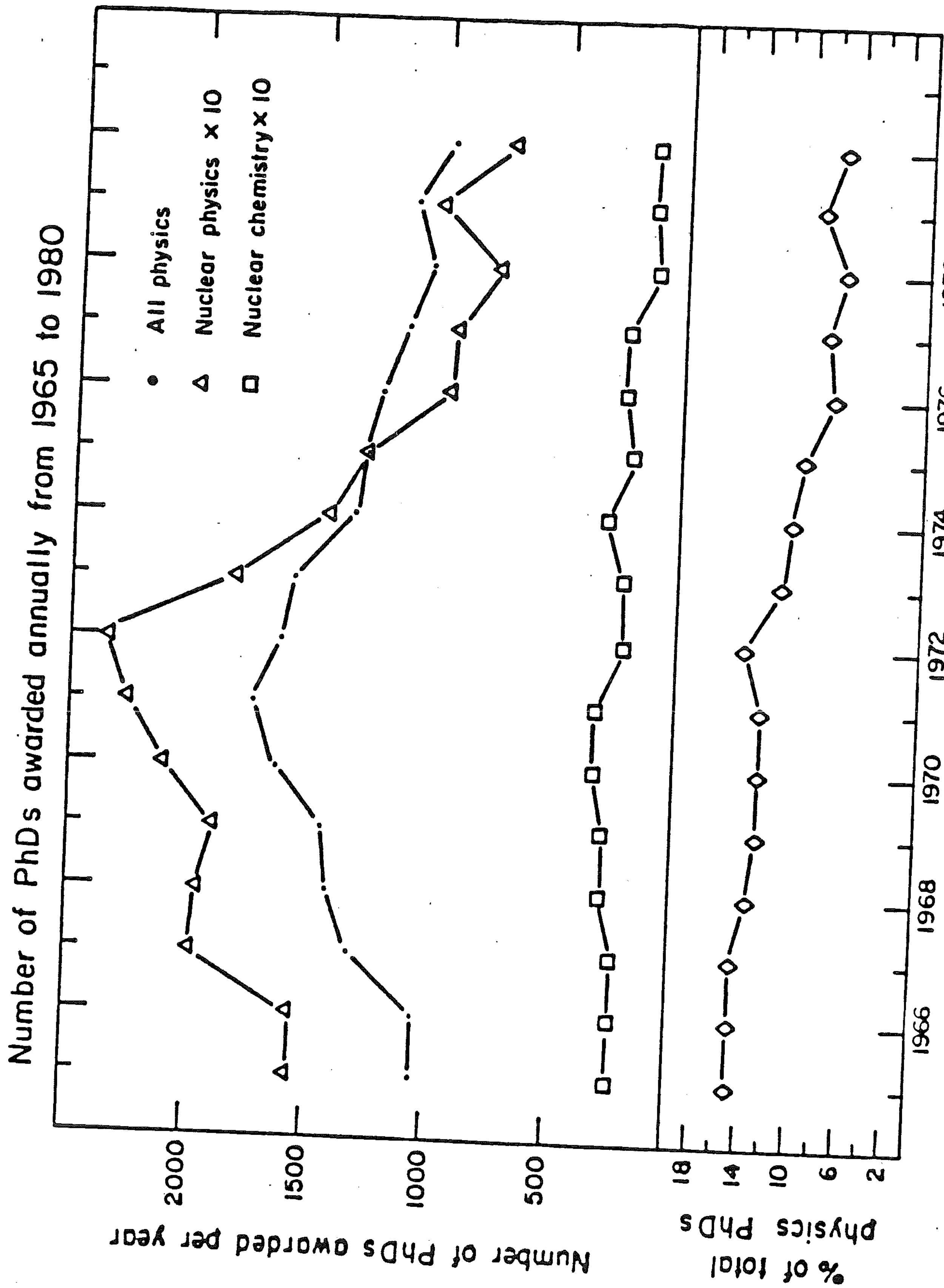

Number of PhDs awarded annually from 1965 to 1980
All physics
Nuclear physics × 10
Nuclear chemistry × 10
Number of PhDs awarded per year
% of total physics PhDs
2000
1500
1000
500
18
14
10
6
2
1966
1968
1970
1972
1974
1976
1978
1980

Fig. 3

have suffered a serious erosion of confidence in their ability to continue being supported on more than a temporary basis.

