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Plans and Problems in Nuclear Research

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PERHAPS THE MOST IMPORTANT THING which has come out of scientific research during the war period is the pile, consisting of a structure of uranium and graphite or equivalent materials. Simple, silent, powerful, these potential giants are waiting for man to decide between abundant life and race suicide. Fantastic quantities of energy can be liberated by them in concentrated form, and they can produce enormous quantities of neutrons and radioactive materials for experimental purposes. In the rush of war research such piles were built in the simplest, surest manner with tight metal enclosures, cooled with air or water at comparatively low temperatures. Many new types of piles should now be designed and built, using all forms of fissionable material with different moderators and different coolants. All these must be investigated as to their ability to withstand high temperatures, erosion, corrosion, and neutron and gamma irradiation. Effective cooling and quick, absolutely reliable methods of control are necessary. A happy hunting ground is waiting here for the inventor and the gadgeteer. Although the Project scientists have considered many possibilities, I am sure that the release of Manhattan Project facts to fresh minds and to men of different experience will lead to important developments in piles. Because the minimum investment for any pile is so large and the physiological and political dangers so great, these piles must probably be government supported and government controlled.

Radioactive Isotopes

Radioactive isotopes are of two general types. The elements of the middle of the periodic table which are formed on fission are abundant on the Manhattan Project because for every gram of uranium or plutonium consumed in fission 0.999 gram of radioactive fission products is formed. The long-lived radioisotopes have been stored ready for separation. This separation from a grand mixture of all the middle-weight elements including all the rare earths is extremely difficult under any conditions, but all the more so because of the intense radioactivity which complicates chemical operations and keeps operators at a safe distance. New methods and techniques must be worked out for separation of these fission products. Some of these middle-weight radioisotopes will be useful as gamma-ray emitters and as tracers, and undoubtedly other uses will be found.

The more interesting and important radioisotopes, however, are those which are produced from light-weight elements by irradiation with neutrons in the pile, giving, for example, radioactive hydrogen, carbon, phosphorus, and iron. These radioisotopes are being produced now, but at the expense of the neutrons in the pile, and their production is limited. To increase this, more powerful piles must be built. Research on the best utilization of available neutrons is necessary in order to produce the maximum amount of these valuable isotopes for use in science and industry. Even if the world should be forced to consider prohibiting piles for power purposes until international morals can catch up with the progress of science, some piles should still be operated for the production of radioactive carbon.

Research is necessary also for the best utilization and recovery of these isotopes, and again more sensitive methods of measuring radioactivity will enable a wider use of the limited available store. Uses for these radioisotopes include radiography, tracers in industry, chemistry, biology, and therapeutics. A careful plan of distribution of these resources outside the Manhattan Project has been worked out and is now being administered (*Science*, 1946, **103**, 697).

Chemical Research

The production of new heavy isotopes and trans-uranium elements opens up an interesting new field which, combined with the study of the fission products,

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gives an extraordinary boost to the development of inorganic chemistry. With 96 elements, over 500 isotopes, and the addition of the time variable of radioactive decay, the new student of chemistry is confronted with an ever-increasing body of knowledge.

For the production of radioisotopes and for useful power throughout the world it will be necessary to obtain larger quantities of fissionable material. Uranium ores of low concentration are fairly widespread, and new methods of recovering uranium from these low-grade ores should be developed. Possibly uranium can be recovered as a by-product in some industries or in industries yet to be established. In the operation of the pile the materials become poisoned by neutron-absorbing fission products and weakened in physical properties because of radiation. When the situation becomes sufficiently bad, the material must be removed and treated chemically so that the atomic fuel of fissionable materials can be recovered, reprocessed, and returned to the pile. In order to handle these materials they must be decontaminated so that the radioactive fission products are reduced perhaps to the extent of one millionth of their original concentration. If this chemical processing has to be repeated at frequent intervals, it is necessary to have extraordinarily high efficiency—99.9 per cent recovery, for example; otherwise, there will be serious loss of the extremely valuable U-235 or other fissionable material used in the pile. Research is necessary to improve still further the chemical processing of the pile materials. It must be remembered that most of these chemical and metallurgical operations must be done by remote control, by pushing buttons and levers and peeking through periscopes at a great distance behind protecting shields. If a pump or a piece of equipment fails in the large-scale processing of pile materials, even this must be removed and replaced by machinery operated by remote controls.

