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Argonne National Laboratory

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September 17, 1951

Mr. W. B. Harrell, Business Manager
University of Chicago
Chicago, Illinois

Dear Mr. Harrell:

This Fall not only marks the time for the renegotiation of the Argonne National Laboratory operating contract, but much more significantly it marks the rounding out of ten full years of service on the part of the University of Chicago as one of the Government's principal contractor-sponsors for research and development in the atomic energy field. It has been a decade of continuous tension coupled with unremitting effort; each achievement, no matter how significant, has been written into the record as a passing onward step toward future urgent and essential goals. There has been little time and less interest in looking back - the critical future has been all-demanding and all-absorbing. It has seemed to the writer that this rapidly approaching tenth anniversary marked at least a chapter in the record and justified a pause to re-read what has been written. Since much of this history has been recorded only in the memory of the personnel involved and since that which is written consists almost entirely of disconnected and uncoordinated technical fragments, some attempt to summarize the story appeared worthwhile.

Since the writer is the only member of the original group responsible for the organization and administration of the Plutonium Project who has been continuously in the midst of both its technical and administrative problems and accomplishments since its formal approval in December 1941, he has taken it upon himself with the assistance of James R. Gilbreath and Charlotte F. Young to present the attached summary report. It is a record of which both the University and the Government can be unreservedly proud.

Sincerely yours,

N Hilberry

N. Hilberry
Deputy Laboratory Director

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CROSS REFERENCE

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This document consists of 35 pages. No. 7 of 30 copies, Series A

1 of 1 series

SUMMARY REPORT ON THE ACCOMPLISHMENTS OF THE PLUTONIUM PROJECT UNDER THE SPONSORSHIP OF THE UNIVERSITY OF CHICAGO DURING THE DECADE 1942-1951

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CLASSIFICATION CHANGED TO: NOT CLASSIFIED 5-14-69 T.P. Heckman

INTRODUCTION

On December 19, 1951 the University of Chicago will have completed ten years of service as one of the U. S. Government's principal contractor-sponsors for research and development in the atomic energy field. It is important to re-examine the reasons that brought the University into this position and to assess the present validity of those reasons. It is important to examine what has been accomplished under the University's administration -

a.) administratively, in the establishment of the scientific and technical staff and the facilities essential to their effective utilization and

b.) technically, in terms of the actual scientific and engineering accomplishments achieved by the staff.

Here is the record.

CONTRACTOR SPONSORSHIP

Almost exactly ten years ago the Committee of the National Academy of Sciences which had previously reviewed the feasibility of developing nuclear energy as a military weapon was re-activated. As a result of this re-evaluation it was decided by the Government on December 6, 1941 to go ahead with a full scale effort in the field. On December 19, 1941 four projects were authorized and tentative budgets approved. As a result of previous work the unique position of uranium-235 was recognized and three of the projects were concerned with isotopic separation processes for the production of uranium-235. The fourth project, which later became known as the Plutonium Project, was concerned -

a.) with the establishment of a controlled slow-neutron fission chain-reaction

b.) with the possible use of such a chain reaction in transmuting uranium-238 into the new transuranic element plutonium which had previously been shown to be fissionable and

c.) with the investigations in physics essential to the establishment of a fast-neutron, bomb type chain reaction.

Dr. A. H. Compton was appointed Project Leader for this Plutonium Project.

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Prior to this time research in connection with the Plutonium Project had been underway at several universities and research institutions with the major groups concerned being located at Columbia, Princeton, and at the University of Chicago. On January 1, 1942 the first meeting of the staff of the new Project was held at the University of Chicago. Included were all those who had been active in the previous research groups, many of them having been engaged in this work since 1939. On the basis of their collective experience two conclusions were reached on which there was complete unity. The first was that the Project had a real chance to achieve its objectives. The second was that such success could only be attained if the entire group could be brought together in a single, strong, central laboratory which could be expanded to whatever extent might be necessary to meet the required time schedule. On this latter point the feeling was very strong and, consequently, this establishment of a central laboratory became the first task of the Project administration.