The funding patterns illustrated in Figs. 1 and 2 are reflected in Fig. 3 in the evolution with time, between 1965 and 1980, of the number of Ph.D.'s awarded annually in nuclear science. The peak in federal funding reached in the late 1960's produced a peak in graduate student training in 1970-72, not only in nuclear science, but in all physics subfields combined. The lower funding levels of the 1970's have been accompanied, again in all physics subfields combined, by a substantial drop in Ph.D.'s awarded. However, the decline has been most precipitous in nuclear science, which from 1965 through 1972 produced a nearly constant 14% of all physics Ph.D's, but by 1978-80 produced only 7-8%. This drop by a factor of two in relative numbers of nuclear science Ph.D.'s has, as we shall make clear below, serious implications for the future manpower supplies needed to carry out the research programs which we feel are warranted by recent and current scientific progress in the field. The decline in nuclear science Ph.D.'s was not an intended goal of federal funding decisions, but it must be traced at least in part to the closing of so many university laboratories during the 1970's. We do not question these past funding decisions; the increased concentration of resources in relatively few large user facilities was an inevitable result of a transition in the nature of the questions addressed by nuclear science research. However, the experience of the past decade points up clearly the importance for future planning of 1) identifying positive measures which may help to improve the educational effectiveness of the various modes of nuclear science research discussed in section II, and 2) folding long-term manpower considerations as well as shorter-term research efficiency into decisions regarding the balance among various types of experimental facilities.

The basic aim of this section is to illustrate how the quantitative manpower needs associated with a long-range plan for nuclear science research may be estimated, and to demonstrate that continued production of nuclear science Ph.D.'s in the U.S. at the present rate will fall far short of meeting any reasonable estimate of those needs. Before proceeding we should note that there is already a widespread perception throughout the nuclear science community, among those currently attempting to fill available post-doctoral and junior staff or faculty positions, of a serious crisis not only in the quantity but also in the <u>quality</u> of applicants trained in the U.S. In particular, we and many of our colleagues feel that the number of highly qualified applicants has, if anything, declined even more rapidly than the total number of nuclear science Ph.D.'s awarded annually. This perception is difficult to document, but two relevant factors are worthy of consideration. The first is that we are only now emerging from a period of about 10 years during which few permanent positions in basic nuclear science research became available each year. This uncertain job outlook must certainly have discouraged a significant number of promising students from beginning graduate work in nuclear science, and furthermore discouraged a significant fraction of those who did get Ph.D.'s from passing up the much higher salaries available in applied research and development positions in industry. These trends are of course not unique to nuclear science, and they may well be self-correcting to some extent through the next decade, when reasonable projections of tenure-line openings at universities and government laboratories suggest that demand will begin to exceed the supply of nuclear scientists (see 1978 NSAC Manpower Census).

The second, more worrisome, factor which may have contributed to a crisis in quality as well as quantity is that those research groups which have traditionally supplied the nuclear science community with large quantities of highly qualified Ph.D.'s have not been especially protected from the general cutbacks in funding for university-based facilities. According to the 1978 NSAC Manpower Census, there were ten U.S. universities* which, during the period 1970-77, graduated at least 25 Ph.D.'s in nuclear physics, of whom greater than 20% remained in the field by 1978. These above-average retention rates provide some objective evidence that the graduates of these universities were often judged to be of high quality by other institutions hiring young researchers in basic nuclear science. All ten of these universities operated their own accelerator facilities in the early 1970's; by 1982, facilities at four (Maryland, Minnesota, Stanford, Texas) of the ten have been closed, and a fifth (Wisconsin) will shortly lose support from its present funding source. Although some of these groups have made a reasonably successful transition to operation in the outside user mode, this transition has certainly reduced the number of students trained, and has had as yet poorly studied effects on the quality of student training.

