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The Status and Problems of High-Energy Physics Today

A report of the High Energy Physics Advisory Panel of the Atomic Energy Commission

In January 1967 the Atomic Energy Commission established a Panel on High Energy Physics, for the purpose of providing advice and guidance to the commission in this area of physical science research. The panel reports to the Division of Research of the Atomic Energy Commission. It was established to consider important matters relating to this area of research and advise the commission concerning the best course of action to be taken in the interest of a vigorous and productive national high-energy-physics program. The panel is composed of 11 physical scientists; at present the membership list is as follows: Rodney L. Cool, Brookhaven National Laboratory; Earle C. Fowler, Duke University; Leon Ledermann, Columbia University; Edward J. Lofgren, Lawrence Radiation Laboratory; George E. Pake, Washington University; W. K. H. Panofsky, Stanford University; Robert Sachs, Argonne National Laboratory; Keith R. Symon, University of Wisconsin; Robert L. Walker, California Institute of Technology; C. N. Yang, State University of New York, Stony Brook; V. F. Weisskopf (chairman), Massachusetts Institute of Technology. When the following report was written, R. R. Wilson, of Cornell University, was also a member. He resigned because of the pressures of his new duties as director of the 200-Bev National Accelerator Laboratory.

One of the first tasks which the panel has set itself is a review of the present status and problems of high-energy physics in the United States and, in particular, the impact of the recent budget restrictions on these activities. The panel has issued a status report on this subject, pointing out the difficulties arising from the large discrepancy between the long-range budget forecasts made in a policy statement of the AEC which was submitted to Congress by the President in 1965 and the financial support actually provided high-energy physics. The report analyzes the serious consequences for the future of this fundamental field in which the United States has invested much effort and money.

The report was submitted to the Atomic Energy Commission and was subsequently transmitted to the Joint Committee for Atomic Energy of the Congress. It is presented here with minor changes for a wider audience.

High-energy physics is one of the main fronts of science and an essential part of our scientific effort. It tries to establish the fundamental laws of physics, which are at the base of all that we know about matter. It searches for the laws governing the four fundamental interactions—nuclear, electromagnetic, weak, and gravitational—with the final aim of unifying these interactions by finding some common origin. In this search, high-energy physics has found new features of natural laws, such as the violation of parity and, recently, an asymmetry between matter and antimatter. Apart from seeking an understanding of "interactions" between particles, high-energy physics seeks to find reasons for the existence of the particles themselves. Why is matter made of nucleons and electrons?

There is a second aspect to this kind of research. High-energy physics discovers completely new phenomena of nature. It observes matter under most unusual conditions which occur in the universe, presumably, only under catastrophic circumstances. For example, in the last decade a new world of phenomena was uncovered by means of high-energy accelerators; it turned out that nucleons and mesons possess a rich spectrum of many excited quantum states (often referred to as "new particles") with their own transmutation laws and reaction mechanisms. A new mode of behavior of matter has been found, as new and unexpected as the world of nuclear reactions discovered 40 years ago. The new 200-Bev accelerator, now under design, will add significantly to this world of new phenomena.

It is no coincidence that the greatest advances in man's knowledge of the basic nature of matter have always been made in the countries which were also the leaders economically and industrially, such as England in the 19th century, Germany in the early 20th century, and the United States in the last 40 years. There is a causal relation in either direction: advanced industry creates the means for research, and basic research creates the knowledge and atmosphere of daring inquiry which is necessary for advances in modern technology.

Since the late 1940's high-energy physics has played the role played by atomic physics in the first quarter of the 20th century and by nuclear physics in the second quarter. It is the present frontier in the ongoing study of the nature of matter. As such, it is an essential part of physics education. Excluding it or relegating it to a minor role would deprive science education of a most essential feature: the quest for fundamental laws and the urge to know more about new and unknown phenomena. Like atomic and nuclear physics in earlier periods, high-energy physics has the characteristics of a frontier area. The excitement of penetrating into the unknown attracts a large number of bright students, so this field plays a relatively large part in the training of physics Ph.D.'s.

Up to now there have been relatively few applications of the discoveries of high-energy physics to other sciences and technologies. It is typical of a field which deals with completely new phenomena that the connections with other sciences develop at a later date. Nuclear physics today is deeply involved with astronomy, biology, solid-state physics, and other disciplines. Thirty years ago it was a relatively isolated science. We can confidently expect that high-energy physics will undergo a similar evolution. At the present there are a number of important instances which show the influence of high-energy physics on the rest of science. The research problems in this field require utilization and development of the most powerful theoretical and technological tools available. This is why high-energy physics has produced ideas and methods which have found application in many other areas of science and technology. Thus, we find high-energy physicists making many of the most important contributions to theoretical techniques in handling many-body problems; to computer technology; to the techniques of dealing with ultrashort time intervals; and to superconductivity technology. Not only the methods but also the discoveries themselves begin to have their impact on other sciences. The discovery of vector mesons (ρ-mesons, ω-mesons) has been essential for understanding nuclear forces and for interpreting nuclear spectra. The discovery of symmetry violations in weak interactions originated in high-energy physics and has had important repercussions in nuclear physics. Today, muons, pions, and kaons are widely used for the study of nuclear properties, in particular the relatively unknown properties of the nuclear surface. Astronomy and cosmology are affected by high-energy physics in many ways; examples are the importance of neutrino reactions in astronomy and the expected relevance of high-energy processes in quasars and exploding galaxies. Here a development may be in the making that parallels the role nuclear physics played for astronomy in the 1930's in explaining the production of stellar energy. In a more down-to-earth field, studies have been made of the usefulness of pion beams in cancer therapy.

The High Energy Physics Advisory Panel of the Atomic Energy Commission (AEC) is deeply concerned with the negative effect of recent budget developments on the future of high-energy physics, a field which, up to now, has been one of the country's most successful basic research programs. The leading position of the United States in this area of research is seriously jeopardized, and there is a grave danger that higher education in science will suffer, especially in newly developing centers of education and research.

