

the AEC's PHYSICS RESEARCH

By *T. H. Johnson*

THE ATOMIC ENERGY COMMISSION and the members of the American Physical Society have many mutual interests. For several years, their affairs have been closely interwoven. The atomic energy project, comprising activities formerly administered by the Corps of Engineers, and now under the Atomic Energy Commission, is a product of physics and physicists had a great deal to do with getting it started. I can think of no other industrial project of comparable size which relies as much on the wisdom of physicists for guiding its operations. Moreover, the growth of American physics and the welfare of American physicists owe a great deal to the Commission and its contractors. This agency gives employment to a large percentage of the membership of this Society; it also budgets for U. S. Treasury support for essential research facilities. Much of the work reported at this meeting, I note, has been financed by the AEC.

It is my privilege and responsibility to manage for the Commission many of its relations with the physicists. There are many occasions when I wish it were possible to pick up the phone and speak collectively with the physicists, to pass on some information, to enlist their help, or more frequently to ask their advice. I am grateful to Karl Darrow for this opportunity to discuss the research program of the AEC, and some of its current problems. Less information has been given out about the research program than is, in many respects, desirable but this has been because of preoccupation and not intent.

Many of you have an AEC contract or are working on some phase of the program. But I wonder how many have an accurate impression of the whole research effort, or even that part of the effort involving physics. In particular I wonder if you realize how much the Commission values the research efforts of the scientists working in certain quite basic fields, or if you appreciate some of the problems the AEC has in making arrangements for those efforts to go on.

Many industries are coming to realize the need for research as a means of improving their product, of cutting costs, and of developing new products, but I know of no industry in which research plays a more important role than it does in atomic energy. The operations of the AEC are highly technical throughout and many of them are based upon relatively unexplored fields of science—not only of physics but of chemistry and metal-

lurgy. Many of the problems involved in the developmental and industrial operations of the AEC are also on the frontier of basic science. They frequently overlap the problems of pure research that a physics professor might want to undertake as a part of his academic research program.

Besides the more obvious interests in nuclear physics, other branches of physics, as well as chemistry and metallurgy, become involved in the many new and unusual materials that have come into use and in the unusually high temperatures and radiation densities that have to be contended with. Although we have all been impressed, and even amazed, by the numerous successes of the AEC program, it is quite evident that these are only the crude forerunners of what may yet be achieved through continued research. In pushing forward we not only need the foundation of factual knowledge and understanding resulting from research, but even more, we need the rare insight of the scientist, trained in research, who is also close to the program. We often draw upon his judgment to help decide the proper relative emphasis between projects or to choose between possible alternative methods. We also need his vision to forecast the future and lead the program on towards new goals.

The Congress foresaw that extensive research would be essential if this country were to hold its lead in atomic energy, and the Atomic Energy Act of 1946 adequately provides for the support of research activities. It directs the Commission to use its powers to insure the continued conduct of research and development in fields related to atomic energy by private or public institutions or persons. It emphasizes the need for independent research, and provides for assisting and fostering it. The Act also provides for a federally conducted program of research aimed at specific accomplishments.

Throughout the various production plants and developmental laboratories of the project, many research activities in support of the particular interest of the establishment are quite naturally carried on, but in addition the Research Division conducts a program of physical research which is independent of all development or production activities. This Division submits and defends its own budget and the Director of Research reports directly to the General Manager of the Commission. The goals of this program are broad: to strengthen the scientific foundations underlying the

PROGRAM

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technology of atomic energy, thus to provide the basis for greater accomplishments in the future, and to acquire the extensive data which can give a more rational basis for effective engineering in what we are presently trying to do. This program includes some projects aimed at specific accomplishments and some to determine the feasibility of some process or device but it also includes many basic studies carried out under the academic principle that what is unknown should be investigated. Physics under the Research Division program is conducted "onsite" by more than 400 scientists in the facilities owned by the AEC, and "offsite" by more than 900 scientists and graduate students in university and other privately and publicly owned facilities. These figures do not include any of the fine physics that is budgeted as chemistry. The onsite laboratories which carry on physics research under this program are the Berkeley Radiation Laboratory, the Ames Atomic Laboratory, the Argonne, the Oak Ridge, and the Brookhaven National Laboratories. The offsite program in physics comprises 63 separate projects in 41 different institutions. In addition the ONR administers a program in nuclear physics comprising 38 projects jointly financed by the AEC and ONR.