Biology

One of the outstanding accomplishments of atomic energy research has been the protection of the health of the personnel. Accidents have been extraordinarily few as a result of vigilance, wise planning, and research. The budget for health and biology has been large, but it has been justified. Tolerance limits for safe handling of materials with alpha, beta, and gamma rays and neutrons had to be established. We came to the Project thinking in terms of millicuries and found that we had to face problems of curies and sometimes of centra- and even kilocuries.

Laboratories, equipment, personnel, clothing, all have to be checked constantly and monitored for radioactivity. Some operations have to be carried out with rubber gloves, often inside awkward dust-proof boxes. Of course, the most difficult problem was to make the eager scientists obey the rules designed for their own good. So much effort has been spent on prevention that very little time has been devoted to possible cures for overexposures or accidental intake of radioactive materials. Research along these lines should now be emphasized.

Disposal of radioactive materials constitutes a very serious difficulty, and new methods, such as precipitation, adsorption, electrostatic-precipitation drying, and incineration, are desired. One of the greatest needs is for a more efficient shield for gamma rays. Lead and concrete are satisfactory, but someone may think of a new principle, possibly using resonance or photochemical reaction or something else, to stop gamma rays which does not depend on just sheer mass.

Research into the mechanism of radiation damage is important and a great deal of work has been devoted to it. Alpha, beta, and gamma rays and neutrons all seem to act through ionization within the body tissue. If one measures the total ionization effect, he will have a fair indication of the body effect no matter which of these different agencies is responsible for the actual ionization. Alpha and beta rays are easily stopped by thin shields, while gamma rays require very thick shielding (more than five feet of concrete for an effective pile), and neutrons require shielding of a special type containing neutron absorbers such as hydrogen, cadmium, or boron.

Even though adequate shielding is provided, one must worry about the intake of materials which will emit these alpha, beta, and gamma rays within the body. Radioactive material may be taken into the stomach, through certain radioactive solutions accidentally dropped on the hands of a laboratory worker and evaporated, or from dust in the laboratory settling on clothes or hands and later transferred to food. Radioactive materials of certain half-lives taken into the stomach tend to be discharged slowly, at rates which have been thoroughly studied. Intake into the blood stream is still more serious, and any scratches or abrasions of the skin must be regarded as a serious condition by all who work with radioactive substances. Such materials can also enter into the lungs in the form of dust. Rubber gloves, change of clothing, special facilities for eating—all these precautions and many more are necessary for those who work with special radioactive materials.

These difficulties pose serious problems of waste disposal. Fortunately, the detection of radioactivity by instruments is extremely sensitive, so that any condition detrimental to living material can be detected first with physical instruments. Radioactive materials cannot be dumped down the sink without eventual pollution of the sewage. Oxidation and chlorination are of no help in radioactivity purification. One cannot allow radioactive materials to get into the air—they must be sent up through hoods, and filters or precipitators may be necessary to prevent the material from contaminating the neighborhood. Disposal of experimental biological material is also a serious problem. For example, the body of a rat which has been injected with radioactive materials cannot be placed in an ordinary collection can or buried upon completion of the experiments. A prowling animal may eat the radioactive carcass. Long after the carcass is disintegrated long-lived radioelements will persist in the ground. Special storage or controlled incineration is needed.

Little has been done on clinical uses of radioactive materials, but research is progressing. Radioactive carbon, iodine, phosphorus, and iron will soon be invaluable for these purposes. Possibly radioactive compounds will be found which will be absorbed preferentially on rapidly growing cells in such a way as to inhibit abnormal growths. The organic chemist is being called on to synthesize from radioactive elements compounds which can be directed to various parts of the body for therapeutic purposes.

New Tools

Successful developments in science follow closely the development of better instruments. We have developed electrometers and Geiger-Müller counters for alpha, beta, and gamma rays and neutrons which are superior to, and more sensitive than, those heretofore available. These are used for laboratory researches, control of piles, health monitoring, and ore exploration. Multiple alpha-ray counters give complete simultaneous information concerning ranges and intensities of a mixture of alpha emitters and have helped to discover new radioactive decay series in the heavy elements. The health instruments are designed to snoop along surfaces of desks and floors for alpha and beta activity to detect gamma radiation and air-borne radioactive dust and to ring an alarm when a person with radioactivity on his clothes passes through a door.

Among the new tools piles stand pre-eminent. By measuring a slight change in activity of the pile one can determine the neutron absorption of a very small piece of material with extraordinary accuracy due to the chainreacting multiplication of neutrons. The high neutron flux makes possible the production of large quantities of radioisotopes and the carrying out of significant experiments with neutron beams, including scattering and absorption measurements with crystal spectrometers. New physical and chemical properties have been made available for study by exposure to intense neutron radiation.

