Physics funding— the

Fifty years ago, the US government funds devoted to research were negligible; now they are dominant—and the proposed cuts may drastically alter the way physics research is done.

Emanuel R. Piore

The role of the Federal government in support of physics has altered and grown over the last fifty years. In this article I will review the evolution of this role within the context of four time periods: about 1930 to 1940, 1940 to 1945 (World War II), 1945 to the present (post World War II); the fourth period is on the horizon as the administration in Washington strives for a balanced budget.

We have seen the emplacement of Federal agencies having mandates to support science, the creation of diverse types of support such as "project grants," and the establishment and Federal support of groups conducting research in universities and at national laboratories. To examine this changing spectrum of support for physics, I will take a broad view of "physics"—including fields that are very close to physics and that, in a sense, rely on much of physics to move ahead.

The pre-War years

In the nineteen thirties, the most costly experimental instruments were the large optical telescopes used for astronomical observations. The 100-inch and 200-inch instruments at Mount Wilson and Palomar were constructed and operated with funds received from private individuals and foundations. These telescopes opened up to the astronomers regions of the physical universe that they had not seen or detected before. The concepts of the Milky Way galaxy, of other galaxies and of the expanding universe were based on observations made with these large instruments—and they became part of the common vocabulary.

These instruments, however, also had an impact outside of their scientific results. Because they were large and isolated, a special management procedure evolved to determine who had the qualifications for their use and the relative importance of proposed observations—thus the use of expensive instruments by visitors was institutionalized, and the concept of a "queue" came into being. A visiting observer made arrangements with his or her home institution to be absent and reside temporarily at the observatory. The analysis of the experimental data was performed wherever appropriate analytical resources were available. In a sense, these large observatories are the precursors to what we now consider "big science."

During the same period, the Woods Hole Oceanographic Institution was created, and the support for the Scripps Oceanographic Institute at La Jolla was supplemented. The identification of the need for additional support for oceanographic research was articulated by a committee at the National Academy of Sciences. Both institutions made facilities available to researchers and were created and supported by private funds, foundations, individuals and the endowments of those institutions.

On a smaller scale than these large institutions there were—as, of course, there still are—intermediate structures—groups, often associated with an intellectual leader, that concentrate their efforts on selected experimental techniques or on specific fields of physics. One such group was working in the 1930s with molecular beams at Columbia University under Isador I. Rabi, who had developed a technique to make extremely precise measurements of hyperfine atomic energy levels using a nuclear-magnetic-resonance method with molecular beams. The resonances were at radio frequencies. The prewar familiarity with rf technology was typical, and was to provide the background for many aspects of research conducted during the war years. Other groups in a number of institutions were studying the thermo- and photo-electric emission from clean metallic and other surfaces, in part motivated by potential applications to vacuum tubes. Understanding of the photoelectric effect has had enormous scientific and practical applicatons.

Theoreticians, utilizing quantum mechanics, illuminated almost all areas of active research in physics during this period: atomic and molecular spectra, the structure of light nuclei, astrophysics, and solid-state physics. The effects of their contributions, such as the invention of the transistor, appear in the post war years. It is a commonplace that the transistor and the associated developments in solid-state physics have had, and continue to have, a profound effect not only on physics and the tools used in physics (both small and large) but on the whole society as well.

Some of what we now consider big science, started small before 1941. Radio-frequency radiation from space was first detected in 1931, by Karl Jansky at Bell Telephone Labs, and from the sun during the war. The seeds of radioastronomy were sown then; its blossoming began in the mid-fifties, and with time radioastronomy became big science, largely dependent on the growth of Federal support.

Prior to 1931, Merle Tuve and Gregory Breit were working at the Carnegie Institution of Washington. They pointed a radio antenna skyward, pulsed the emitted radiation to measure altitudes and other characteristics of the various atmospheric layers above the earth, and found the ionosphere. This was the precursor of pulsed radar. Note that at the time those experiments were small science, conducted at a foundation-supported institution, with funds from an endowment, but from those experiments radar ultimately developed, now necessary for military operations and for the guidance of airplanes to safe landings.

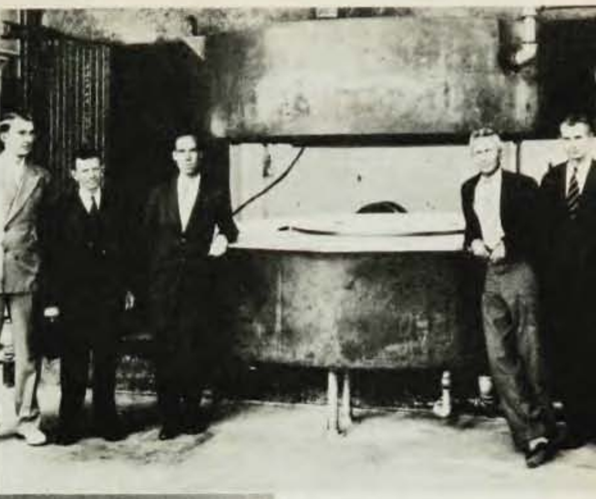
Instruments were designed to probe the lighter nuclei—accelerators such as the cyclotron or various electrostatic machines: These permitted a whole new approach to nuclear physics, as well as paving the way to whole new families of elementary particles. By accelerating charged particles through known electric and magnetic fields, they permit greater control of energy and direction than was possible using natural sources of radiation. They became the primary tools for nuclear physics, enabling the measurement of nuclear energy levels of light elements and the investigation of the interaction of charged particles with matter.