In view of these adverse consequences, the High Energy Physics Advisory Panel has carried out an evaluation of the status of the field under the present budget conditions.

General Status

When the Physics Survey Committee of the National Academy of Sciences–National Research Council assessed the state of the subfields of physics in this country in 1964–65 (*1*), its conclusions in regard to high-energy physics were as follows:

> 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 (CERN), is certainly competitive. Furthermore, present U.S.S.R. 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.

The High Energy Physics Advisory Panel of the AEC has now surveyed the status of the field and concludes that "the next logical steps have *not* been taken rapidly enough." The long-range prospects for the United States' retaining its vigor and preeminent role in this most basic field appear definitely threatened, primarily as the result of budget decisions of the last 2 years. Moreover, the panel concludes that the present support of existing facilities permits exploitation far below that commensurate with their excellence; as a result, however, a relatively small increase in funding would generate a disproportionately large gain in scientific output.

High-energy physics requires long lead times for planning. The time interval between the initial concept for a new large accelerator and its completion is a decade or more; new large pieces of research equipment do not become active until 3 to 5 years after their authorization; even scheduling a specific experiment frequently requires a lead time of 2 years. This is why the effects of recent budget restrictions are not yet fully manifest in the U.S. scientific output but soon will affect adversely the entire U.S. research effort in high-energy physics.

Comparison with 1965 National Policy

The Congress, through its Joint Committee on Atomic Energy, recognized the need for long-range policy planning and requested that the Executive Branch prepare a projection of its plans for at least a decade. The resulting paper, "Policy for National Action in the Field of High Energy Physics" (*2*), prepared by the AEC with the assistance of other federal agencies supporting high-energy physics, was based in part on studies by special panels of the AEC's General Advisory Committee, the President's Science Advisory Committee, and the National Academy of Sciences–National Research Council. This report was transmitted to Congress by the President on 26 January 1965.

In Fig. 1, A and B, actual development is compared with the planned development. Figure 1 shows the annual expenditures (operating and equipment costs in Fig. 1A; total costs in Fig. 1B) as projected in the AEC policy paper. As originally indicated in the AEC policy paper, the "national policy" curves represent a level of funding of existing facilities, of new needed facilities, and of university-user activities, adequate to provide for a nationwide research program as planned in the policy paper. Figure 1B also includes the Physics Survey Committee recommendations, for comparison. Figure 1 also shows the actual U.S. support up to fiscal year 1969 (costs for fiscal years 1968 and 1969 are estimates). In addition, Fig. 1A shows two curves that exclude the Stanford Linear Accelerator Center (SLAC) effort, in order to demonstrate the lack of growth in the rest of the program. The dashed curves give an indication of the real effort, since they take escalation of cost into consideration. Figure 2 shows the projected schedules, as indicated in the policy paper, for major new construction, and the actual or earliest possible dates for design and construction authorization. From fiscal year 1966 on, construction dates have slipped considerably. The 200-Bev accelerator can now be authorized for construction in fiscal year 1969 at the earliest, and it appears that the earliest possible authorization date for the electron-positron storage rings at SLAC and the large bubble chamber at Brookhaven National Laboratory (BNL) is fiscal year 1970.

Figure 1A demonstrates clearly that, during the last 2 years, all increases in operating and equipment budgets for high-energy physics have been absorbed by cost escalation and by the advent of SLAC as a new accelerator facility. Hence, the programs at other national laboratories and at universities during the last 2 years have had to operate at constant or decreasing levels, while the cost and complexity of experimental apparatus has increased, while the number of university-user groups has been growing, and while many new and existing problems have been opening up experimental and theoretical opportunities.

It is difficult to enumerate specific missed opportunities caused by these shortcomings in a field potentially as rich in unpredicted discoveries as high-energy physics. However, the following points stand out.

1) The dominant important contributions in high-energy physics have been made by young investigators, both at the national laboratories and at the universities. Several of our most gifted younger physicists have been attempting to set up independent user programs at new universities or at universities formerly not sufficiently in the forefront of research to support high-energy programs. In fiscal year 1967, U.S. federal agencies were able to support only three out of 18 outstanding proposals for new user groups, and those only at the expense of the needs of the established groups. It is anticipated that, in fiscal year 1968, support of new user groups will be essentially nil and, indeed, some productive existing groups will be losing their support.

2) University users find it difficult to adjust their experimental methods to meet changes in experimental demands, for lack of more flexibility in support. It has been particularly difficult to mount new university-operated experiments that require the use of modern electronic detectors.