The first four weeks of the Project's existence were given over to a determination of where this new laboratory should be located and the corollary decision as to who should sponsor the work as contractor. The character of the task ahead was clear. It was obvious that much in the way of development and engineering would be required. It was equally obvious, however, that the paramount considerations were research considerations and not matters of technical engineering detail. At every point, engineering practice would of necessity have to be subordinate to the controlling requirements established by research progress. It was clear, therefore, that the establishment of immediate objectives and of operating program were of necessity the prerogatives of scientific rather than administrative judgment.

With this in mind there was no question but that the proper contractor for this work should be one adept in the administration of major activities where many of the administrative decisions were of necessity made on the basis of the scientific judgment of the technical staff concerned rather than directly by members of the administration on the basis of purely administrative considerations. Without question the contractors most skilled in meeting these requirements were the universities. However, although the administrative skills of a university administration were ideally suited to the requirements of the Project, no university had adequate administrative staff nor adequate facilities to absorb within itself a project of the magnitude which all realized the Plutonium Project would of necessity be. A university contractor would require major expansion of its administrative staff and of its physical facilities to accommodate the Project. Consequently, the possibility of an industrial contractor was immediately explored. Certain of the major industries would possess staff and facilities for research and development work which might prove adequate, with a minimum of supplement, for the needs of the Project. In spite of the high quality of research carried on in certain of these industrial laboratories, their administrations do not really meet the criteria stated above. In any such organization research as such is of necessity subordinate to the primary development responsibilities of the organization and all decisions are strongly or wholly subject to over-riding administrative considerations. The urgency of the situation, however, was such that this difficulty was tentatively

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waived. It became immediately obvious that any of the industrial laboratories whose research competence and research facilities were sufficiently adequate to justify their consideration as contractor for the Project were already so completely involved in research responsibilities in the area of their own industrial competence that they were unavailable. Doubt as to the real adequacy of industrial administration and particularly as to the specific question concerning the ability of the Project to procure proper scientific staff under industrial sponsorship had been so deep that it was with a real sense of relief that the Project made the decision to obtain a university contractor in spite of the well realized problems of organization and of provision of adequate facilities which this decision entailed.

Prior to the formation of the Project as such the three strongest groups engaged in research in this area were at Columbia, Princeton and the University of Chicago. Much of the initiative for obtaining Government recognition of the importance of nuclear energy as a military objective lay with the Columbia and Princeton groups. It was perfectly natural for the research men from these two universities to be anxious to have the administration of the Project undertaken by their own institutions. The administrations of Columbia, Princeton and the University of Chicago all agreed that they would be willing to undertake the responsibilities involved. While military considerations indicated preference for an inland site, this factor was not given undue weight. Full consideration was given to possible eastern sites. The final decision was essentially based on the following two factors. The character of the work approached top secret category and would, therefore, require much in the way of blind acceptance of the word of the project leader on the part of the contractor. It was obvious that the personal relationships established by Dr. Compton over a period of twenty years with the administration and the Board of Trustees of the University of Chicago would provide a much firmer basis for this kind of operation than could be provided by relative strangers regardless of their earnest desire to cooperate. This point was an accident of personalities brought about by the appointment of Dr. Compton as Project Leader. The second and more significant consideration lay in the character of the administration of the University of Chicago itself. If the Project were to succeed, major gambles would have to be taken. There would be scientific and technical gambles and upon occasion financial gambles when the urgency of a particular task would not permit time for due process to cover commitments prior to initiation of the necessary action. The University of Chicago's fifty year record attested to its ability and its willingness to take such gambles in stride in either area and to do so without hesitation once agreement had been reached that the objectives at stake were vital. With all other points essentially in balance between the various potential locations, it was these latter factors which led Dr. Compton to decide on the University of Chicago as the contractor, a decision with which the participating scientists concurred although with definitely varying degrees of conviction.