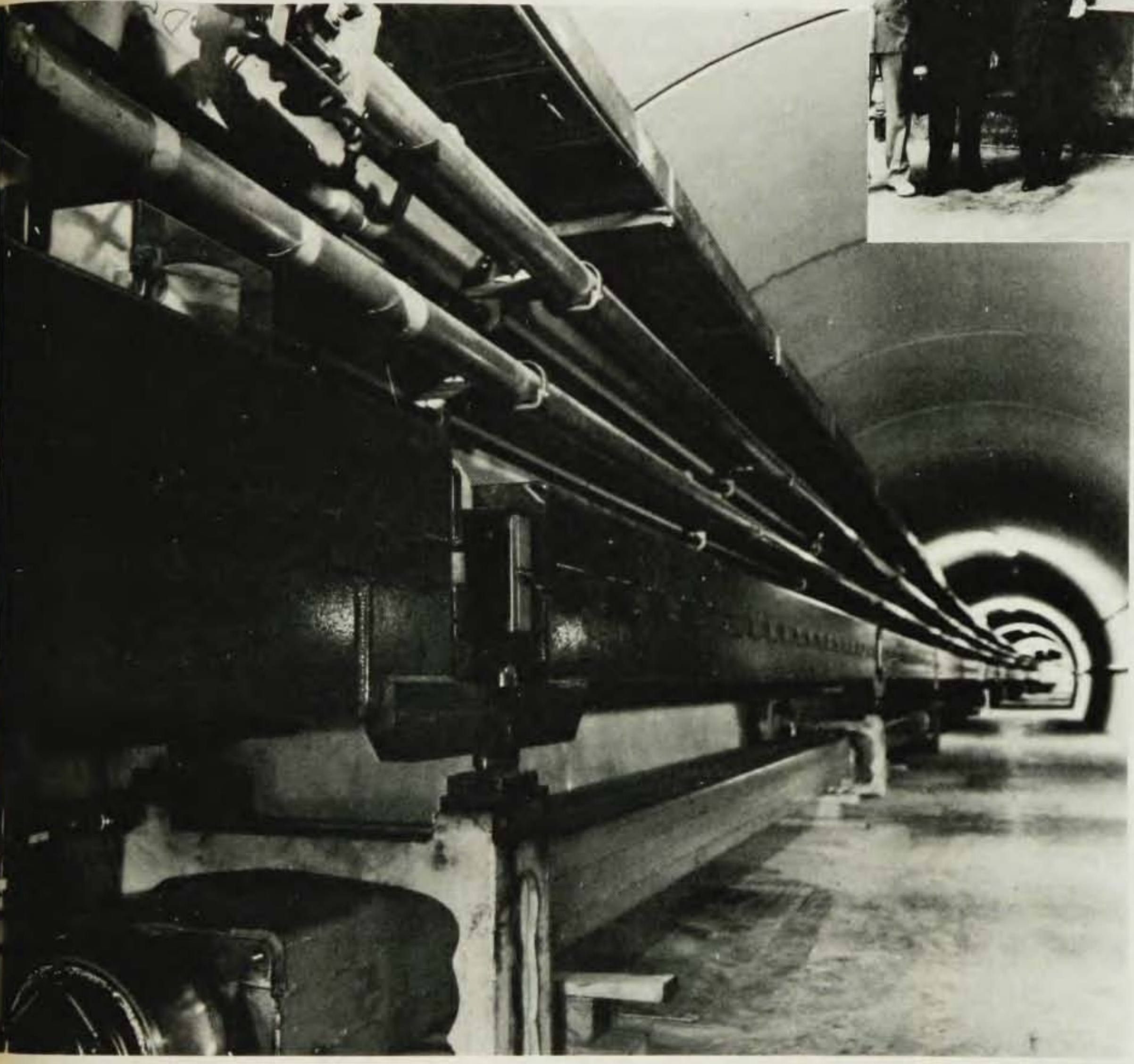
The physicist whose efforts led to the recognition of the importance of accelerators to laboratories (especially the cyclotron) is Ernest Lawrence founder of what was then called the Radiation

Emanuel R. Piore, formerly Chief Scientist at ONR, has served as a member of PSAC, NSB and NRAC. Now retired, he remains an active participant in numerous administrative bodies that shape science policy.

0031-9228 / 81 / 120038-08 / $00.50

evolving federal role





The dramatic growth of accelerators since the 1930s is evident in these two photographs. Above, flanking the cyclotron from left to right, are: Luis Alvarez, William D. Coolidge, William Brobeck, Donald Cooksey, Edwin McMillan and Ernest O. Lawrence. These key figures in the early use and development of the accelerator are shown inspecting the 60-inch machine under construction in 1938 at the Lawrence Radiation Lab at Berkeley. At left, a small portion of the main tunnel at Fermilab is shown; the entire ring is 2 km in diameter. (All photos courtesy of AIP Niels Bohr Library; picture above from U. C. Berkeley.)