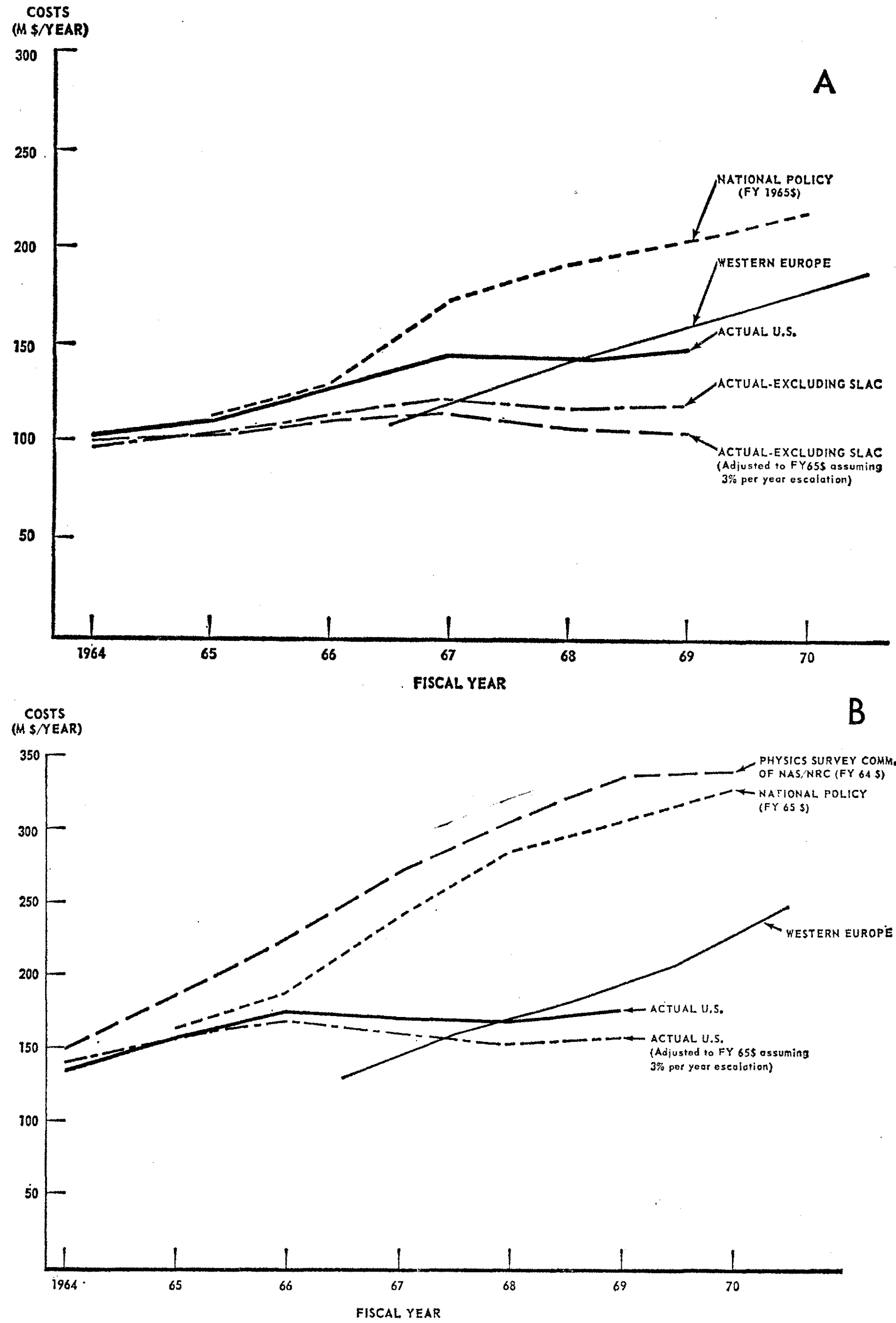

Fig. 1. Annual costs for high-energy physics. (A) Annual operating and equipment costs only. (B) Total costs, which include operating, equipment, and construction costs. Curves labeled "National Policy (FY 65 $)" represent the costs recommended in *High Energy Physics Program: Report on National Policy and Background Information* (1965). Curves labeled "Actual" represent the actual funding by all U.S. federal agencies. Curves labeled "Actual-Excluding SLAC" represent actual operating and equipment funding less the operating and equipment funds of SLAC. Dashed curves indicate the level of real effort normalized to fiscal year 1965, and reflect escalation of costs at the estimated rate of 3 percent per year. The actual funding figures were provided by the AEC's Division of Research. Costs for fiscal year 1968 are based on the apportioned budget. They also include some minor costs for medium-energy physics (less than 1 Bev). The curve labeled "Physics Survey Committee of NAS/NRC (FY 64 $)" presents the total costs as recommended in *Physics: Survey and Outlook* (*1*). Curves labeled "Western Europe" give the approximate level of Western European support for actual costs. This approximation includes support for the CERN proton-synchrotron and intersecting storage-rings programs, CERN efforts funded by non-member states, member-state collaborations with CERN, and national programs independent of CERN. Estimates of costs at CERN were obtained from CERN Council budgets and forecasts, from European Committee on Future Accelerators projections, and from private communications. Since the CERN budgets so far have always been adjusted to the real cost of the planned program, the support estimates were increased by 3 percent per year, starting in fiscal year 1967, so that they would be comparable to the U.S. figures. The curve is based on an exchange ratio of 4.3 Swiss francs to 1 U.S. dollar. The costs include minor amounts for medium-energy physics.

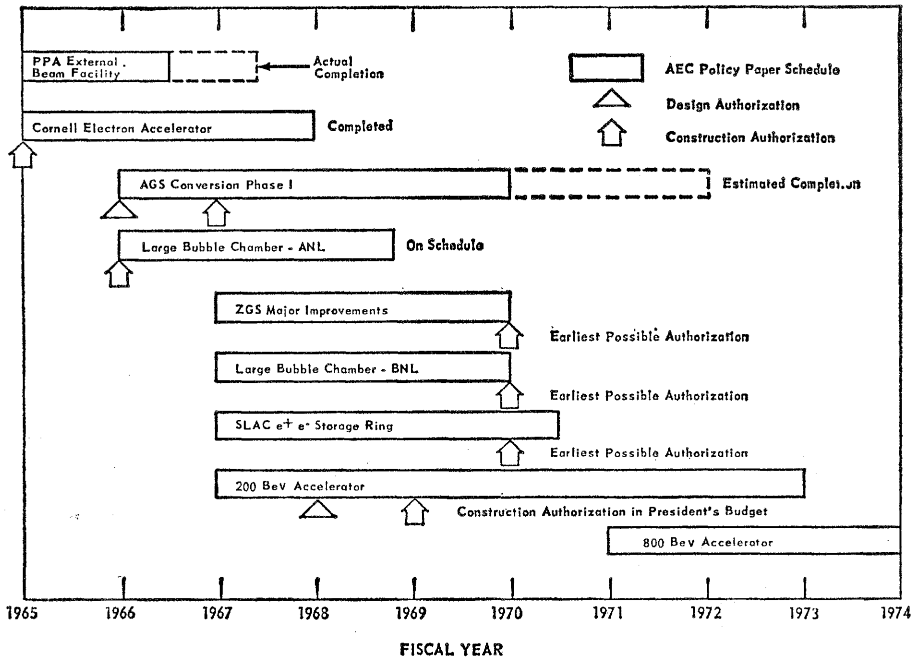

Fig. 2. Major construction assumptions. Comparison of the schedule for large construction projects given in *High Energy Physics Program: Report on National Policy and Background Information* (1965) and actual and budgeted design and construction authorization dates. The AEC policy paper relative to the construction of large bubble chambers at Argonne and Brookhaven indicated that two to three large chambers should be started within 1 to 3 years of fiscal year 1965. Authorization of the large chamber requested by Brookhaven was to follow the fiscal-year 1966 authorization of Argonne's chamber.