In attempting to assess the level of crisis in the U.S. training of nuclear scientists, and the quantitative corrections needed, one must project the demands of basic research, applied research, and industrial research, and the supply of nuclear scientists well into the future. There are, of course, sizable quantitative uncertainties associated with any such projections. For example, an estimate of future demand requires assumptions about the mixture of large, intermediate, and small accelerator facilities which will be warranted by scientific activity in the field, and about the number of Ph.D. scientists needed for optimum operation of the various kinds of facilities. There are also many unfathomable factors influencing the attractiveness of nuclear science to undergraduate and graduate students, the fraction of Ph.D.'s

---

*Duke, Michigan State University, MIT, Stony Brook, Stanford, Univ. of Maryland, Univ. of Minnesota, Univ. of Texas, Univ. of Wisconsin, Yale.

likely to remain in permanent positions within the basic research community, the number of conversions to nuclear science from other disciplines etc., and hence the manpower supply for the long-term future. In view of these uncertainties we have adopted a limited goal in the following numerical examples of supply-demand comparisons. For several different conceivable mixtures of facility types, each involving a significant reduction from the present level of manpower (and hence probably also research productivity) in basic nuclear science, we use presently available data (primarily from the 1978 and 1980 NSAC Manpower Censuses) to estimate steady-state demand and supply. This exercise serves to illustrate the interrelationships between the facility mix and the ability of the community to supply sufficient manpower to operate those facilities, and also the magnitude of the problem we face in supplying such manpower at present rates of student training.

The essential ingredients and results of our steady-state supply-demand estimates are given in Table 2. The numbers of full-time-equivalent (FTE) Ph.D. nuclear scientists assumed necessary to operate future facilities in various classifications at efficiency levels comparable to those attained presently (which are sometimes less than desirable) are based simply on averaging the appropriate current numbers from the 1980 NSAC Manpower Census[2]) over the active laboratories of each variety. Note that there are approximately 85 Ph.D. FTE's presently involved in research at foreign, high-energy, or applied facilities; some such involvement is healthy for U.S. nuclear science, and we assume in Table 2 that it will continue at the current (absolute) manpower level. Usage of all available accelerator facilities currently occupies 630 Ph.D. FTE's, slightly more than half the total number of Ph.D. scientists in basic nuclear research. The factor of 1.9 difference between total Ph.D. scientists and Ph.D. FTE's utilizing accelerator facilities reflects the present

Table 2. Estimates of Steady-State Ph.D. Manpower Demand and Supply for Three Different Mixtures of Nuclear Research Accelerator Facility Types

Facility or Group Classification[a]	Input Data[b]: Average #Ph.D. FTE Researchers Required for Operation	Input Data[b]: Average #Ph.D.'s (Theory + Experiment) Awarded Annually	Projections: Number of Facilities or Groups			Ph.D. FTE's Occupied			Ph.D.'s Awarded Per Year		
			Mix I	Mix II	Mix III	Mix I	Mix II	Mix III	Mix I	Mix II	Mix III
Large user facility, national laboratory	62		3	3	4	186	186	248			
Medium-sized user facility, university	20	4.0	3	4	3	60	80	60	12	16	12
Medium-sized user facility, nat'l laboratory	27		3	3	3	81	81	81			
Small facility, university	6.3	2.6	20	14	6	126	88	38	52	36	16
Small facility, nat'l laboratory	14		1	2	3	14	28	42			
All other accelerator facilities combined	85					85	85	85			
Exclusive outside user group with >4 Ph.D.'s on perm. staff		0.8	35	40	49				28	32	39
All other (<4 Ph.D.'s) outside user groups combined		10							10	10	10

	Mix I	Mix II	Mix III
Total Ph.D. FTE's =	552	548	554
x 1.9 → total Ph.D.'s needed in field =	1049	1041	1053
Total Ph.D.'s awarded/year =	102	94	77
x0.35→U.S. Scientists entering (leaving) temporary pool/year =	36	33	27
x0.5→U.S. Scientists entering permanent pool/year =	18	17	14
Total U.S. Ph.D. Pool (temporary/year x 4 years + permanent/year x 30 years) =	684	642	528
Fraction of total Ph.D.'s needed in field =	0.65	0.62	0.50

a) See 1980 NSAC Manpower Census, Tables X,Y,Z, for facilities which currently fall in each of these classifications.

b) Input data are based on currently applicable numbers extracted from 1978 and 1980 NSAC Manpower Censuses.