The Physical Research Program as a whole is limited to investigations related to atomic energy. These more obviously include studies of nuclear radiations, nuclear reactions, and nuclear structures. They also include studies related to processes, materials, and devices, and to the development of techniques for research in the nuclear field. Most of the investigations of the Research Division, especially those in physics, are unclassified. Training is an important byproduct which I shall speak of more fully in a moment, but other than the expiring fellowship program, no activities are supported because of training benefits alone.

A large part of the physics program is concerned with the nucleus and the properties of the elementary particles. Most of these projects depend upon an accelerator or a reactor. The latest count of machines involved in AEC-supported studies gives 11 synchrotrons, 7 synchrocyclotrons, 20 cyclotrons, 10 betatrons, 7 linacs, 32 Van de Graaff generators, and 11 research reactors. The interest to the AEC in research done with some of those machines is related to the fact that they produce under controlled conditions on a laboratory scale the same reactions that are involved in the large scale re-

lease of energy in fission and thermonuclear devices, but some of the largest and most expensive to operate of these machines, like the proton synchrotrons at Brookhaven and Berkeley, and the large synchrocyclotrons at some of the universities, were constructed solely for basic studies with no thought or promise of any foreseeable practical rewards, other than a general faith that new knowledge almost always proves useful.

It might be interesting to give a brief run-down on all of the physics projects supported by the AEC so you can get a better idea of what is being supported and with what emphasis. Here I will include work administered and jointly supported by the ONR, with whom the AEC Research Division enjoys close relations. The work on high-energy meson physics is supported at about 8.2 million dollars a year. \$7.4 million of this goes to studies based on the use of high-energy machines for producing mesons and \$0.8 million for cosmic-ray studies. I refer to 15 machines in this category: the synchrocyclotrons at Berkeley, Carnegie Tech, Chicago, Columbia, and Rochester; electron-synchrotrons at Berkeley, Caltech, Cornell, MIT, Michigan, and Purdue; a betatron at Illinois; a linear accelerator at Stanford; and proton synchrotrons at Brookhaven and Berkeley. Design studies looking towards machines of still higher energy are supported at Brookhaven and through subcontracts of Brookhaven at Harvard-MIT and Princeton. Cosmic-ray studies are supported directly by the AEC at Syracuse and North Carolina University. Work in this field under joint ONR support includes projects in 17 institutions: Bartol, MIT, California, Caltech, Chicago, Duke, Michigan, Minnesota, New York University (Square & Heights), Princeton, Washington University (St. Louis), University of Washington (Seattle), Yale, Iowa, and Cornell.

The second largest category in the AEC physics program might be called classical nuclear physics. Including a million dollars of Navy money, this effort under AEC support is costing \$7.8 million, only slightly less than the cost of the meson studies. In this category are included: work with accelerators of lower energy than the meson threshold; studies of radioactive nuclei with the various kinds of spectrographs; nuclear moments and masses; and neutron physics.

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The number of projects is too large to list in the time allowed and I will mention only a few. Roughly 40% of the money for nuclear physics is spent in the National Laboratories. Their program includes:

The work at Brookhaven on isomers, decay schemes, beta rays, capture gamma rays, reactions produced by high-energy protons and deuterons, neutron interactions, cross sections, and the neutron moment;

The work at Oak Ridge on neutron diffraction, polarization of nuclei and neutron half life, and the program there with the Van de Graaff and Cockcroft-Walton accelerators and with the two cyclotrons which includes neutron cross sections, nuclear diffraction of protons, the interactions of heavy nuclei, and excitation functions and thresholds;

The work at Argonne on capture gamma rays, double beta decay, neutron cross sections, inelastic neutron scattering and the distribution of fission products; (Argonne has a Van de Graaff, a 60-inch cyclotron, and will soon have a fine new research reactor).