3) A large part of our knowledge of the new spectroscopy of nucleons and mesons has come from large-scale analysis of bubble chamber pictures. This is why there is a tremendous demand for bubble chamber pictures on the part of workers from all over the nation. This demand cannot be met. Brookhaven alone reports a backlog of 3 years, for about 15 million pictures.

4) In addition to the bubble chamber backlog, every high-energy physics laboratory in the country faces a serious overdemand, from many productive physicists, for accelerator beam time and for laboratory space. For example, Brookhaven has a 2-year backlog of important counter and spark chamber experiments. The backlog will continue to increase, in part because of increased user demands and in part because limitations of support produce some inefficiency in the procedures for operating the accelerators.

5) The fiscal squeeze has produced conservatism in relation to technological innovation. For instance, exploration of superconducting technology for beam transport and for accelerator application has proceeded much too slowly to permit maximum exploitation of the potential advantages of this technology for high-energy physics.

Quite generally, the comparisons in Fig. 1 show dramatically how far actual accomplishments have lagged behind the policy projection. This lag is, of course, partially a consequence of the fiscal stringency imposed by the Vietnam war, but unfortunately its impact on scientific productivity is much more severe than a simple scaling down of the program. Because of the long lead time for planning in this field, departure from a planned funding program unavoidably results in a severe under-use of facilities designed in the expectation of greater support. This situation is especially acute today because a new large facility (SLAC) began its operations recently. As a consequence, we face a much greater limitation of scientific productivity than the deviation from the planned budget would indicate. Not only does this represent a serious limitation in scientific output; it also influences adversely the quality of the program. Long-range technological innovation is given low priority, and the enormous pressure for accelerator time tends to eliminate daring experiments of high interest in favor of more certain investigations which may be of somewhat less interest.

Furthermore, the budget limitations prevent adequate support of the existing user groups at many universities and practically exclude the possibility of initiating new groups. These conditions represent a serious threat to higher education in science, since, without high-energy physics, this education would be deprived of important and essential features: the quest for fundamental laws and the urge to know more about an unknown world of new phenomena. Without new user groups it is next to impossible to incorporate high-energy physics into the new and growing institutions which are appearing all over the country in the present expansion of higher education.

It is at the level of operation and exploitation of existing facilities that the budget reductions hit hardest. Insofar as the projected new constructions are concerned, the picture is brighter, because of the request contained in the President's budget for fiscal year 1969 for full authorization for the construction of the 200-Bev accelerator. If everything develops on schedule, the machine will be ready for research in 1973.

It is most gratifying that the construction of the 200-Bev machine is becoming a reality. We regard this project as one of highest priority. It is of overriding importance that the U.S. obtain an instrument which allows deeper penetration into the world of high-energy phenomena. Many questions will be answered, and new horizons will be opened. The importance is emphasized by the fact that a proton accelerator has been completed in the U.S.S.R. and operated at 76 Bev, and that construction of a 300-Bev machine is under serious consideration in Western Europe.

However, the situation is discouraging in other respects. Authorization for the construction of several items of major importance for research with existing machines has been deferred year after year—items such as a large bubble chamber at Brookhaven and a colliding-beam storage ring at SLAC. Scientific justifications, certifying to the unique importance of these two items in particular, have been repeatedly provided. A number of extremely interesting and fundamental investigations requiring these facilities cannot be carried out and are being postponed in the United States. A large bubble chamber is under construction today at CERN, and storage-ring activity is being heavily pursued in both Western Europe and the U.S.S.R.

Comparison with Western Europe

Figure 1 also contains projections of the expected expenditures on high-energy physics in Western Europe, and permits a comparison of our future development with theirs. The Western European picture looks very promising, both in respect to the balanced choice of their research program and planned facilities and in respect to the quality of their output. Western Europe is in a better position to realize its plans than the United States is, because the planning arrangements agreed upon by the CERN member states give them greater latitude to plan for the future. In view of these trends, of the expected close collaboration of Western Europe with Russia at Serpukhov, and of the high probability that Western Europe will soon authorize construction of a 300-Bev proton accelerator, there is a clear and present danger that the United States will lose its leadership in this fundamental field. Such a loss would be an ominous step toward the situation in which the United States found itself before the 1930's, when most of the major discoveries in fundamental science were made in Europe. It would have adverse effects on our scientific life, and consequently on our society as a whole.

Recommendations

The recommendations of the High Energy Physics Advisory Panel are based on the premise that development of high-energy physics is essential for the progress of science and education in the United States. The curves of Fig. 1 present clear evidence that the development of the U.S. effort in high-energy physics is at present severely restricted. Because of budgetary restrictions, existing facilities are inefficiently exploited. Furthermore, a growing number of important and unique advances planned within the national program are not proceeding. If present trends are permitted to continue, the U.S. effort is going to suffer serious setbacks, which will have grave consequences for science and education in our country.

To remedy this situation, the Panel makes the following recommendations.

1) That a substantial increase followed by moderate growth in the annual operating budget for high-energy physics be made as soon as national problems permit. The fiscal year 1968 operating budget, after apportionment, of $113.4 million and the fiscal year 1969 President's budget of $120.4 million fall short of meeting even the most urgent needs in several essential categories. It should be noted that at least $3.5 million of the budget increase from fiscal year 1968 to fiscal year 1969 is needed to cover the cost of escalation; at least an equal amount is going to be used to meet the increase in costs that will result from the growing complexity of research, and $1.45 million of additional funds are assigned for development of the 200-Bev accelerator. Thus, the $7-million increase from fiscal year 1968 to fiscal year 1969 meets *none* of the urgent needs for increased support of existing laboratories and user groups but will, in fact, result in a decrease in the actual effort. Additional operating funds of approximately $15 million to $20 million would be needed at present for a reasonable exploitation of existing facilities, including the new ones at SLAC, and $10 million to $15 million would be needed for adequate funding of user groups in proportion to the research and educational needs of the country.