Atomic Power

One of the most intriguing problems raised by the atomic energy program is the production of useful power to give electricity from piles. Power piles are technically feasible, and now that the war strain has been released, attention is being devoted to the building of pilot plants. Little can be said yet regarding the economic possibilities of power. If we take a short-range view with the expensive enriched materials now available, we know that we can produce useful power throughout the world, but we know also that at least in this country it will be much cheaper to use coal or other combustible fuel in standard machines. On the other hand, if we take a long-range view, it seems likely that power piles will be important, and they will do much to supplement the available sources of combustible fuel, heretofore considered our only sources of useful fuel. We should consider not only our own country but also other regions of the world where there is impelling need for the development of more electrical power. Because power piles must be operated at high temperatures to give high thermodynamic efficiency, the properties of suitable moderators and coolants must be studied over a wide range of conditions. A great deal of time-consuming research remains to be done.

Neutrons are lost by internal absorption as well as by external escape. They may be absorbed by the moderator, by impurities in the moderator and in the uranium, and by structural materials of the pile. One of the most important bottlenecks in building the first pile was the production of metallic uranium and graphite of sufficient purity. Some of the common structural metals which one would like to use inside the pile cannot be used because they absorb too many neutrons.

One of the most challenging problems in pile design is removal of the enormous quantities of heat. Particularly in small piles, using plutonium or pure or enriched U-235, heat-transfer problems of a new order of magnitude will be involved. Water, gases, gases under pressure, and liquid metals are among the possible coolants. The coolants, of course, must have a low absorption for neutrons, must be chemically and physically stable when subjected to intense radiations, and must not corrode or erode the material of the pile with which they come in contact.

The burning of a fuel such as coal or gas in air gives a temperature which is limited to perhaps 2,000° C. No such limits exist for the heat generated in the pile. But again there is no way of utilizing heat at higher temperatures because at present no alloy or metal is available which will withstand the oxidizing conditions of the ordinary combustion fuel at temperatures above 1,000° or 1,100° C. In the pile, however, an oxidizing atmosphere is not needed—helium or metal can be circulated through the pile, the oxidation being avoided. Theoretically then, it would be possible to use tungsten or molybdenum at temperatures up to 2,000° C. At present we are limited to about 1,000° or perhaps 0.1 electron volt. Possibly we may some day climb up to around 0.2 volt and obtain a much higher thermodynamic efficiency than we have at present. Theoretically, perhaps these atomic fuels could give us energies of millions of volts instead of the 0.1 or 0.2 volt, but no means of utilizing this high-intensity energy directly has yet been developed.

Let us turn now to some of the *problems* involved in nuclear research.

Secrecy

The compartmentalization of scientific workers on the Manhattan Project, which prevented free exchange of scientific reports and information from one laboratory to another, has been annoying, and it has constituted a handicap in the research program. During the war we all accepted it as a necessary evil. Now that the war is over, the scientists object strenuously to its continuation. But many are convinced that secrecy and restrictions of publication will still be necessary in some branches of atomic energy research. Prior to the atomic bomb, only philosophers and economists had to consider their responsibility to the public in their speeches and pronouncements, while scientists were perfectly free to talk about anything they chose because anything they might say would have little influence on the social and political aspects of their society. Now, however, public release by a physicist of the number of neutrons produced in fission of plutonium or the description by a chemist of a means of effectively separating plutonium from its fission products on an industrial scale immediately carries international complications.

I am afraid that some of the bars of secrecy will have to remain. The scientists at the Metallurgical Laboratory know nothing about the construction of the atomic bomb, and we have in our library nothing about the weapon. Moreover, none of the scientists wants to have any such material available, and I am sure that they welcome this restriction.

Publication

The publication of research offers serious difficulties. The situation is somewhat unique—hundreds of scientists have worked feverishly for four years without any chance to publish their material in the standard journals or in books. The material is recorded in the form of thousands and thousands of reports, many of which have been progress reports and hastily prepared reports designed to meet emergencies.