The other 60% of the money is spent in the universities where it supports: precision beta spectroscopy and the Van de Graaff program at Caltech; cross sections for interactions of the light elements at Rice and at Minnesota; fast neutron cross sections and the characterization of excited levels at Wisconsin, Johns Hopkins, Westinghouse, and Bartol; interactions of protons at 100 Mev at Harvard; proton cross sections and angular distributions at 32 Mev at Berkeley; neutron cross sections and other work with a 6 Mev Van de Graaff at Duke; work with synchrotrons or betatrons at Ames, Case, Chicago, Illinois, and Pennsylvania; neutron physics, beta spectroscopy, and neutrino properties at Columbia; neutron cross sections, nuclear properties of separated isotopes, and reaction energies at Yale; beta spectroscopy and decay schemes at Indiana, Washington University, Illinois, and MIT; reaction energies and excitation functions at Princeton, Rochester, MIT, Washington University, the University of Washington, and Texas; and nuclear moments at Columbia, Rutgers, Duke, Brookhaven, Argonne, Oak Ridge, California, Stanford, and Harvard.

It is a large program suggested only in part by the list I have just given. At this meeting 21 of the 29 papers on Cosmic Rays reported work supported by AEC. 18 of the 24 papers on Mesons reported work supported by AEC. 24 of the 29 papers on Neutron Physics reported work supported by AEC. 31 of the 41 papers on Nuclear Reactions reported work supported by AEC.

Among the new machines under construction for work in the program are the following:

The Caltech synchrotron will soon be raised in energy to one Bev.

The Cornell synchrotron is being increased in energy.

The Michigan synchrotron will be increased in energy.

The 300 Mev synchrotron at Purdue is getting into operation.

A 500 Kev Cockcroft-Walton is being assembled at Brown University.

A 68 Mev proton linac is nearing completion at Minnesota.

A 32-inch cyclotron is partially completed at Oregon State College.

A 10 Mev electron linac is under construction at Purdue.

An electron pulsed linac for neutron time-of-flight spectroscopy is under construction at Yale.

A 6 Mev Van de Graaff will soon be ordered by Columbia.

The bevatron at California is less than a year from completion.

The 1 Bev electron linac is completed but not up to energy at Stanford.

An increase to 750 Mev of the Berkeley cyclotron is under design and is authorized.

Three groups are interested in variable frequency cyclotrons for heavy particle acceleration.

Interests are developing in multibillion volt machines based on alternating gradient focusing at Harvard, MIT, Brookhaven, Princeton, and in a group of midwestern universities.

The rest of the program costs \$1.5 million and comprises cryogenic work at Oak Ridge, Argonne, Ames, MIT, Wisconsin, Ohio State, and the University of Pennsylvania; theoretical work at Columbia, Rochester, Chicago, Cornell, Wisconsin, and in all of the National Laboratories; spectroscopy at Johns Hopkins, MIT, Oak Ridge, and Argonne; and electronic techniques and detectors in all of the onsite laboratories and at Stanford, Princeton, Johns Hopkins, and other places.

As far as manpower is concerned about 3/4 of the basic physics program is in the university laboratories, but that part of the program costs only about the same as the other third carried on in the National Laboratories. There are several reasons for the lower specific cost of university research: (a) it employs a large percentage of low-salaried students; (b) the university staff though counted in the total manpower is usually paid from the AEC contracts for only part time; (c) substantial contributions to the cost of this research are made from other funds available to the universities; and (d) overhead in the National Laboratories is high because of large expensive facilities and the need for security and classification protection.

As I pointed out at the beginning of my talk, although basic physics projects are usually initiated by the university scientist as an extension of his academic research program, they often have a direct bearing upon the practical objectives of the AEC. I could give you many specific examples of university research which has paid off in the AEC program, but if I were to do so I would be giving the value of this work the wrong emphasis; for its main and most valuable contribution is to expand and organize the whole body of basic knowledge underlying our technical capability in the nuclear field. Although the neutron cross section of some nucleus measured in a university laboratory may have been used as an essential piece of information in the design

of an important reactor I would contend that the general understanding of the interaction of neutrons with matter is more important by at least an order of magnitude because from such understanding we know how to use particular numbers and we gain confidence that other relevant effects are not being overlooked. A good basic understanding of nuclear physics is as much of a practical need of the designer of a reactor as an air reconnaissance map is to the builder of an Alaskan highway. In addition to knowing a way of reaching the goal one must also know that there are not other better ways just over the ridge than the one he is taking. For this reason the AEC has as much of an interest in very basic and exploratory investigations as it has in what might be described as applied research.