How do these early considerations apply now, ten years later? In spite of spectacular industrial achievements it is still true that if the Nation is to maintain its leadership the basic character of the work in the atomic energy field has not changed. In so far as the potentialities of nuclear energy are significant in determining national security, that security is assured only to the extent that the Nation is able to maintain a high rate of progress. Acceptance of the status quo as adequate marks the beginning of senescence and in a field as little understood as is that of nuclear energy, senescence may progress to ultimate demise in a very short period of time indeed. With the establishment of the elements of a working technology the importance of the industrial contractor to the development of nuclear energy as a production tool is greater today than it was ten years ago. However, it cannot be stressed too strongly that the major role which industrial participation plays in the development of this field lies in the area of the introduction of operating philosophy into its technology rather than in the area of scientific and technical originality. During the past decade administrative techniques have been developed which insure that the research effort and the industrial effort each play their most effective part in assuring maximum progress. The achievements of the Metallurgical Project and of the Argonne National Laboratory in working with the duPont Company and with the Westinghouse Electric Corporation are examples of the effectiveness of these techniques. More recently Argonne's program of cooperation with the industrial groups examining the feasibility of direct industrial participation in the atomic energy field gives promise of equal fruitfulness in this new area. This being the case it frees industry to operate under its most effective administrative pattern and simultaneously frees the national laboratories to operate under the type of administration clearly best acepted to their requirements for maximum effectiveness. Obviously the initial potential advantages that first led to the consideration of a possible industrial contractor no longer obtain. Questions of existing organization, of readily available existing facilities and of technical and scientific staff are no longer germaine. Argonne National Laboratory has an administration which has been hand-tailored to its own peculiar and highly individual needs. It has facilities designed to meet the unique requirements for work in the atomic energy field. Finally it has a staff which no industrial organization can match in combined quality and breadth of scientific competence. Progress in the atomic energy field is a complex process impinging simultaneously on nuclear and classical physics, on nuclear, classical and radiochemistry, on chemical engineering, on unorthodox as well as standard metallurgy, on equally unorthodox approaches in engineering and on the whole field of radiobiology and radiological medicine. Real progress demands the simultaneous approach and the continual interaction of all of these disciplines on the problems in hand. Such diversity is characteristic of a university and brings to the university administrative understanding in all of these areas while no single industry is competent and experienced in the administrative requirements of more than a few of these fields.

Since the basic requirements for progress in the utilization of nuclear energy have not changed, since the initial handicaps to university administration have been removed and since administrative techniques have been developed enabling industry to make its most effective contributions within a framework providing for university administration of the national laboratories, it is clear that

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if real progress is to continue, the considerations which led to the initial choice of a university contractor-sponsorship are fully as compelling at the present time as they were initially ten years ago.

ADMINISTRATIVE HISTORY

Any definitive evaluation of the success attained by the Metallurgical Project and its successor the Argonne National Laboratory must be based upon their scientific and technical achievements. However, the ability of an organization to achieve such scientific and technical success is dependent to a significant extent upon its intermediate accomplishments in establishing an effectively functioning organization, upon its ability to recruit necessary technical and supporting staff, and upon its skill in acquiring or improvising the facilities necessary for efficient operation. Therefore, before proceeding to a summary of scientific and technical achievements it is proper to review the administrative history of the Project in order to appraise the degree of ingenuity, flexibility, and skill brought to bear on the exceedingly difficult and complex administrative problems faced by the Project as attested to by its administrative achievements.

When the decision to establish the central laboratory at the University of Chicago was made on January 29, 1942 the Project had the following assets. First, it possessed a directive from the Office of Scientific Research and Development of the U. S. Government, directing it to proceed with investigations of both the slow neutron and fast neutron fission chain reactions and to determine the feasibility of the use of the slow neutron chain reaction for the production of Plutonium as a possible bomb material. This directive also appointed Dr. A. H. Compton as Project Director and guaranteed adequate financial support. Second, the Project had a potential staff of some 50 scientists working in independent groups on problems vital to the success of the Project at various scattered locations. The principal groups were at Columbia, Princeton and the University of Chicago. Finally, the Project had the promise of the University of Chicago that it would enter into a contract with the OSRD to assume responsibility for the administration of the Project and that the University would give the Project its complete support. These were the modest assets. By comparison the liabilities were of major magnitude. The Project had no organization. The OSRD had appointed Dr. Compton as Director of the Project although he had not been active in the actual scientific work prior to this time except for his somewhat tenuous connection as Chairman of the National Academy of Sciences Committee which had been responsible for the feasibility review. The potential scientific staff, although of the highest possible competence, were widely scattered, had little experience in general in large scale team work, and were almost entirely physicists. Facilities designed to meet project requirements were non-existent and it was clear that the problems of dispossessing established university departments from their accustomed quarters would be far from simple. Moreover, the Project was faced from the start with the problem of operating under an atmosphere of compelling urgency since it was known that the German scientists had been very active in the field as early as 1939. This almost desperate conviction of the need for the utmost speed