2) That construction of the electron-positron storage ring at SLAC and of the 14-foot (4.2-meter) bubble chamber at Brookhaven, adapted to meet current needs, be authorized as soon as possible. Note that both these projects have been deferred annually, from fiscal year 1966 to 1967, to 1968, and to 1969, for fiscal reasons, in the face of the strongest possible scientific endorsement.

3) That authorization for construction of the 200-Bev accelerator be granted in fiscal year 1969. The construction of the 200-Bev facility should remain the new item of highest priority in the national program.

4) That the budget planning should permit sufficient flexibility for the negotiation of U.S.–U.S.S.R. collaboration at Serpukhov to proceed with minimum cost impact on the balance of the program.

Implementation of these recommendations may well require a revision of the present budgetary process. Under present conditions, insufficient consideration seems to be given to the "Executive Agent" concept, under which the AEC has special responsibility for high-energy physics within the nation's total basic research program. High-energy physics budgets are prepared by the AEC's Division of Research. They are then reviewed in direct competition with the AEC's other specific mission-related program responsibilities, such as reactors, weapons production, and applied research. Although an appeal to take special needs into account can be made at higher levels of government, neither the procedure nor the result appears to be in accordance with the "Executive Agent" concept.

Relationship of Program Cost to Degree of Utilization of Facilities

Experimental programs in high-energy physics involve large and complicated facilities, and thus the cost, in terms of effort and expense, is substantial for even a minimal program. With the present degree of exploitation, a small increase in funding would result in a proportionately much larger gain in scientific output.

If we first consider operation of the accelerator, distinct from the experiments, we find several factors responsible for this relationship. Continuous maintenance is needed for many components, to keep them in running order whether or not they are run; indeed, some components are run continuously because operation is then more stable and less maintenance is needed. It is necessary to have people with highly specialized skills (for example, engineers) available, and the number of these people does not increase greatly with increase in operating hours. The same stipulation applies in the case of tools and test equipment; here again the cost depends little on operating hours. The number of operating personnel, of course, increases with operating hours, but the number of supervisors of the operators goes up more slowly.

These factors have been carefully analyzed for the Bevatron at Lawrence Radiation Laboratory, and the conclusion is that, of the total operating cost for 21 shifts per week, 56 percent is required for the first five 8-hour shifts per week, 75 percent for the first ten, and 89 percent for the first 15. The SLAC accelerator is a very different machine; however, the corresponding figures—56 percent, 69 percent, and 86 percent—are remarkably similar to those for the Bevatron.

Looking next at the cost and effort involved in providing beam for an experiment—that is, the items usually supplied to the experimenter by the accelerator facility—one finds the following. All of the large accelerators are generally capable of delivering more beam than is needed for a single experiment, and, provided suitable auxiliary equipment is available, several experiments, requiring a variety of techniques, can be run concurrently. Thus, within reasonable limits, the operating cost of the beam from the accelerator hardly varies with the number of experiments. Only the cost of acquiring and servicing the beam transport and other auxiliary equipment increases with increased experimental use.

It is of course difficult to make quantitative estimates of cost factors other than those relating to accelerator operation because there is no reliable unit for measuring the productivity of an experimental group, but the general picture is quite clear. For the existing facilities, a very minimal program—that is, five 8-hour shifts a week and little multiple operation—costs about 50 percent as much as a program involving nearly continuous operation and multiple experiments, so far as costs of accelerator operation are concerned. The scientific output and the number of students trained may be typically four to six times as great for the continuous-operation, multiple-experiment program as for the minimal program.

Effect of Budget Deficiencies on Character of the Work

The stringencies of the fiscal year 1968 operating budget are forcing the accelerator laboratories to make severe short-term adjustments in their programs. Those adjustments will have a damaging long-term effect because they tend to introduce a high degree of conservatism in the programs of the laboratories. Excessive conservatism is damaging, since the ultimate payoff in a frontier scientific field often comes from its high-risk programs. All aspects of the operation of any laboratory, including justification for support, rely heavily upon an ongoing, highly productive program of successful experiments. Therefore, the laboratories will find it necessary to reduce the element of risk as funds become tighter, and to place the emphasis on dependability rather than originality.

Under budgetary pressures a laboratory faces difficult compromises: accelerator operations may be shut down for part of the time; operation of major facilities (such as bubble chambers) may be curtailed; support for experimental groups may be reduced, thereby reducing manpower or materials and services; or design and development programs may be cut. The blend of these possibilities that is chosen by each laboratory will depend on the stage of development of the laboratory, its history, the nature of the accelerator, and many other factors. The shutting down of accelerators or major facilities, or a reduction in support for experimental groups, defeats the immediate purpose of the program. Therefore the most rational short-term choice will usually be to curtail design and development programs disproportionately. Although such curtailment may have little immediate apparent effect on the program, its long-term consequences will be very serious indeed. Design and development of new or modified devices provide the means to carry out the most original and fundamental experiments in the future.

High-Energy Physics as an Educational Need

The population expansion in the United States and increases in the fraction of high school graduates going on to universities and of college graduates going on to graduate schools have caused, in recent years, the establishment of many new universities and graduate schools, and the enlargement of many existing institutions of higher learning. The number of bachelor degrees granted each year is expected to increase by 50 percent, from 314,000 in 1964–65 to 460,000 in 1969–70. The number of Ph.D.'s in physics granted each year increased from about 500 in the period 1955 to 1965 to 1000 in 1965–66, and it is expected to go on increasing by 100 percent over a 10-year period (*3*). This expansion has created an enormous number of problems as well as great opportunities. If standards are not maintained, if conscientious efforts are not made to ensure high quality, the thing most likely to happen is the creation of vast amounts of mediocrity. The federal government is aware of this danger, and the establishment of the "Centers of Excellence" program by the National Science Foundation is aimed at avoiding this possible pitfall. Emphasis on a high standard of academic excellence is of critical importance; this can be achieved only in the atmosphere of research departments or laboratories devoted to studies at the frontiers of knowledge. Past experience in the building up of new universities and the expansion of old ones has borne this out very clearly. Where frontier research is emphasized, faculty and students alike are active and inspired; where frontier research is not emphasized, faculty and students are languid and uncreative.