In the past we have attempted to differentiate between what we have called *programmatic* research, or research having a direct bearing on the practical objectives of the AEC's program, and *nonprogrammatic* research or that undertaken to solve a problem of purely scientific interest. Sometimes the terms of the contract have depended upon this judgment. The AEC has been willing to pay a larger share of the costs for programmatic than for nonprogrammatic research. I hope we are now beginning to realize that basic work is just as important to the AEC although its bearing may not be quite so obviously traced. Moreover, the obvious bearing of the investigation on the program is not the only factor upon which the AEC's willingness to pay the costs should be based. Timely research on problems of scientific interest by qualified scientists in institutions where the policies and environment favor scholarly activity of the highest standards is most likely to be productive and of greatest interest in the long run to the AEC.

Since I am aware of some feeling that the AEC may have overemphasized its interest in applied research, may I digress for a moment to say that scientists are innately modest and they have a certain pride. They do not like coming to Washington to plead for support of their work, and yet there may be some reluctance on their part to undertake work at the request of the AEC on the ground that it might be wanted for some narrow programmatic interest, or they may feel that it is not useful for another to suggest to a scientist what he should work on. In order to establish good understanding and satisfactory relations between the AEC and the scientists, the Washington Office is staffed with men who understand physics and know physicists. This background is needed if one is to be able to deal in a personal way as one physicist to another with the scientists working on the program; or if he is to be able to interpret the results and the needs of the program to non-scientific personnel in the AEC upon whom we rely for support of financial estimates and for many of the policies under which the program operates. I must confess that we are having considerable difficulty in finding physicists who are willing to spend more than a few days each year in Washington or who will sacrifice their scientific ambitions to serve their science and their

fellow scientists in an administrative capacity even though the work is essential, challenging, and rewarding in its satisfactions. It takes scientists in the Washington office to understand the point of view of the scientist working in the laboratory and to help the administrators evaluate the essential contribution that basic research makes to our technological capability. These relations are not obvious to the administrator not scientifically trained.

Contracting for research in universities is a peculiar business when viewed as a government procurement operation. There is no established requirement, and there is no promise of delivery, either as to what (aside from a report of results), how much, or when. The impetus for placing the order usually comes from the supplier and not from the government in the role of consumer. It takes a fairly intimate knowledge and deep understanding of the nature of the AEC project and the way it works to realize that research is indeed a rewarding way to spend public money. It also takes an understanding of the nature of research to assure that the arrangement for supporting it really fosters rather than stifles it. It is a great tribute to the ONR that it seized the opportunity at a propitious moment for putting the resources of the government behind research and for working out an arrangement for research procurement. It is now coming to be recognized as legitimate procurement in many government agencies, especially in the Department of Defense and the AEC. The National Science Foundation is making steady progress, though there is in the government as a whole some lack of enthusiasm for any activity unless it is related to a definite mission for accomplishment. The AEC is in a more favorable, though perhaps a less logical position, than the NSF to support research—more favorable because it can show by numerous examples how this activity saves money in its own program or returns more for the same money and how it contributes to its main objectives: a greater national security and a higher standard of living for the American citizen. Its position is less logical because the benefits of research are always unpredictable and are often without favor to the supporting agency. Much of the research which the AEC is supporting should go ahead whether reactors and bombs are needed or not. This of course raises the old question: what is basic research?

The discourses and definitions one hears about basic research and applied research remind one of difficulties we used to have about particles and waves. On the one hand one recognizes that the pure scientist is guided by principles which can be well defined in terms of scientific objectives but are not concerned with practical accomplishment. Nevertheless practical accomplishment derives from scientific accomplishment; we might say that scientific accomplishment bears an analogy to a Schrödinger function in that it gives rise to a probability that practical accomplishments will materialize. We can in that sense define the expectation value for practical accomplishment in terms of scientific accomplishment. It is, however, usually meaningless to try to

identify a particular accomplishment with a particular scientific effort, especially if one is thinking about the future. If one tries to focus scientific effort too sharply upon a desired accomplishment one encounters a basic incompatibility which, in analogy with the Heisenberg principle, can be stated as follows:

The more specifically one tries to define the practical purpose of a research, the more indefinite becomes its bearing on the important questions of science and the less reason a scientist can find for doing it.