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intensified the critical character of all of the administrative problems throughout the war period and by its absence magnified the problems arising during the period between the end of the war and the establishment of Argonne National Laboratory because of the resulting exaggerated appearance of aimlessness which its sudden removal entailed.

It was clear from the beginning that the Project's responsibilities with respect to the fast neutron, bomb reaction were in most respects distinct from its responsibilities with respect to the slow neutron chain reaction and the use of the latter for the production of plutonium. As a result this work was separately organized. A small coordinating group was established at the Laboratory in Chicago and research teams were sponsored at a number of universities and research institutions possessing qualified scientific staff and the specialized equipment requisite for the experimental program to be undertaken. In the spring of 1942 the Project administration obtained the services of J. R. Oppenheimer to direct the work on the "fast" reaction and a theoretical group was established at Berkeley during that summer. By this time the full magnitudesof both the Plutonium Project and of the "Bomb" Project were becoming clear. Since they were distinct and separate operations full responsibility for the latter was transferred to Oppenheimer under a contract between the University of California and the OSRD. The group at Berkeley together with the coordinating group at Chicago and their associated sub-projects immediately began the organization and planning of the facilities for the Los Alamos laboratory. The group at Chicago carried the responsibility for providing the necessary experimental facilities and continued their operations from the Metallurgical Laboratory until April of 1943 at which time the facilities at Los Alamos were ready for occupancy and the two projects were definitely separated except for a minimum of scientific liaison. The University and the Project had thus fulfilled their responsibilities in connection with this phase of their assignment.

A detailed administrative history of the Plutonium Project and its successor the Argonne National Laboratory would be interesting and instructive for the growth of the Project at all stages has been a conscious experiment in scientific administration. A continuous effort has been made to maintain an administrative structure within which the immediately available scientific and technical staff could operate with maximum effectiveness. This has involved the testing of known administrative devices and the invention of new administrative techniques. Some have proven effective, others have failed. Throughout the ten year period there has been a continuing and earnest effort to determine the basic Project requirements in terms of staff and facilities needed to achieve specified objectives within established time schedules. As the character, magnitude and urgency of the Project's assignments have varied new information concerning basic requirements has been developed. Concurrently, experience has been gained with respect to the assignments to be expected. "Bigness" in itself is the nightmare of any conscientious administrative officer. On the other hand, an organization inadequate in terms of basic requirements to handle effectively the workload in assignments which experience has shown are to be expected under existing conditions is equally as culpable as the organization devoted to "empire building."

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It has been the consistent endeavor of the Project administration to determine its own minimum effective size based on its experience with anticipated workloads. Questions of proper distribution of staff among the various scientific and technical disciplines to yield a balanced attack on characteristic assignments, questions of proper research strength to balance a given development potential, questions of proper ratio of technician support to scientific and technical staff in order to utilize the staff at maximum efficiency in the various disciplines, questions of the strength of service operations really essential for effective staff operation, these and many more have received continued study and certain basic information has been developed. Obviously, however, such a detailed history is beyond the scope of this report. Here it is only possible to describe in the broadest of outline what has been actually achieved in terms of administrative progress.

The administrative problems faced by the Project fall into two major periods, that extending from its inception in January 1942 until the delivery of the bombs on Japan in August 1945 and that subsequent to this latter date. In the first period the basic consideration governing all administrative actions was that time was the primary currency - days not dollars measured the costs. In the years immediately following the end of hostilities the reverse was justly true and dollar costs became the basis upon which administrative justifications had to be based. At the present time some of the old urgency has returned and the Laboratory finds itself caught in an administrative vise between the jaws of established "dollar cost" procedures for operating requirements on one side and "time cost" demands for the production of urgently needed technical results on the other. At each stage of the Project's development the above fundamental considerations have been governing and have consequently strongly influenced the character of the administrative structure.