Appendix to Table 2. A Sample Calculation for Mix III

A. Steady State Ph.D. Manpower Requirement in Nuclear Science

Total number of Ph.D. FTE's required for accelerator research in nuclear science =

$$62x4 + 20x3 + 27x3 + 6.3x6 + 14x3 + 85 = 554$$

Total number of Ph.D.s needed in all of nuclear science (including theory and non-accelerator research) =

$$554 \times 1.9 = 1053$$

B. Steady State Ph.D. Manpower Pool in Nuclear Science

Total number of Ph.D.s produced annually =

$$3x4 + 6x2.6 + 49x0.8 + 10 = 77$$

Total number of Ph.D.s entering nuclear science pool per year =

$$77 \times 0.35 = 27$$

Total number of Ph.D.s entering nuclear science pool per year on a permanent basis =

$$27x0.50 = 14$$

Total steady-state pool of nuclear scientists =

$$27x4 \text{ years in pool} + 14x30 \text{ years in pool} = 528$$

C. Fraction of Manpower Needs Produced by Mix III

$$528/1053 = 0.50$$

values for the ratio of theorists to experimentalists in the field (≈0.2), and also for the average fraction of experimentalists' time devoted to accelerator-based research. We use this same factor of 1.9 in Table 2 in estimating the total number of Ph.D.'s which would be needed in the field to support possible future mixtures of facility types. It must be noted, however, that the present crisis in student training is equally severe in nuclear theory and it will require substantial corrections to present trends to maintain the present ratio of theorists to experimentalists.

The average number of nuclear science Ph.D.'s awarded annually by all "Type A" U.S. universities (58 institutions with at least four nuclear science Ph.D.s on their permanent staffs) with facilities or research groups in the various categories specified in Table 2 has been estimated from Table 4 of the 1978 Manpower Census,[3] by assuming that the experimental graduate students reported in training there remain so for an average of 3.3 years, and that 20% as many Ph.D.'s are awarded in nuclear theory as in experimental nuclear science. From the 1978 and 1980 censuses one may expect a total of roughly 10 Ph.D.'s in nuclear science to be awarded each year by all "type B" universities (68 institutions with 1-3 nuclear science Ph.D.'s on their permanent staffs) combined; we assume in Table 2 that this number will remain constant in the future.

Each of the three alternative long-term mixtures of facility types considered in Table 2 is constrained to require approximately 550 Ph.D. FTE's for operation of all the facilities combined, and thus to correspond to a steady-state total of approximately 1050 Ph.D. nuclear scientists in temporary

3) "The 1978 Census of Basic Nuclear Scientists in the USA" by G.D. O'Kelley, D.D. Parker, F, Aizenberg-Selone (Chairman), T. Sugihara and J.D. Walecka.

and permanent basic research positions. These numbers represent about a 10% reduction from the current (1980 Census) manpower level. The three mixtures differ primarily in the balance between small university laboratories and the other classifications of facilities. In estimating the total number of nuclear science Ph.D.'s which would be awarded per year for the three mixtures, we assume that the total number of "type A" university groups will remain constant at the level (58) of the 1980 Manpower Census, so that groups which lose their accelerator facilities will still remain active in an outside user mode. This assumption ignores a disturbing trend toward significant reduction in the ranks of type A university groups indicated by comparison of the 1978 and 1980 censuses. Since groups operating exclusively in an outside user mode currently train substantially fewer students than groups with an in-house small accelerator facility, the decrease in such small facilities from mixture I to mixture III in Table 2 is accompanied by a significant drop in the projected number of Ph.D.'s awarded. If the analysis of Table 2 were applied to the current mixture of facilities in the field, (which is similar to Mixture I in the table) one would expect slightly over 100 Ph.D.'s per year, a number close to the average production (for nuclear physics and nuclear chemistry students combined) for the years 1977-80.