Many of these should never be published. Most of them should be coordinated and rewritten in the light of subsequent findings in the laboratory. For the past year this Laboratory has devoted a considerable part of its time to writing up in final form this vast accumulation of scientific material. Other laboratories within the Manhattan District have been writing similar records, and when all these reports can be published you will be surprised to learn how much has been accomplished in science even though the advancement of science was not our chief aim. As an illustration, I think that we know more about the chemistry of the new, artificially-produced element, plutonium, than we know about the chemistry of half of the prewar elements. The Government has undertaken to have all the scientific material published either for public or private circulation.

The declassification of the secret documents of the atomic energy project has been a difficult problem. A civilian committee headed by R. C. Tolman was established by the Manhattan District of the U. S. Army to formulate rules by which the research material can be made available to the scientists and the general public. This declassification code is now in operation, specific documents being declassified on the recommendation of the Laboratory Director, a responsible referee, and the patent advisers. The Army administers this procedure, but the rules are established and interpreted by the civilian scientists. A large fraction of the material is now declassifiable, and provision has been made for revision of the rules from time to time.

A troublesome problem now being faced is the publication of this material in the standard journals, since, once it has been published in book form, the scientific journals will probably not wish to accept it. Conversely, it may be difficult to find a book publisher if much of the material has appeared previously in scientific journals. Another problem involves the release by individuals of this work which has been done at government expense. It might be easiest to adopt a laissez-faire policy and attempt no control, but then the more aggressive men would get their material out first and in so doing might rob the less aggressive men of the proper credit. The situation differs from that which prevails under ordinary conditions in scientific laboratories because free publication in the usual manner has been denied for the past five years.

Another problem is that of review articles. Ordinarily it is proper and desirable for an expert to comb the public literature and write review articles which will present the material of any individual paper in a critically evaluated and convenient form for the average reader. But if these review articles are made up from project reports which have not yet been published the reviewer will in a sense skim off the cream for publication, and even though the scientific worker is given full credit for the experimental work, he would probably prefer to present his own work first in the standard scientific journals. On the other hand, the men of the Manhattan District feel that they are carrying a heavy responsibility as custodians of the vast amount of scientific knowledge which properly belongs to the Nation and to the world.

These problems are acute, and they have been given very conscientious, thorough attention by both scientists and Army officials. Whereas many have blamed the Army for the secrecy restrictions and the publication difficulties, the unique situation rather than the Army itself is to be blamed. The Army acts as a buffer between the scientists and the public. A long time will be required to educate the public with regard to our point of view, namely, that (1) there are no secrets in the fundamental facts of science; (2) even if there were secrets of science, we could not hope to keep them from others except for a very brief time; (3) we should not handicap our own scientists and the normal development of scientific research in our own country by withholding the knowledge which we have accumulated during the war; and (4) by attempting to withhold the so-called secrets we would incur ill will throughout the world.

Let me emphasize, however, that we have taken positive forward steps in publishing the Smyth Report and the State Department Report on International Control.

Much of the disagreement concerning secrets of atomic energy is caused by a confusion in definitions. Information concerning weapons, production rates, and plans constitutes military secrets which should not be made public, whereas constants of nature and ordinary fundamental work in science cannot be kept secret. Engineering information and technological techniques constitute an uncertain borderline field similar to that in which industrial companies sometimes try to keep trade secrets.

Shortage of Scientists

A most serious problem facing the development of atomic energy is the shortage of men trained in the sciences. This situation is, however, not unique in the field of atomic energy: there are too few scientifically trained men for the whole country—in industry, in research, and in teaching. Unfortunately, the training of young scientists in the colleges of the United States practically ceased for the period of the war. Other countries were not as shortsighted. The demand now is so great that competition for men is acute, and the government laboratories find it difficult to keep their men. Industry probably pays higher salaries, while universities offer greater freedom of research, more attractive surroundings, and greater security. Reasonably high salaries and freedom of research will be necessary in order to keep even a skeleton crew of atomic scientists at work on the development of this important field.