Lab at Berkeley. Lawrence not only invented the cyclotron, and had the vision to see its potential importance, but he also trained the physicists who scattered across the US to physics departments, building 20-inch cyclotrons. The corps that Lawrence inspired and trained became, in large measure, the future designers and constructers of ever larger accelerators

One of the important components of the coming of age of American physics during the 1930s was the corps of postdoctoral fellows, tenured for one or two years and supported with private funds. One of the most prestigious of such fellowships was the National Research Council Fellowship, selected by a committee at the National Academy of Sciences. Other fellowships were supported by individual universities. The selected fellows worked either in the US or abroad and were exposed to some of the best minds and current thinking in physics. There was then a flow of physicists between Europe and the North American continent, as students studied abroad and European professors served as visiting scholars here. As the recipients of these postdoctoral fellowships were appointed to the faculties of American universities, they became the teachers of the next generation of physicists.

The 1930s also saw the introduction of the vacuum-tube amplifier as a replacement for the electrometer and galvanometer, and the beginning of the development of large complex instrumentation for particle physics, and optical and radio astronomy." The experimental equipment was not only conceived and designed, but also, for the most part, was actually constructed by the experimental physicist, with the aid of mechanics from the shop and glass blowers. Funds were very limited, but a corps of fine researchers was trained.

1940 to 1945

Beginning in 1940 the leading researchers in physics started drifting into defense activities—dropping their research, migrating to defense laboratories, grouped in formation. These laboratories were in the government, in universities and in industry. Some joined the military directly. The same pattern prevailed among scientists in Western Europe, particularly in England. By the middle of 1942 almost all nondefense research in physics at universities had been stripped of manpower. The PhD candidates had migrated with their senior colleagues and joined the defense effort.

The Federal government established the Office of Scientific Research and Development (headed by Vannevar Bush) and the National Defense Research Committee (headed by James Conant). The National Academy of Sciences played an important role as structures evolved to support research during the war. In addition, the Manhattan District was created to develop nuclear weapons. A varied and resourceful pattern of financial support and administration was thus established between the Federal government and the universities. These initial contractual relationships are the precursor of present university–government relationships.

The Manhattan District was organized under the Corps of Engineers, as part of the Department of War; it included the Los Alamos Laboratory, managed by the University of California at Berkeley. Argonne Laboratory was created as the defense work at the University of Chicago expanded beyond its capacity. Oak Ridge Laboratory and Hanford were established and responsibility for their operation was given to several industrial firms. As part of this concentration of national effort, some accelerators were borrowed from universities and moved to Los Alamos.

In addition, research conducted by the scientists remaining at universities was funded by the government and oriented toward defense. The enormous Radiation Lab at MIT, headed by Lee DuBridge, concentrated on microwave radar techniques and developed hardware that was successfully used in all types of military operations. Caltech tackled the development of military rockets and supplied hardware that was initially used by the Navy; from this effort the Jet Propulsion Laboratory evolved. Columbia, the University of California, Scripps and Woods Hole Oceanographic Institution had major responsibility for the investigation of underwater acoustics and explosives for anti-submarine warfare. The study of anti-submarine tactics and strategical analysis by physicists and mathematicians led them to develop the concepts that became the basis for what is now called operations research. Harvard directed the electronic countermeasure activities and also developed the first very large mechanical computer. The proximity fuse was developed at the Applied Physics Laboratory, a Johns Hopkins responsibility.

This is not a complete list, nor have I discussed the work done at the various military labs, but the partial listing does indicate the extent to which government funding and government needs had permeated physics research. A major portion of the research conducted by the physics community was done by physicists under forty years of age. The participation of these young scientists in the war effort exposed them to sophisticated instrumentation, a large source of money, and the high level of technical accomplishment that is possible when teams of highly trained researchers, technicians and graduate students work in concert. This exposure was to change the way science was conducted in the future. Many of the older physicists were involved as members of the scientific committees in OSRD, NDRC and NAS which had oversight responsibility for these projects. The ability of the physics community to staff this great effort was, in some measure, due to the extensive university network which taught and trained these young scientists. The war years were to have an effect more far-ranging than their brevity would suggest. The adjustments made during these years were to establish relationships and organizations that would form the basis of a continuing Federal role in scientific research.

1945 to the present

As the war ended, some of the efforts listed above were reduced in size or deactivated. The Federal administrative structures responsible for the great technological effort were closed down with little concern for the future of university research and thus research in this country. This was the backdrop at the beginning of the third period.

The physicists—the young, middle-aged, and the statesmen of science—returned to their academic bases full of ideas for research that had been geminating for five years. They found that the universities were not prepared for the transition between war and peace. The GI Bill of Rights provided funds for those who served in the armed forces, so that large numbers of students, many of them highly motivated, flocked to the universities, both as undergraduates and as graduate students. But while there was adequate support for tuition, other needs were more difficult to fill. Space—both for housing and for classes—was a real problem. Furthermore, the traditional sources of support available prior to the war, from private sources, state legislatures, and endowments, were not sufficient to continue to nurture and develop research given the increase in scale of the scientific technologies developed during the war.