At the bottom of the last three columns in Table 2 we estimate, for each facility mix, the total pool of Ph.D.'s in temporary (post-doctoral plus visiting) and permanent positions in basic nuclear science research which could be supported by steady-state Ph.D. production at U.S. institutions at the indicated rates _if_ the retention rates of the recent past are assumed to continue. In particular, data from the 1978 and 1980 Manpower Censuses on recent (1970-80) Ph.D.'s suggest that approximately 35% of U.S. Ph.D.'s in nuclear science enter temporary positions in basic research, and that perhaps 50% of these subsequently are offered and accept permanent positions in this field. The total U.S.-trained Ph.D. manpower pool is deduced in Table 2 by assuming that those in temporary positions remain so for an average of 4 years (the present average is closer to 3 years), while those in permanent positions remain so for an average of 30 years. The final estimates for the total Ph.D. pool in Table 2 are clearly sensitive to the assumed balance among facility types, but in none of the three cases considered does this supply account for more than approximately 65% of the projected Ph.D. manpower demand for operation of the available facilities and interpretation of the data obtained with them. There is no basis in recent experience or suspected trends to expect that scientists trained at foreign institutions will be able to make up for more than half of the shortfall between supply and demand for Ph.D.'s in basic research, even in the most optimistic mixture considered in Table 2. A sample calculation for Mix III is illustrated in the Appendix to Table 2.

Despite the many quantitative uncertainties in the analysis we have presented, it is clear that a real problem exists. The results in Table 2 suggest that in order to support even quite modest goals for the future of basic nuclear science research in this country, it will be essential to effect over the coming years <u>at least a 50% improvement</u> in the production of nuclear science Ph.D.'s awarded per year in the U.S. and retention rate of those Ph.D.'s in basic research positions. The analysis presented above indicates that such an improvement is likely to require positive action on several fronts simultaneously (see Sect. VI).

Finally, we should note that we have concentrated above on <u>steady-state</u> manpower training needs to match long-range research goals in nuclear science. The transition from the current inadequate rates to those desirable for the long-term future will introduce special problems and opportunities. The 1980's represent a critical period for this transition, in that continued Ph.D. production at the present rate is projected (see 1978 NSAC Manpower Census) to begin leaving open permanent positions unfilled by the end of the decade. In an era of declining enrollments, university positions which are not filled rapidly are increasingly likely to vanish. Thus, if we are unable to effect a significant improvement in U.S. Ph.D. production in nuclear physics within the next decade, a downward spiral may be initiated, in which more and more university nuclear science research groups become sub-critical in size, and unable to contribute effectively to future manpower supplies. Even if we are successful in training more young nuclear scientists throughout the next decade, the nuclear science community will have to adjust its operating mode to accommodate the smaller number of post-doctoral workers that will be available during this transition period. On the other hand, this reduction in numbers should be viewed as providing an opportunity to increase the average post-doctoral compensation, without requiring an immediate increase in overall funding levels.

VI. RECOMMENDATIONS

1) As long as forefront physics remains to be done at small university laboratories (see Sect. III. A), there should be a commitment from the funding agencies to maintain a reasonable balance among such facilities. The University facilities have formed the backbone of nuclear science manpower resources in this country traditionally, and are likely to remain a very important component in the future. The commitment should be especially strong to those university groups which have access to high-quality students and have traditionally supplied the field with significant numbers of scientists.

2) Those university laboratories which remain must be well-funded, in order that they keep up with technological improvements and retain confidence in continued support. The mode of support in which many laboratories have marginal funding yields an erosion of confidence, ambition, and productivity in both research and education.

3) It is clear that in the foreseeable future a growing fraction of university-based nuclear research groups will operate exclusively in an outside user mode. It is therefore crucial to identify and institute improvements in student training in this mode of research. Especially important is a commitment to provide adequate funds for such groups to maintain strong instrumentation development programs at their home institutions.

4) As the transition to fewer and larger accelerator facilities continues, it is important to institute national research participation programs aimed at maintaining involvement of undergraduate students from a broad university base in forefront nuclear science research.

5) The retention rate of highly qualified Ph.D.'s within the field is likely to improve naturally to some extent during the next decade as more permanent basic research positions open up. However, a general increase in

post-doctoral salaries, to make them more competitive with those typically available in industrial positions, will help considerably in convincing promising young scientists to enter the "holding pattern" of temporary employment within the field.

6) There should be priority given to placing new intermediate-sized accelerator facilities on university campuses whenever consistent with efficient operation of such facilities.