A second general approach in analyzing the history of the Project can be made from the point of view of the nature of its sponsorship within the Government. From pre-project days most of the significant work on the utilization of nuclear energy for military objectives was under the administration of the Office of Scientific Research and Development of the U. S. Government. When the four formal integrated projects were established they were consequently organized under OSRD sponsorship. The administrative philosophy of the OSRD was to place essentially total responsibility for the achievement of the contractural research and development objectives directly on the contractor. Fiscal control was largely limited to the establishment of general budgetary requirements and general supervisory inspection of the reimbursibility of the contractor's vouchers. Even in this latter case the direct line of responsibility lay between the contractor and the General Accounting Office with the OSRD serving as the contractor's supporting agency in those instances in which a particular voucher was called in question. The scientific and technical responsibilities of the OSRD were discharged by frequent review of the actual results obtained by the contractor in the process of his operations.

The OSRD sponsorship continued from the initial organization of the Project until May, 1943. During this period the fundamental research and development work essential to establish processes for large scale plutonium production

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was carried to the point that all necessary basic data were available; the first controlled slow-neutron fission chain reaction was established and the Argonne National Laboratory in the Palos Park section of the Forest Preserve was designed and constructed to provide facilities for "pile" investigations; the design of the facilities for Clinton Laboratories were essentially completed by the Laboratory staff with the assistance of the duPont Company; finally, the basic designs for the Hanford plutonium producing piles and the associated chemical processing facilities were essentially frozen, again in cooperation with the duPont staff.

By May, 1942 it was clear to the Project administration that success was sufficiently assured to justify proceeding with the provision of the pilot plant and semi-works facilities which the Project would require. A site for these facilities was chosen and organization of an operating group was initiated. Again the University of Chicago was requested to assume the contractural operating responsibilities. The Project also initiated action leading toward the construction of the full scale production facilities to follow. Since production operations were beyond the scope of the OSRD the Government assigned this phase of the work to the Corps of Engineers, U. S. Army who in turn established the Manhattan Engineer District to discharge their responsibilities in this connection. This was formally accomplished in June, 1942. Throughout the succeeding period from July 1942 until May 1943 the Manhattan District served as administrative representative of the OSRD and provided the Project with an increasing measure of operating support. With completion of the fundamental phases of the work and with the responsibilities of the Project shifted to direct support of production activities the contract between the University and the OSRD was replaced by a contract between the University and the Corps of Engineers. This latter contract with certain supplements has remained in force ever since, being transferred by presidential order to the Atomic Energy Commission on January 1, 1947 and being extended by the Commission until July 1, 1952.

The administrative policies of the Corps of Engineers were basically the same as those of the OSRD. The principle of placing primary responsibility for performance on the contractor and of judging performance on the basis of results produced were the same. In the case of the OSRD this philosophy had grown out of a thorough recognition of the requirements of carrying out research and development assignments successfully; in the case of the Corps of Engineers it had been developed through many decades of responsibility for major construction projects. The technical program control was continued intact from the OSRD. Since the project was operating on a war emergency basis there was little change in budgetary requirements. In the matter of fiscal control the procedures shifted to more orthodox governmental methods.

The project was fortunate during this time in that Col. K. D. Nichols who served as District Engineer for all but the initial organizational period had himself had considerable research and development training and experience and had also the responsibility for the direction of a research and development laboratory. This background provided a basis for a firm working relationship with the Project administration which might otherwise have been difficult to achieve. This basic understanding became vitally important in the transition period after the principal objectives of the Project had been achieved. With the cessation of hostilities the position of the Manhattan District became most difficult in that the directive under which it was operating provided only for the support of activities which could be effective in the "present" war. The war was over and with that event the detailed approval of fiscal matters reverted to Congress. Obviously, in the national interest the Project activities could not be allowed to come to a stop. Equally obvious, however, was the fact no clear basis to continue then existed. This situation gave rise to most of the administrative difficulities existing during 1945 and the first half of 1946. By July 1946, the future pattern was clear enough for the Manhattan District to approve the reorganization of the Metallurgical Laboratory into the Argonne National Laboratory. However, it was only with the signature of the Atomic Energy Act of 1946 by the President in August that a firm administrative basis was re-established.