During the war times scientists would accept any working conditions and any arbitrary rulings which were necessary to help win the war. The same spirit of subordination of personal desires cannot be expected now that the war is over. One of the most cherished prerogatives of the scientist is to carry his research wherever his ideas may lead him. Under Army direction there was extraordinary cooperation between the academic scientists and the industrial engineers even though these two groups have rather radically different philosophies. In industrial developments the ideas come largely from the top, and orders are given to those who are helping with the project. In academic research the ideas come largely from the bottom. Each investigator is more or less of an individualist whose ideas and accomplishments are transferred into action through supervisors and administrators. Under peacetime conditions it is more difficult to continue this type of wholehearted cooperation between groups with such different viewpoints. The scientists in one laboratory may be asked to work primarily on weapons, but they do not want to work on weapons—they insist on working on fundamental academic research for at least part of their time. Scientists in other laboratories are told that they must concern themselves primarily with industrial applications and production, but many of the creative scientists, who are needed to make such a project a success, strenuously object to restrictions and insist properly that they have a right to work on fundamental research as well. Still another laboratory is supposed to be constituted primarily of academic scientists in a university atmosphere who are to devote themselves to fundamental research. Some of these, however, may develop practical ideas for the construction of some unit which calls for an engineering development. They want to go along with this development and see their ideas carried through to successful conclusion. If such scientists are denied the chance to carry through to a pilot-plant stage, they will become dissatisfied. It will be necessary for successful development in the field of atomic energy to allow the academic scientists considerable freedom to choose their own research problems. However, there are important jobs which the Government must get done, and the scientists of the government laboratories have an obligation to see that they are done.

Research Policies

The determination of nuclear constants; the design of piles; the development of new chemical processes; the discovery of new elements and their chemical and physical properties; the invention of new instruments; the production of uranium, graphite, and other materials on a large scale at previously unheard-of purities; the design and construction of enormous operating plants in record time—all these and many more stand out as almost miraculous accomplishments. But they were not obtained without the sacrifice of thousands of scientists drawn from other important activities, draft deferments, top priorities, much of the country's stainless steel, and 1 per cent of the Nation's wealth. Although some praise the great accomplishments of scientific research in wartime and imply that they are due to the war effort, we do not subscribe to the view that war accelerates science. We know that these dramatic results merely represent a cashing-in on years of fundamental research which went before. Meantime, the reserve of fundamental science is not being replenished at its normal rate, as is evident from the dwindling size of our scientific journals through the war period. I must emphasize, however, that the Manhattan Project has contributed its share to the development of pure science. Thousands of pages of finished manuscript on plutonium, uranium, radioactive substances, and biological effects of radioactivity are now awaiting release for publication, and a large part of the record in chemistry, metallurgy, and physics is ready.

The importance of fundamental research should again be emphasized. Although near-miracles were accomplished by mass production and organized research in an uncharted field, better results can be obtained in a normal, long-range program by a more fundamental approach in which experiments are planned not for immediate answers to specific programs but for the mastering of general principles. In this way we can more intelligently design our machines and processes, and when we find that we need to make changes in the light of further testing, we can alter our plans without having to wait for a whole new set of empirical laboratory experiments.

Regional Laboratory

The Army has very wisely decided to continue the research laboratories which were so successful during the war and in general is trying to set up organizations which can be taken over easily by the new Atomic Commission when it is established. It is planning to make the laboratories available for the use of the universities. An effective cooperating organization has already been set up in connection with the atomic energy laboratory at Chicago. Twenty-five universities of the Middle West are cooperating in the administration of this laboratory, operated for the present under contract by the University of Chicago. Pioneering work is being done in the organization of this regional laboratory, and the articles of organization will soon be available to those interested.

It is proposed that atomic energy research of value to the Government be carried on by a permanent staff. This permanent staff also will have opportunity to engage in a research program of its own choosing. Temporary staff members will be welcome from anywhere in the country and in particular from the staffs of the cooperating universities. If the research program is of primary interest to the cooperating university, the salary of the investigator who comes to this Argonne National Laboratory will be paid by the cooperating university, and the research will be published from the cooperating university with a by-line to the Laboratory. If the work is of primary concern to the Government or if the visiting scientist prefers to work on a problem sponsored by the Argonne National Laboratory staff, the salary of the visiting scientist will be paid by the Government, and the publication will be from the Laboratory and the cooperating university.

Among the many problems which are now being solved are the fixing of legal responsibility for accident compensation, the loan of special instruments, and arrangement for transportation of radioactive materials, for financial reimbursements, if any, and for the use of special utilities and materials. New laboratories must learn safety methods and will want the loan of our health experts. We look for a vigorous, interesting development not only in the encouragement of scientific research but in the cooperation of many separate universities and in the training of atomic scientists.

Conclusion

These problems which I have attempted to enumerate seem important, but they are insignificant in comparison with the one fundamental problem of international control and the organization of the world to prevent war. If the human race is to survive, war cannot continue. As scientists we are keenly aware of the benefits of international cooperation. We want world-wide freedom for the human mind. As discoverers of new nuclear forces we feel our responsibility for their use in the world. As citizens we must use our influence vigorously toward effective world government as the means for permanent peace.