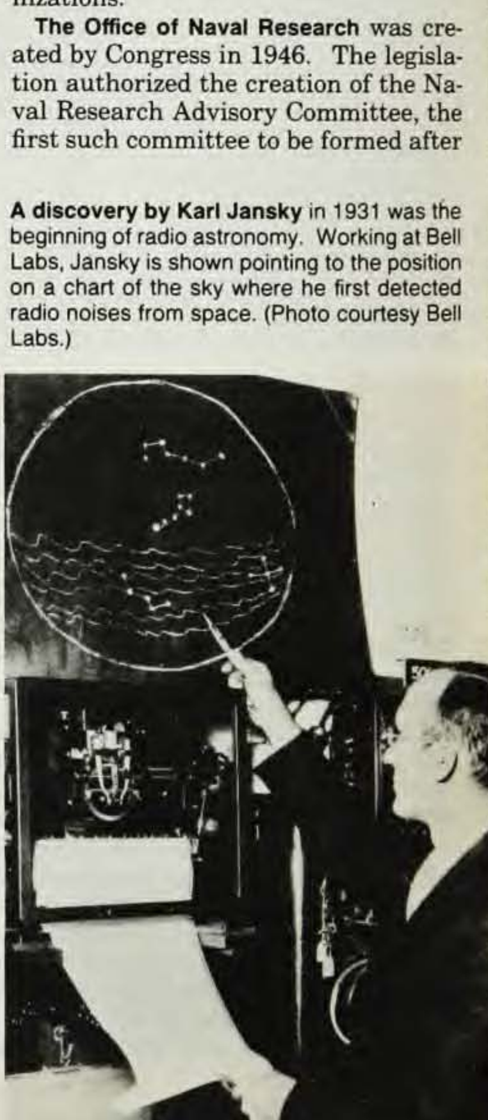
It is difficult to reconstruct the motivation that led the government to support research in the university. There was never an open debate on this newly evolving government policy and written documentation is almost nonexistent. A commitment that the Federal government assume responsibility for the support and the health of research was made, based on the state of affairs in the last half of the 1940s and on the realization of the importance of science to our society.

The war effort had clearly demonstrated in Washington the creative ability and usefulness of scientific laboratories and research groups. The future well-being of the national economy and defense required that such resources be preserved. It was imperative that research be given the appropriate funds. Graduate instruction, and thus the continuing creation of research talent, required revitalization. Much of this line of thought came from the civilian secretaries of the military departments and their staff and reflected the attitude of the senior military officers who had had intimate contact with the physicists during the war. Broadly speaking, the attitude prevailed that research is vital to the continued well-being of the nation, and research is best performed at universities.

In 1945 the Army, the Air Corps, the Navy and the Manhattan District had money left over from defense appropriations. Thus the climate was right—both financially and psychologically—to promote the establishment of government-supported scientific organizations.

The Office of Naval Research was created by Congress in 1946. The legislation authorized the creation of the Naval Research Advisory Committee, the first such committee to be formed after

A discovery by Karl Jansky in 1931 was the beginning of radio astronomy. Working at Bell Labs, Jansky is shown pointing to the position on a chart of the sky where he first detected radio noises from space. (Photo courtesy Bell Labs.)



the war, whose membership was appointed by the Secretary of the Navy. At that time the organization of the Navy was different from the Army and other services. In the Navy responsibility for non-military functions was lodged in the Secretary of the Navy's Offices and there were two chains of command, one civilian and one military. ONR was not in the military chain of command, but succeeded the Office of Research and Invention, the former contact point between the Navy and the OSRD and NDRC. Admiral Howard Bowen, former head of ORI, became the first chief of ONR. The Research Group within ONR was given responsibility for external research which supported academic research.

In 1946 the governmental administration was less structured, with fewer administrative layers and more informal means of communication, than present-day Federal organization permits. In this setting it was possible to form relationships that enabled government to react to the needs of the scientific community and vice versa. There was a need in demobilizing the war research activities to provide funds for unclassified academic research. This need was appreciated by the Secretary of the Navy, James Forrestal and his aide, then a reserve Rear Admiral, the late Lewis Strauss and Admiral Harold Bowen. The late Captain Robert Conrad, more than any other person, was responsible for the initial structure of ONR and for developing and promoting the concept of support for academia by the military. NRAC gave enthusiastic endorsement to these concepts. Working closely with Conrad were John Burwell, Gordon Dike, Ralph Krause and James Wakelin, all naval reserve officers with graduate degrees in physics and engineering.

NSF. Alan Waterman, who became Deputy Chief and Chief Scientist at ONR, subsequently played a major role in establishing the National Science Foundation. When Waterman left ONR to become the first director of the NSF, a number of ONR staff joined him. In addition the membership of the first National Science Board, which sets policy for NSF, overlapped to some extent with the NRAC and provided some initial continuity in national policy for research. Through these people the experience and initially the style of administration at ONR was continued at NSF.

For example, in 1945 and 1946 the scientific community in Europe was in disarray and ONR created a scientific office in London as part of the American Embassy there, to partially rectify this situation. Some very distinguished American scientists participated in this London office, each spending a year there, informing the European scientific community about the research being conducted in the US and sending reports home about events in science in Europe. James Webb, as under-secretary of the Department of State, asked Lloyd Berkner to study and assist the ONR operation. Berkner produced a report recommending that scientific attachés be assigned to our embassies abroad. As NSF grew in size and responsibility it became involved and the recommendation was executed with the creation of science attachés who had the same status as economic, agricultural and cultural attachés. Berkner also recommended creating an assistant secretary of state for science, a post that was established during the 1950s, and whose occupants played a role in Federal decision-making until the position was eliminated during the 1960s.