With the appointment of the first Commission and the first General Manager and their subsequent assumption of full operating responsibility on January 1, 1947, the Project started its career under its third government sponsorship.

The Commission operation has continued the philosophy of contractor-operation. During the 1945-1946 transition period the over-all Project Office organization had ceased to exist since it was founded on the existence of a national need which had been satisfied. As a result the Commission was faced with the administration of many independent and disconnected groups varying widely in strength instead of the previous situation in which the Government sponsorship had to deal with only three major strongly centralized administrative units. (The fourth fell by the wayside). This has resulted in the development of a strong administrative structure within the Commission to replace the old contractor sponsored project organization and has, therefore, limited the area of the individual contractor's responsibility. As a corollary to the contractor's filling a segmented responsibility, the requirements for centralized scientific and technical reporting both for purposes of control and of planning have increased. The requirements for centralized technical control have been automatically accomplished by the imposition of administrative limitations which guarantee its effectiveness. On both scores the potential contributions of the contractor and his operating staff have been significantly reduced as a result of the external circumstances under which the Commission must operate. A further compelling factor leading to the same end result lies in the necessities for fiscal and consequent program planning for budgetary purposes which are inevitable within the framework of our governmental operations. Thus within the pattern of Commission administration, while its actual operations are still carried out under the contractor system, the responsibilities of the individual contractor and his staff have been reduced in scope step-by-step in response to the pressures placed upon the Commission's own administrative staff by the circumstances under which they in turn must act. In certain respects this decreases the usefulness of the contractor relationship as far as the Commission's direct administrative activities are concerned

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but by the same circumstances the contractor sponsorship becomes more imperative in the maintenance of the scientific and technical staff essential to carry out the Commission's work program. The contractor and his staff are now engaged in a continuing mutual effort with the Commission staff to develop administrative procedures which will provide the maximum possible contribution on the part of the contractor and his staff within the requirements under which the Commission must operate.

Even before the decision to establish the Project at the University of Chicago had been reached, the Project administration had been actively engaged in recruiting necessary additional staff. With that decision made this effort was intensified. Space was acquired from the Physics Department of the University in Eckhart Hall, the cyclotron area in the old University plant department building was taken over and further space was obtained from the Athletic Department under the West and North Stands. At the start it was a physicists' project and it was in this field that the first organizational steps were taken. The various research groups already established moved to Chicago as rapidly as current problems and space at Chicago would permit. The first large scale exponential experiment - an extremely powerful analytical tool invented previously at Columbia - was completed at Columbia and the intensive program of exponential pile and sigma pile investigations which led finally to the first fission chain reaction on December 2, 1942 and then provided much of the critical design data for the Clinton and Hanford piles was inaugurated at Chicago. The theoretical analysis of the chain reaction and its control proceeded concurrently with these experimental investigations. Also associated closely with these studies was the basic design work directed toward an eventual full scale plutonium producing reactor. All of the various other essential approaches in experimental nuclear physics and in a wide variety of applied physics activities were likewise initiated. This organizational approach by stepwise transfer and the initiation of specific assignments led to a multiplicity of physics divisions which was poor from the point of view of sound administrative practice but excellent in terms of the immediate technical results achieved. The long term result, however, was that it was not until 1950 that it was finally possible to combine all of the activities in physics into one properly constituted and coordinated physics division.