In administering the research program it is important to recognize this basic incompatibility and I would suggest that a reasonable policy must satisfy the following principles:

1. The AEC should not expect universities to undertake research unless it is motivated by scientific considerations or, in other words, unless it can be carried on as a part of the educational function of the university.

2. Basic research of the kind that universities should undertake is essential to continued progress in atomic energy; the AEC has a rational as well as a legal responsibility to encourage and assist it.

3. One should not try to distinguish between programmatic and nonprogrammatic research. Such a distinction is irrelevant to its performance and is not a sensible criterion for determining how the costs should be shared. The AEC's interest in the work depends fully as much on the competency of the investigators and the research environment provided by the institution.

To these three principles I should add a fourth for the guidance of the university in seeking support for research from the government. It is:

4. Basic research is a traditional responsibility of the universities and should continue to be supported by the university insofar as its resources and the competition of other activities permit. A situation in which the government is paying all of the costs of all of the research in an institution is likely to be neither good for the institution nor beneficial to the government.

As I have already pointed out, research projects supported by the AEC are usually initiated by the investigator with the approval of his institution. Some of you have known this already but I want everyone to know it. We are interested in receiving more good proposals so that we can make a better selection. Some of the projects we are now supporting are not as productive as they should be and they are going to be terminated. Dr. George Kolstad is the Head of the Physics Branch. He receives the proposals in physics, but before acting upon them he usually sends them to three or four physicists of recognized judgment selected because of their knowledge of the field, their knowledge of the proposer's qualifications to do research, or their familiarity with the AEC program. These reviewing services are usually requested without regard to the reviewers' contractual relations with the AEC and they are rendered without financial reward. On the basis of the opinions of the reviewers, other information, and the availability of funds, the proposal is accepted or rejected on the re-

sponsibility of the Washington staff. If accepted, it is forwarded with the necessary funds to the AEC Field Office which arranges the contract. Most of these contracts provide a lump sum covering the share of the costs which the AEC agrees to bear. The institution usually contributes certain salaries, overhead, and facilities. If the project is a large one such as the operation of a large cyclotron, the university is usually unable to make a very substantial contribution and the AEC pays nearly the full bill. If you have something to propose, the AEC Division of Research in Washington can give you specific instructions on how to proceed.

The university research program is essentially the only regenerative force of the atomic energy project; the expansion of research and of many other activities, or even their continuation at present levels, depends upon it. It is interesting to see how the program multiplies. Between 1948 and 1953 the AEC has administered a fellowship program but this has now been terminated. The National Science Foundation has started a new fellowship program slightly above the peak of the AEC program in physics so no ground has been lost. On the other hand this level could advantageously be raised—perhaps even doubled. In addition to the estimated 60 predoctoral students in nuclear physics who get aid from NSF, direct AEC contracts for university research in physics employ about 300 graduate students and 300 more are employed under AEC-ONR contracts. The total of 660 pretty well accounts for all of the graduate students in branches of physics related to atomic energy. Of course others are employed as teaching assistants, or have university fellowships, but these about make up the losses and permit us to estimate that $\frac{1}{3}$ of the 660 (or 220) students graduate each year with a PhD in nuclear physics. After graduation they do one of four things. About 10% stay in the universities where their research is supported by the Research Division, 20% join a National Laboratory and there continue in the program of the Research Division, 45% work for the AEC or one of its contractors on programs other than that of the Research Division, and 25% leave the AEC for other jobs. Those added to the permanent staffs supported by the Research Division is almost exactly 10% per year. (These comprise 225 off-site, exclusive of students, and 415 onsite, or 640 physicists in all.)

In conclusion I would like to express my admiration for the splendid work that is going on in the National Laboratories and in the universities under AEC support. I believe the scientists in the universities feel that they share in the successes and the responsibilities of the program. I also believe that they derive a certain moral encouragement and incentive for greater achievement because of being a part of the program. No man and no laboratory ever achieves greatness without the responsibility of a job to do and I am confident that physics as we know it derives much more encouragement from this great national effort to develop atomic energy than that represented by the dollars which go to its support.