WWII brought teams of scientists together, many of whom were concentrated at government-funded labs. Three physicists important to the development of the atomic bomb—Ernest O. Lawrence, Enrico Fermi and Isador I. Rabi, from left to right, are shown conferring at Los Alamos during the war. (Photo courtesy of Lawrence Berkeley Lab)

At the same time that ONR was established, comparable legislation was passed for the other military services, thus establishing their right to support research. Congress also appropriated funds directly for research in academia for the sciences; traditionally funds had only been available for research concerned with agricultural and health problems. The Atomic Energy Commission was created by Congress in 1946 and was in business with transfers of funds from the Manhattan District and additional appropriations. Although the National Science Foundation was established in 1950, a result in part of Vannevar Bush's document the "Endless Frontier" in 1945 and John Steelman's report on "Science and Public Policy" in 1947, Congressional appropriations were modest until the launching of the Sputnik by the Russians in 1957. Committees of research scientists were created to advise the NSF by 1953, and plans for national facilities were discussed as early as 1954.

NASA. The successor to the National Advisory Committee on Aeronautics was the National Aeronautics and Space Administration, created in 1958. The energy of James Webb, the first administrator, became a driving force in NASA's expansion. He took the initiative to convince a number of universities to form departments of space science and to arrange for NASA to provide funding for these departments.

NASA has opened new areas to observation or experimentation by permitting observations above the various gaseous layers that surround the earth's ionosphere and which had restricted observations to a limited optical and radio spectrum. Important advances in the study of energetic particles and magnetic fields in the solar system were made first by satellites and later on interplanetary missions. Experiments using space vehicles require a number of years to plan and to build experimental equipment. Thus a queue is involved. The advisory committee in the National Research Council of NAS plays an important role in identifying experiments to include on a space vehicle. In addition, NASA administers laboratories which, with the exception of the Jet Propulsion Lab, are all government facilities that make their experimental equipment available to academic scientists. Many of the scientists using such facilities, including the JPL, were trained as astrophysicists or physicists.

Research support. With the formation of these major federal organizations, whose primary responsibility is science, the ground was laid for the development of more extensive government involvement with research. At the end of the war, both individual universities and the Federal government (in the main branches of the Defense Department) concentrated their efforts to conserve the talents of the physicists that had been members of war time groups or laboratories. As a result of these efforts, the blossoming of many new research universities occurred in the late fifties. These services, the Army, Navy and Air Corps, jointly supported scientific research. Each created its own office for university research support, with varying commitments to basic, as against applied, research. This joint support originated in conversations between members of the scientific community and the late Harold Zahl of the Army, Jake Manachetti of the Air Corps, and myself representing the Navy—all civilians with technical undergraduate training. From time to time they formed a "visiting committee" to discuss the content and quality of the research being conducted at these institutions. The universities felt at home with those representing the military departments and all understood that the name of the game was to move research forward.

At MIT, such joint service contracts supported projects at the Research Lab of Electronics that included microwave spectroscopy, the construction of an electron linear accelerator using magnetrons (a technology very familiar to Cambridge physicists), molecular beams work, cryogenics and information theory. The Radiation Lab at Columbia, which included the research projects of a number of physicists, and the School of Applied Physics and Engineering at Harvard also received funding under joint service contracts. At Harvard, Purcell's detection of neutral hydrogen in space was part of this effort.

The AEC and ONR also provided support for research projects conducted at universities. For example, ONR funded low-energy nuclear physics at Caltech, including Charles Lauritsen and William Fowler's very careful measurements of energy levels in light nuclear elements with electrostatic generators. Bill Hansen and the Varian brothers, inventors of the klystron, were funded in their work to apply klystrons as the power devices for the linear acceleration of electrons at Stanford. The design concept and construction stages in building the first billion-volt machine included the participation of not only Hansen but also Ed Gintzon and Marvin Chodorow. This machine was made available to Robert

National labs grew out of an expanded government commitment to science. Sir Edwin Plowden, Walter Zinn, Lewis Strauss and John Flaherty, from left to right above, inspect construction plans at Argonne in 1956. Now Argonne's Cockroft–Walton preaccelerator, at right, receives protons and speeds them to 750 keV. (Courtesy Argonne)

Hofstadter for his research, and later their familiarity with this technology became the basis for the selection of Stanford as the location for SLAC. The ONR funded the newly-formed Nuclear Physics and Engineering Lab at MIT, including the construction and utilization of a 150-MeV electron synchrotron. At the University of Illinois the Kerst Betatron received support from the AEC (Manhattan District). The Bevatron at Berkeley and, more generally, Berkeley Radiation Lab continued to have AEC support. This type of support was the precursor of big physics and later block grants and was offered as a result of clear articulation by academic physicists of their needs for equipment.

Support was also given to individual investigations. During the early days in physics the selection was based on the personal judgement of the granting officer in informal consultation with members of the physics community. This type of block grant has not been increasing recently although its use has a number of positive effects. The academic control of reseach to a large extent, continues to reside at the university. In addition, the tradition of identifying talented researchers and giving them appointments as assistant professors resides in the individual department of the university. The universities with the self-interest of developing the talents of their faculty, can employ block grants or departmental governmental support to this end.

At present peer review of specific individuals is increasingly used to select recipients of government funds; its use has produced a continuing debate—how does one identify promising young men or women who have yet to make a research record? Peer review consists of soliciting comments from fellow scientists through the mail or in a committee meeting and arriving at a consensus. This method of selection assures that ideas in the mainstream of current thinking within a field are emphasized, based on the past performance or the reputation of the applicant. It is a time-consuming procedure. The average time between submitting a proposal and receiving a reply can be two to three years. From that point in time until the actual performance of the experiment can be much longer, depending on the experiment, the necessity of building new equipment and other factors. This procedure, although democratic, can be brutal to young investigators just starting their research careers. I need only mention the length of time it took his contemporaries to recognize the contributions of Einstein, for example, to illustrate this point.