As soon as the plans for the physics work were well established immediate attention was given to acquiring suitable engineering support. Through the assistance of the top OSRD advisory committee such help was procured and an engineering division established early in February, 1942. This group in collaboration with the theoretical physicists began the design of a full scale gas cooled plutonium producing reactor. By December, 1942 this design had proceeded to the point that it was ready for review by the duPont Company staff for possible construction. In the meantime a full scale program of essential engineering experiments was undertaken. With the new information made available by the first chain reaction it was finally clear that a water cooled reactor was feasible and the theoretical physicists produced a basic design for such a reactor early in January, 1943. DuPont decided that either design was feasible but that the operating simplicities of the water cooled design

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particularly from the point of view of materials handling was sufficiently superior to the operating requirements of the gas cooled pile that the former was chosen for final design and construction. Thus although the steel for the pressure vessel had already been produced "Mae West" was never constructed. The engineering division immediately shifted to a program of experiments to support the water cooled design. The metallurgists who had been hired earlier by one of the physics divisions were transferred to the engineering division. It was this division which carried out the basic flow and pressure drop studies and the corrosion investigations prior to the establishment of the flow laboratory at Hanford by duPont. It was also this division that developed the fabrication methods for the Hanford fuel elements and upon whose basic work the Hanford canning process was developed by duPont and the division.

No sooner had the engineering division been initiated than the magnitude of the chemical separations problems began to be apparent. Immediate effort was directed to obtaining the necessary staff of qualified chemists. Space was obtained from the Chemistry Department of the University in both Kent and Jones laboratories. It was soon apparent that the space available was not only inadequate but was not properly designed for work with radioactive materials. As a result the temporary structure known as New Chem was designed and constructed on University property. It was this chemistry division together with associated groups that worked out the chemical separations process for Hanford on the basis of experiments utilizing sub-microscopic quantities of materials.

By late spring of 1942 the design work on production reactors had progressed to the point that the theoretical physicists, with the disastrous history of early X-ray facilities in mind, insisted on the formation of a health division to operate as an integral part of the design team. Since radiation hazards were already appearing in connection with the chemistry studies and since the radiation from an operating reactor and from the materials irradiated within such a reactor which later had to undergo chemical processing would be many orders of magnitude greater than the radiation levels with which there was any experience, such a division was organized and staffed by medical men experienced in radiotherapy and with biologists and biophysicists having experience suitable for work in radiobiology. This division was initiated just at the time that pressure for additional engineering space was becoming intense. As a result the Laboratory took over a University property part of which was in use as a bottling works and the remainder as a riding academy. The buildings were renovated and expanded with temporary construction. When completed the health division, the metallurgy section and certain phases of the experimental engineering work moved into "the Brewery", Site B. It was this health division which established the initial permissive doses both for external radiation and for internal radioactive emitters. It has also been responsible for a continuous survey of the toxicity of the many new elements which previously had been chemical curiosities but which became common project materials.

With the formation of the health division the basic organizational framework of the Metallurgical Laboratory was completed. After that time the

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organizational problems within the Laboratory were problems of expansion, of contraction due to the transfer of personnel to other Project activities and eventually, the problems of transition from emergency status to stability.

Even before the Laboratory organization was well underway it became evident that the original ideal of a single central laboratory was inadequate. When the problem of transfer of the chemical activities at the University of California to Chicago was undertaken it was found that for various reasons only part of this, the most skilled group in the field, could be transferred. Those remaining would have adequate facilities and it was obvious that they should be included in the project.

At the same time a similar situation arose with respect to the production of pure uranium metal. The Project administration realizing that the major bottleneck in achieving success lay in the procurement of adequate quantities of graphite and of uranium metal of the necessary extreme purity had pushed forward to establish industrial production of these materials. Success in this direction with graphite was immediate but with uranium metal the situation was obviously going to be difficult. Oxide of the necessary purity was achieved by inducing the Mallinckrodt Chemical Works to scale up a laboratory procedure to a production operation which they accomplished in a matter of weeks. The transformation of the oxide into metal on a production scale was another matter. It was then discovered that qualified man-power and certain of the necessary experimental facilities which could be used in solving this problem were available at Iowa State College at Ames, Iowa. Since neither personnel nor facilities were available at Chicago it was again obvious that the Project should extend beyond the central laboratory.