In view of this fact, in the creation of new universities or the expansion of old ones, great emphasis has been placed on high-energy physics, as it represents a major frontier of research in the physical sciences. It is directed toward the disclosure of the most fundamental laws of nature, and it investigates a completely new world of phenomena discovered by the use of high-energy accelerators. It is impossible to exclude or to minimize this part of physics in our science education since it is part of the essence of science: the search for basic laws and the quest for new phenomena.

While it is true that research in high-energy physics is expensive, this fact is somewhat compensated by the relatively large proportion of academically related research in this area. Thus, viewed from the point of view of educational value, the total federal research expenditure on high-energy physics per Ph.D. produced is of the same order of magnitude as the total federal expenditure per Ph.D. in other areas (*1*, pp. 92, 93). This reflects the contrast previously pointed out between a frontier area which attracts a relatively large proportion of graduate students and an established area where a relatively larger proportion of research funds is spent on non-Ph.D.-producing research. Almost half of the high-energy physics Ph.D.'s take jobs in industry or teaching and devote their research skills to other areas. High-energy physics is thus a source of, rather than a sink for, trained manpower.

The size of our educational effort establishes a lower limit for the size of our effort in high-energy physics. This lower limit should be such that our major educational centers can participate in the research effort, since teaching and research must go hand in hand. One cannot learn science without active participation in the process of analyzing facts, sifting evidence, and recognizing new phenomena. The present financial support of high-energy physics is insufficient to fill this need. It is not even sufficient to enable the existing user groups to carry on high-energy research at the level of past years, because of the escalation of costs and the mounting complexity of methods. This lack of funds seriously inhibits the creation of new research centers needed to fill the requirements of the expanding research and educational effort. Since the number of accelerator centers working at the frontiers of research on particle energy and intensity is actually decreasing, the broadened academic need can be met only through the establishment of new user groups at those established institutions where "university-size" accelerators have been closed down, and at the new institutions.

Special Operating Problems in Fiscal Year 1968

Most high-energy physics laboratories have suffered a reduction of operating and capital-equipment funds in fiscal year 1968 as compared to 1967. These reductions have a much larger effect than any percentage decrease would imply at first sight. This is due in part to the escalation of prices and the mounting sophistication of research, which, together, increase the cost of research by about 6 to 8 percent annually. More importantly, expenses such as the cost of electric power, most salaries, administrative overhead, and plant maintenance take a large part of the operating funds, so a reduction of x percent in dollars results in a much larger percentage reduction in research, especially if the reduction is applied on short notice, as has occurred in fiscal year 1968. This is why all national laboratories and all universities will have to reduce their research plans drastically. The effect of these reductions is not only a general decrease in scientific output. A more serious consequence is a forced shift from the support of long-range planning to the support of ongoing research. The development of new instruments, the exploitation of new techniques, the following up of new ideas is severely handicapped. The impact will be felt especially a few years hence, in a lack of vigor and up-to-date exploitation—qualities which have distinguished U.S. high-energy physics research in the past.

Brookhaven National Laboratory. At Brookhaven, operating funds in fiscal year 1968 are less than they were in fiscal year 1967 by $300,000. In spite of the shutdown of the 3-Bev Cosmotron, there will be a reduction in alternating-gradient-synchrotron (AGS) activities, since most of the reduction in costs that results from the shutdown of the Cosmotron is compensated by the initiation of the AGS conversion program. Only two bubble chambers will be run simultaneously instead of three, the output being thus reduced by approximately 2½ million pictures. The counter-spark-chamber program will be slowed down by about 10 percent. The reduction in capital and equipment funds will seriously delay the conversion program. For example, it will be impossible to provide the necessary external-beam facilities in the new East Experimental Building. The installation of additional on-line computers, necessary for many experiments, will have to be postponed. A proposed data-terminal network for bubble chamber work and new special magnet projects will have to be sacrificed.

This situation is critical, especially since Brookhaven's alternating gradient synchrotron is one of the world's most important installations in high-energy physics.

Lawrence Radiation Laboratory, Berkeley. The Lawrence Radiation Laboratory (LRL) is the oldest of the laboratories engaged in high-energy physics research and has been the world's most prolific contributor to the field. Lawrence Laboratory has a first-rate research staff and support organization, which is an invaluable asset to the Atomic Energy Commission's program. As work in support of the 200-Bev machine at Weston, Illinois, decreases, the Laboratory is faced with the task of reorganizing and redirecting its accelerator research activities toward the exploitation of new technology. In addition to maintaining the Bevatron for a productive particle-physics program, for both LRL staff and outside users, the Laboratory will naturally also assume an increasing commitment for other, more modern facilities. At current funding levels, these programs cannot be carried out.

The Laboratory's operating funds are about 6 percent less than they were in fiscal year 1967; this makes it impossible to alleviate the acute shortage in the number of postdoctoral researchers and also requires a reduction of about 15 percent in the number of data analysts. The development of promising on-line techniques must be stopped, and the level of operation of the Bevatron must be drastically reduced. The installation of badly needed new beam facilities will be seriously delayed. The budgetary flexibility severely slows down the pursuit of new ideas such as the promising coherent electron acceleration concept.