With the use of block grants, the administrative controls of research remain closer to the head of the laboratory group and are not removed completely to the vice president for administration or finance as they are using peer review. Many scientists, on the other hand, feel that block grants reduce the amount of funds available to individual investigators seeking support from government agencies. The mechanism they prefer is peer review, which permits the government auditors and the vice president for administration or finance to exercise administrative controls that often interfere with research.

Equipment needs of researchers were also appreciated and given Federal support. One such instrument was the

helium liquifier designed by Samuel Collins at MIT. Twenty to thirty were built, and funds were made available to various groups to acquire the liquifier; this action resulted in the expansion of cryogenic research in this country. Another example of equipment which was initially supported by government is the digital computer. AEC gave support to Los Alamos and Lawrence Livermore Lab. Groups in those labs set the standard and their judgement of performance was based on measurements of the time required for selected procedures, and computation within the laboratory. In addition their application of Monte Carlo methods had a profound effect on the final design.

It is hard to document who deserves the credit for recognizing the importance of computer research in the early days. As more and more powerful machines were developed, operating at higher speeds, and built with integrated silicon circuits, computers became an integral part of particle and nuclear physics. Data can be analyzed rapidly, stored, and then studied at leisure. The contribution of machines in identifying strange events in accelerator bubble-chamber pictures is the precursor of pattern recognition and manipulation. The computer also controlled the actual operation of accelerators—monitoring them and directing the adjustments to obtain optimum performance. Computers have become absolutely essential for astronomical observations both on the ground and in space. In fact, some of the largest computing facilities are necessary for radio astronomy and atmospheric research and modelling. In the last decade the cost of equipment for the individual investigators or university-operated facilities has grown enormously. Funding of these has been short-changed with the growth of support for national facilities.

The thrust of physics is to attain a rational explanation or description of the external world. There is an experimental probing, an observational approach and theoretical speculation and structure. The coupling between theory and experiment points to the need for further experimentation and additional observations to obtain a clear picture of the external world. Obviously the experimental results are based on what can be seen and felt. Almost all of contemporary physics requires instruments that provide visible indicators for events than cannot be sensed directly. Dealing with such phenomena, instruments of detection become greater and greater in complexity and such needs provide the drive for the creative development of instruments.

In the case of elementary particles, the investigation of ever smaller dimensions has required equipment capable of producing probes of ever higher energy. Many of the ideas to produce such energetic equipment had been on the back burner during the war. The postwar construction of such machines opened up new, previously unobtainable regions of the physical universe and created a field that became known as particle physics. Accelerating equipment was not enough, detection devices were required, such as the bubble chamber, scintillation counters, Čerenkov counters and spark chambers, all connected by sophisticated electronics to select and record significant events. To develop this instrumentation, researchers perceived a need to establish large facilities that could support expensive and complex equipment. This was to provide the impetus for the formation of national laboratories.

National laboratories

A seminal meeting took place in March of 1946 at Columbia out of which a corporation, Associated Universities, Inc., was created to be operated by nine universities. Half of the directors of this corporation represented the fiscal offices of the universities, the other half were scientists. The latter group assumed responsibility for the research content. The concept of a laboratory for unclassified research, and the formation of the corporation to develop this idea was, in large measure, due to the creative ability of Isador I. Rabi. He presented the concept and created the consensus among the physicists. Rabi also "sold" the idea to General Leslie Groves, the head of the Manhattan District, and participated in finding the location, Camp Upton.

The establishment of Brookhaven National Laboratory at a former Army base, Camp Upton, is an event that has had profound impact on physics. At the time, the Manhattan District's functions were being taken over by the newly formed AEC. The AEC entered into contractual arrangements with AUI the result of which was the designation of Brookhaven as a national facility dedicated to unclassified research. Limits were set on the size of the internal research staff to assure the availability of the facilities for visiting physicists and their graduate students. With time AUI had a full time president and director selected by the board. The division of responsibility between them was such that the president dealt with the external world—the Federal establishment—and the director was responsible for the execution of the research programs and the operation of the equipment. A procedure was established to select the experiments and experimentalists and to place them in order in the queue. The initial equipment was a nuclear reactor, important as a neutron source, and the Cosmotron (operating at 3 GeV). At present Brookhaven has in operation the Alternating Gradient Synchrotron which, for a number of years, was the most energetic accelerator in the world; a superconducting accelerator, and ISABELLE, is under construction. Leland Haworth was the director of the lab through the design and construction of the reactor, the Cosmotron, and AGS.

The national need for large accelerators was first articulated by NSF's Advisory Board, then chaired by Robert Bacher. A few years later the President's Science Advisory Committee and the AEC formed a joint committee, which I chaired initially, and later Leland Haworth. This committee may not have produced greater wisdom than the first NSF committee, but it was closer to the source of funds and had leverage in Washington. There was discussion about the need for an experimental facility based on the best theoretical thinking, the size, whether to emphasize voltage or beam current, and what would be the most useful incident particle—electrons or protons.

Some time was also spent on the possibility of an international joint effort between the USSR and the USA. At the Presidential Science Advisory Committee meeting in Puerto Rico, two important discussions took place, the results of which were reported to President Eisenhower, who approved both recommendations. The first was the decision to initiate with the USSR a discussion on limiting nuclear testing, and the second was to proceed with an electron accelerator in the range of twenty billion volts. James Killian and I briefed the President.