Argonne National Laboratory. Ever since the initial difficulties of beam intensity and the experimental program were resolved, Argonne National Laboratory's zero gradient synchrotron has had a highly productive year, and it now plays a major role among U.S. high-energy facilities. In spite of the increased beam exploitation and the increased demand, the financial support in fiscal year 1968 is reduced as compared to fiscal year 1967. This prevents a sorely needed increase in the number of physicists employed at the Laboratory—a number which at present is much too low to meet the needs of the users. The number of shifts will have to be reduced from 21 to an average of 15 per week. Among other reductions it has been necessary to give up operation of the M.I.T. 500-liter bubble chamber at Argonne National Laboratory.

Stanford Linear Accelerator Center. The Stanford Linear Accelerator Center began research operations during fiscal year 1967. The activation of SLAC has added a fourth major laboratory to the three other large national high-energy physics facilities (Argonne, Brookhaven, and Lawrence). Clearly one cannot expect activation of SLAC to be absorbed into an essentially constant budget without injury to existing programs. The fiscal year 1968 operational funds for SLAC were reduced by the Bureau of the Budget by $3 million below the amount appropriated by Congress. This means that only an average of about 12 shifts per week can be scheduled at SLAC during the year. The output of bubble chamber pictures had to be reduced greatly for financial reasons only. Important experimental programs have to be postponed, as well as the work on storage rings, on automatic data processing, on future superconducting magnet developments, and on other improvements.

Cambridge Electron Accelerator. The number of shifts devoted to experimental work, beam storage, accelerator improvements, and the preparation of new beams must be reduced from 17 to 13 per week. This is particularly serious since the operating time is shared between current particle-physics research and preparation of the only experimental clashing-beam experiments being performed in the United States, which are showing excellent promise.

Princeton-Pennsylvania Accelerator (PPA). This laboratory has played a leading role in weak-interaction physics, especially in studies bearing on the violation of matter-antimatter symmetry. Budgetary limitations will force reduction in the amount of operating time and will curtail projects for increasing the beam intensity. The recent construction of an external beam target area has effectively doubled the experimental facilities, but no use can be made of this opportunity because the operating funds have not been increased in fiscal year 1968 and may be decreased in the next fiscal year.

Serpukhov collaboration. It appears, on the basis of preliminary contacts, that initiation of collaborative U.S.–U.S.S.R. experiments with the Serpukhov 70-Bev accelerator may materialize in the near future, but it is also clear that the "price of admission" to the highest-energy accelerator in the world will be some substantial contribution in terms of equipment and cost of operation away from home. The value of such experiments in providing a new dimension in international collaboration would transcend even their great scientific merit.

The SLAC Storage Ring and the Brookhaven Bubble Chamber

Funds are not provided in the fiscal-year 1968 budget or in the President's Budget for fiscal year 1969 for two urgent projects—the SLAC storage ring and the Brookhaven 14-foot bubble chamber. The following arguments show how severely our high-energy effort is hurt by these budget restrictions. The lack of approval of these two projects demonstrates clearly the long-range effects of the present crisis; for the first time in the history of this field, U.S. physicists will be unable to make use of some of the most modern means of research.

The SLAC storage ring will provide access to two areas of physics totally intractable by other means, since collisions generated with the storage ring have the same reaction energy as collisions between 36,000-Bev positrons and electrons at rest. One of these areas is that of electrodynamic interactions with momentum transfers higher than any ever attained with any other facility. Here the limits of validity of electrodynamics—one of the fundamental problems of physics—will be tested. The other area is the creation of unstable particle pairs under well-defined conditions. Pairs of mesons or excited baryons are created by a purely electrodynamic process, the electron-positron annihilation; the creation of hadrons by any other device necessarily involves largely unknown strong interaction effects. With such a storage ring information can be obtained about hadron structure which is unobtainable with any other instrument. From the technical point of view, construction of the storage ring at SLAC is an urgent necessity because no other major storage-ring facility is planned or under construction in the United States. Such devices will play an increasingly important role in high-energy physics, and we are losing experience in building and instrumenting these devices. In contrast, both Western Europe and the U.S.S.R. are vigorously pursuing this technique; major storage rings at CERN, Frascati (Italy) and Novosibirsk (U.S.S.R.) are under construction; a device very similar to that contemplated for SLAC is proposed for the DESY accelerator in Hamburg (Germany) and another is proposed for Yerevan (U.S.S.R.); Orsay (France) has one such device operating and contributing to research, while Novosibirsk has a smaller device in operation and a number of larger projects in preparation.

The salient arguments favoring construction of the storage ring are therefore these: (i) the device penetrates into specific new areas of research: high-momentum-transfer electrodynamics and hadron-pair creation; (ii) it is important to the development, in the United States, of a new technique in high-energy physics.

The arguments for construction of the 14-foot bubble chamber at Brookhaven are very different in character, except in one important respect: the chamber also will provide access to a field almost intractable by other means —that of neutrino physics. Indeed, because of the limitation of presently available methods of detection, experimentation with neutrinos has virtually ceased, pending the availability of beams of higher intensity and a suitable bubble chamber. The higher intensity will be provided by the AGS improvement program, but without the 14-foot chamber the intense neutrino beam can hardly be exploited. One of the most interesting and novel kinds of research will be left unexplored in the United States if construction of the chamber is not approved in the immediate future.

The bubble chamber is still one of the most widely used of detection devices. In about half of the AGS research efforts this technique is used for a large variety of investigations. The bubble chamber maintains an extensive university-user program. In particular, in the detailed study of resonances, bubble chambers have long been the major source of information. Interest in physics is now turning to resonances of higher mass with decays into a larger number of secondaries. Here a large-volume chamber becomes very important. The increased track length of the secondaries results in a better determination of momentum, allows more of the secondaries to stop in the chamber, and permits observation of more secondary interactions along the track. All this will make it possible to unravel high mass resonances and other strong interaction effects at higher energy. Furthermore, with the addition of a certain amount of neon, the new chamber will also be able to convert gamma rays and thus allow determination of neutral secondaries. This will increase the versatility and usefulness of the chamber.

Apart from the 14-foot bubble chamber's unique role in neutrino research, its great value lies in the fact that it greatly enhances the effectiveness of research performed by the numerous user groups. Therefore this project has received strong support from a large number of high-energy physicists.

The 14-foot chamber would play an essential role in exploitation of the opportunities created by the converted AGS facility. The conversion to higher intensity demands exploitation with a large bubble chamber. A similar chamber at CERN, which is under construction and will be ready when the CERN proton synchrotron is converted to higher intensity, underscores the importance of this technique. As a result of these delays it may no longer be advisable to attempt to build a chamber for use at Brookhaven, and the work may be reoriented to provide a large bubble chamber for the 200-Bev accelerator at Weston. An important scientific opportunity has thus been missed.

Situation in Western Europe and the U.S.S.R.

It is well known that the existence of CERN gave European particle physics a tremendous boost. Both in quantity and quality, the Western European effort is now comparable with the U.S.

effort. The high-energy activities are by no means concentrated at CERN, in Geneva. In fact, the expenditures for high-energy research outside CERN are higher than the total cost of CERN research.

Major accelerators now operating in Europe with energies higher than 1 Bev are the CERN proton synchrotron, with 28-Bev protons; NIMROD in England, with 7-Bev protons; DESY in Hamburg, with 6-Bev electrons; NINA in England, with 4-Bev electrons; SATURNE in France, with 3-Bev protons; a 2-Bev electron accelerator in Orsay (France); a 2-Bev electron accelerator in Bonn (Germany); and 1.2-Bev electron accelerators in Frascati (Italy) and Lund (Sweden). Most of these accelerators have excellent performance, equal or sometimes superior to that of comparable U.S. installations.

In the past the high-energy-physics program of Western Europe has grown financially at a rate of approximately 12 percent per year in real costs—that is, at the rate of about 16 percent per year in actual funds. The European program consists of two parts: (i) that associated with CERN, and (ii) the national programs of the West European countries. A certain fraction of the national programs consists of collaboration with CERN, and the growth of that part will roughly keep pace with CERN's internal growth. The CERN Council prepares a 4-year budget, which constitutes a reasonably valid 4-year forecast, while the national program is subject to the year-by-year budgetary processes of the member states, similar to U.S. procedures. Figure 1, A and B, shows projections for Europe based on the known CERN budgets. In the projections, the part of the national budget which constitutes the user program at CERN has been scaled up in proportion to the CERN projections, while the part of the national budget which pertains to programs centered around the accelerators of the member countries (such as DESY, NINA, and NIMROD) has been increased at a growth rate of 6 percent per year, plus an anticipated amount for escalation. This is considered a reasonable estimate since it is likely that, in view of the high priority given the 300-Bev accelerator in Europe, the member states are imposing austerities on their own national programs. It is relevant to point out that the CERN Council determines the future budgets on the basis of real costs and, so far, has always increased the planned budget figures by a realistic escalation factor.

Inspection of Fig. 1, A and B, shows that the growth of high-energy physics in Europe is considerably in excess of the growth experienced in the United States in recent years, and we believe the projection to be reliable, for the reasons given. Although the 300-Bev accelerator is the new construction item of highest priority in the European program, the spending curves through 1970 do not depend significantly on its construction.

The assured long-range financial support has had a very salutary effect on the quality and vigor of high-energy research in Europe. Plans for large construction items, such as large bubble chambers and accelerator improvement projects, are implemented in a systematic way. The construction of proton storage rings at CERN is an example of a bold step into a field of untried techniques and unknown physics, for which we have no match yet in the United States.

It is, of course, much more difficult to obtain quantitative information about growth rates and absolute magnitude of effort in high-energy physics in the U.S.S.R. than about the rates and effort in Western Europe or the United States; we can only look at present and projected achievements.

The U.S.S.R. program has been distinguished by important "firsts" in the construction of facilities but has been somewhat less productive in terms of scientific results. One of the reasons must be the fact that an entire generation of physicists who would have come to maturity shortly after World War II is missing; another may be a certain awkwardness of the procurement system, which, with the notable exception of Novosibirsk, separates the laboratories from industry. These deficiencies may well be disappearing; a young and very well educated group of high-energy physicists is entering the field, and the barriers between industry and the laboratories are being effectively broken down. Moreover, during the last decade high-energy physicists have greatly improved their contacts with the West. In particular, the 70-Bev accelerator at Serpukhov appears to be well designed, and an active group of Soviet accelerator people is now in residence at CERN to work with CERN workers on the design and construction of external-beam facilities.

Accelerators now operating in the U.S.S.R. in the range greater than 1 Bev are the proton synchrotron at Serpukhov, which has operated at 76 Bev; the 10-Bev original synchrophasotron at Dubna; the 7-Bev proton synchrotron in Moscow; the 2-Bev electron linear accelerator at Kharkov; and the 6-Bev electron synchrotron at Yerevan, similar to the Cambridge Electron Accelerator (CEA) and DESY accelerators. The performance of all these accelerators has been comparable to that of Western installations in most instances.

In summary, one would assess Soviet high-energy physics as having considerable latent potential. This is particularly evident in two areas: the Serpukhov Laboratory and the Novosibirsk Laboratory. The Serpukhov proton synchrotron is completed and is expected to be operative in 1968. For the reasons given above, reinforced by Western initiative, collaboration with CERN has been started, and also with France, which has agreed to deliver a very large hydrogen bubble chamber to Serpukhov. In all probability Serpukhov will become a unique and first-rate research institution of prime importance.

A second center of excellence is the Novosibirsk Laboratory. The Laboratory is a center for the development of new ideas in the area of acceleration of charged particles, ideas which have the potential of leading to unconventional designs. At present no comparable establishment exists in the West.

The operation of the Serpukhov machine will no doubt give great impetus to the U.S.S.R. high-energy effort, and will lead to important discoveries. Hence, it is imperative that U.S. physicists collaborate with Russians in exploiting the new machine. Western European physicists have already made important and successful steps toward collaboration, whereas negotiations regarding U.S. collaboration are only in a preliminary stage. It would be regrettable if only Western Europe were to take advantage of this opportunity. Here, also, financial support is essential, as well as a constructive and vigorous attitude toward the political problems.

References and Notes

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