The first decision led to the growth of geophysics to develop techniques to detect underground testing, and the second was the beginning of the process that led to the formation of the Stanford Linear Accelerator and Fermilab. The creation, the authorization and the funding of these experimental national facilities went through more formal procedures starting in the late nineteen fifties for SLAC and the nineteen sixties for Fermilab. The estimated cost for SLAC was about one hundred million dollars and the estimated construction time was about four years; the estimated cost was not exceeded and the construction schedule was met, an unheard of performance in government circles. Robert R. Wilson was the first director of Fermi Lab and Wolfgang Panofsky was the first director of SLAC.

The selection of Stanford as the site for the accelerator was based on the groups's klystron experience and their construction of the less energetic klystron electron linear accelerator. At present SLAC has an energy of 36 GeV in its colliding-beam device, SPEAR which produces 18-GeV electrons and positrons.

The decision creating Fermilab was in the hands of the AEC. There were the problems of size, details of design, location of the accelerator and the organizational structure needed to develop it. The chairman of the AEC, Glenn Seaborg, and Fred Seitz, the President of the National Academy of Sciences, working with other members of the scientific community, were able to persuade a large group of universities (about forty in number) to form University Research Associates. Each University contributed five thousand dollars to generate working capital. AEC asked the NAS to create a site selection committee; I was named chairman. After a year of deliberation, six appropriate sites were presented to Glenn Seaborg, who presented them to President Johnson, who was to make the selection. The site selection committee, in consultation with AEC considered the following: ease of access by commercial air flight (taking into consideration the expected geographic distribution of experimental particle physicists), availability of 5000 acres, the proximity to leading research institutions, living conditions, schools, cultural facilities, and so forth. Over eighty communities submitted proposals (one proposal site turned out to be under two feet of water). The six recommended sites were near Madison, Wisconsin; Ann Arbor, Michigan; Denver, Colorado; Sacramento, California; Batavia, Illinois; and Brookhaven. The site chosen was the one the AEC recommended—Batavia, Illinois (a powerful Senator at the time was Everett Dirksen of Illinois).

The target for the proton synchrotron machine was 200 GeV. The initial beam was indeed 200 GeV; now it is operated at 400 GeV and work is in progress on the Tevatron to produce 1000 GeV protons. Robert Wilson was selected by the URA to be the director and Norman Ramsey became the president of the URA Board. The organization of URA, with scientific advisory, experimental selection and administrative committees and the board is similar to that of the AUI. The national laboratories, while being similar in their dependence on Federal support, are different in operation. SLAC and Fermilab were, and still are, single-purpose labs, whose research activities are characterized by their accelerators. Brookhaven, on the other hand, is in the best sense a multipurpose facility, as are Los Alamos, Livermore, Oak Ridge and Argonne. These labs have a primary responsibility to respond to the needs of the DOE and conduct research programs in diverse fields.

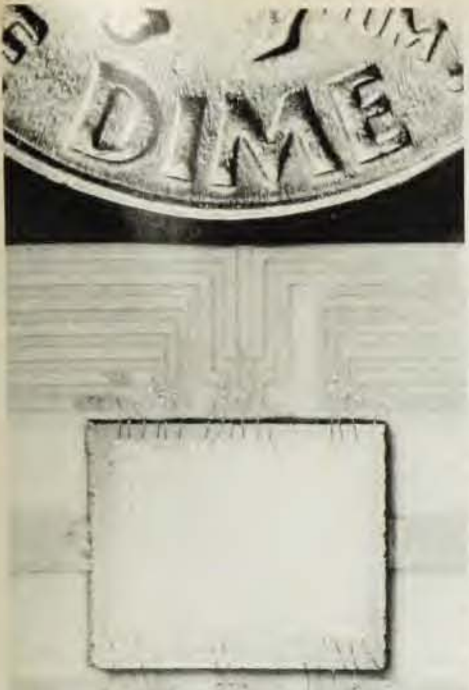
The ONR and AEC were well aware of the need for equipment and instruments. There was a very close working relationship between ONR and the Research Division of the AEC. The first Director of the Research Division was the late J. B. Fisk, Kenneth Pitzer was the second, both scientists of distinction. Thus support was given to construct circular and linear accelerators ranging from 150 to 500 million volts and also electrostatic machines ranging from a few million to twelve million volts. With time more and more of the research and construction was moved to AEC from ONR, and NSF acquired and took over some of the support. The 8-GeV synchrotron at Cornell, initially designed and constructed under the supervision of Robert Wilson, moved from ONR to NSF. The AEC underwrote the 3-GeV electron synchrotron at Cambridge and the 3-GeV proton synchrotron at Princeton. As the funding needs for SLAC and Fermilab increased and with the expansion of Brookhaven, many of these university-run experimental facilities and smaller accelerators became casualties.

Astronomy had been one of the first expensive, big sciences. The development of radio astronomy required new techniques of signal detection, low-noise receivers at high frequencies, big dish antennae, extended arrays for interferometry. AUI took responsibility for the creation of a national radio astronomy observatory at Green Bank, West Virginia, with offices and laboratories at the University of Virginia and later for the giant very large aperture interferometer in New Mexico. The optical astronomers of a dozen universities formed the Association of Universities for Research in Astronomy (AURA) to manage national optical observatories, one of which was even outside of the continental US. A group of universities formed a non-profit corporation, the National Center for Atmospheric Research at Boulder, Colorado. In addition to experimental work in the laboratory, this center provided balloon and airplane flights to explore the atmosphere.

Alan Waterman is shown inspecting the national radio observatory in Green Bank, West Virginia at an Associated Universities, Inc. meeting held in 1959. AUI was formed to establish and support various national facilities. (From AIP Bainbridge Collection.)

Future prospects

Throughout this historical review of the increasing Federal role in support of physics research, I have emphasized the beginnings, because these set the patterns and established the organizations, institutions and facilities, over the steady-state. This steady-state of continued support for research by the Federal government has prevailed for forty years or more. This support was underlain by an unspoken commitment



Industrial labs contributed, for example, this silicon chip covered with an array of metal electrodes that serves as the image sensor for a solid-state camera built by Bell Labs.

to science, and a recognition of the contributions to our technological society that scientific research and education have made in the past and can make in the future. The Federal government has become the principal supporter of research in physics. But while the Federal government's role in support of science has grown, its responsibilities for providing guidance in the form of a national science policy, and for the presidential science advisor's advocacy of science have not grown.

No single agency in Washington has the exclusive responsibility to support physics. Instead, every agency or department with a Congressional mandate can and does support research related to its mission. The division of fields between agencies is complicated and derives from many historical, political and practical considerations. Thus the Department of Energy supports particle physics and research in nuclear physics, in part, as a result of its evolution from the former AEC. The National Oceanic and Atmospheric Administration works in concert with universities in the areas of weather prediction and climate modelling. The DOD has an interest in many areas of research in physics and so on. The only agency acting in the general interest of science is the NSF. All of these agencies have in the past had a profound impact on the content of research. I have mentioned for example, the increased support of geophysical research provided to implement the Test Ban Treaty and the creation of space science departments by NASA. The DOD was also instrumental in creating materials science labs and has currently shown great interest in research on semiconductors. Thus our science policy has been determined operationally—not by articulation, but by action. It has not been chiseled in marble but has evolved from the historical interaction of principles, politics, national goals and the needs of the scientific community. The conflicts which arose from this interaction often required an arbiter at the national level.

Historically the President's Science Advisor acted in this capacity for science policy at the Federal level. This is no longer true. The Golden Age for PSAC started in 1957 after Sputnik. The Science Advisor became a full-time resident staff member at the White House, and PSAC was established with the Science Advisor as chairman and with the initial membership predominantly physicists. The primary function of PSAC was to advise the President to assure that full consideration was given to the scientific component of policy decisions. The Science Advisor was a member of the National Security Council. PSAC's first report dealt with international affairs and nuclear weapons; it initated policies that eventually led to the Test Ban Treaty. The committee was instrumental in the creation of the Disarmament Agency, NASA, and many others. In spite of occasional criticism of public policies, PSAC only lost the presidential audience when they maintained a critical attitude towards our policies in Viet Nam. At present PSAC no longer exists and the Science Advisor runs a variety of errands for the White House staff but no longer participates in policy-making decisions even when there is a heavy scientific content.

NSF has acted in some ways both as an arbiter within the scientific community and as an advocate for science. The Congressional Act of 1950, which established NSF, gave it responsibility for the overall health of science in this country. Although most of its expenditures were used to support research, NSF also initiated programs committed to such diverse goals as increasing the public understanding of science, revising elementary curricula, increasing the participation of minorities (such as blacks and women) in science, promoting the study of the history of science, encouraging international scientific cooperation and strengthening physics departments in colleges and universities. NSF also acted to provide a "safety net" to enable activities to continue after other departments or agencies reduced or terminated them. For example, when DOD lost interest in materials science labs, NSF assumed responsibility for these undertakings.

The function of NSF and its concern with science education, research and the general health of science is now under review. The change in the state of affairs for science began prior to the Reagan Administration with increases in formalism—accounting procedures, requirements for time-clock records for researchers, and other bureaucratic procedures. As the organization and funding of research has changed over the last thirty-five years, the style and procedures for the conduct of research have been modified. These modifications may have perturbed the "free spirit" of physics and thus may have restricted the creative atmosphere needed for research. Flexibility has been lost, both in the selection and in the performance of research. Further reductions in the resources available for research may enhance this trend toward increased formalization of the procedures that govern research selection, fiscal accountability, the use of facilities, and the development and design of new equipment.

Currently the NSF responsibilities for the health of science are being eroded by the Congressional appropriations process, initated and spurred by the Office of Management and Budget. The physics programs supported by DOE face cuts that are substantial enough that their viability is at stake. The national labs, fellowship programs, and many other areas of research and scientific education are facing cuts in funding. Industry can act to partially mitigate these actions, at least for applied research, but industry cannot replace the Federal government. Only time can tell what mischief will occur.

To avoid the erosion of science in this country, many thoughtful and knowledgeable people have been striving for a more well-defined national science policy." They would like to see established some centrally controlled organization to implement this policy. Science in the US has reached its prominence and achieved great results without such central control. What is missing at the Federal level, however, is not an administrative organization, but a renewed commitment to support science as a whole, a commitment to encourage cooperation both among the various domestic agencies that promote scientific research and internationally. This commitment would require a willingness to hear and heed the independent opinions of scientists as part of national policy formulation. Science policy is now being determined, not by perceived national needs and the interactions of the scientific community, Congress and the various agencies with substantial mandates for science, but by the budget-makers. More seriously, as the budget-makers juggle figures to reach fiscal goals, the commitment itself hangs in the balance. □