Consequently, the Metallurgical Laboratory was placed under the administration of a Laboratory Director and a Metallurgical Project Office was established with Dr. Compton as Project Director. It was clear to the University administration that subcontracts from one university to another would be unsatisfactory. Consequently, the Project Office arranged for prime contracts between the OSRD and later the Manhattan District and these so called out-lying universities. The semblance of authority which the Project Office possessed was that the University of Chicago prime contract called for the contractor "to do all things necessary for the design of a production plant." If the associated laboratory did not produce the results expected of it it was clear that the central laboratory would be required to duplicate the man-power and facilities necessary to produce the results under its own management. Such a situation never arose. The work programs and budgets for all of the Project units were drawn up in collaboration with the administration of the unit, were put in final form in the Project Office and then forwarded to the administrations of the various Project's units for transmittal through their regular contractural channels to the OSRD or later to the Manhattan District for official action.

The scientific and technical coordination of the various diverse elements within the Metallurgical Laboratory itself had led to the formation of a central

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planning committee consisting of the Laboratory's key scientific and technical personnel. In these committee meetings, held weekly at the start, then biweekly and finally as the work crystallized at monthly intervals, the areas of agreement and divergence were quickly established and the technical basis upon which these were based were throughly explored. After each meeting each division director did exactly as he pleased but he did it in the light of what the others had discovered and with the knowledge that his own point of view would be subject to the most critical review in the light of new data at the next meeting. No better system of coordination in view of the high competence the professional pride, and the scientific integrity of the key staff could conceivably have been devised. Under this procedure the Project procured the ultimate in scientific and technical originality, planning and execution from every key staff member and they in turn were careful to utilize their own personnel to the best possible advantage.

When the Metallurgical Project was formed the key staff of the new associated units were added to the central planning committee. Each unit then operated as if it were an integral part of the central Laboratory.

After the first chain reaction was established under the West Stands facilities were completed to house the unit in the Argonne Forest section of the Palos Park District, Cook County Forest Preserve. This site was chosen because it provided real isolation for the chain reaction studies and yet was relatively close to the University campus. When the first pile (CP-1) was moved to its new location and rebuilt as CP-2, the new facility was called the Argonne Laboratory and was considered as an independent unit within the Project although its budget was combined with that of the Metallurgical Laboratory since both were operated under the same prime contract.

As the metallurgical problems increased Battelle Memorial Institute at Columbus, Ohio was added to the Project and later another metallurgical group was added at Massachusetts Institute of Technology.

By April of 1942 the Project administration was so convinced of success that it began a search for a suitable site for a production plant. It was felt at that time that the Argonne site could be used for necessary pilot plant and semi-works facilities. As a result of the search the Project recommended to the OSRD in May, 1942 the acquisition of the "Elsa site" near Knoxville, Tennessee, now Oak Ridge. By mid-summer the planning for the pilot plant pile was well along and some consideration was being given to a possible chemical semi-works installation. When it was proposed to construct these in the Palos Park area the OSRD executive committee refused its approval because of the still unknown character of high level pile operations and because of the close proximity of the Chicago metropolitan area. They directed that the new facilities be constructed at the Oak Ridge site which was then in process of acquisition by the Corps of Engineers. The Project was thus faced with the necessity of organizing and staffing a new and major facility. The help of the duPont Company was obtained to aid in the final engineering design of the facilities and assume responsibility for their construction. The University of

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Chicago was requested to act as operating contractor for the new installation both on the basis of the previously presented considerations and because the operations of the new unit would of necessity be closely integrated with those of the rest of the Project. Using the name of the nearest town the new organization was called the Clinton Laboratories. A laboratory director was appointed and the organization of staff to operate the new facilities was begun. The staff at the Metallurgical Laboratory were at first insistent that the work at Clinton Laboratories be under the administration of the division directors in Chicago with the scientific leaders at the new laboratory serving as section chiefs in the Chicago divisions. It was obvious to the contractor and to the Project Office that such an administrative arrangement would guarantee a position of official subservience to all members of the new organization and that, therefore, the problems of staffing would be insuperable and those of general operating requirements impossible of solution. This was the more emphatically true since the major responsibilities of the new laboratory were to be primarily developmental in character which meant that strict adherence to tight time schedules would be of the essence in the new operations. After a major administrative struggle the decision to establish the Clinton Laboratories as an independent unit within the Metallurgical Project was accepted. With this decision finally determined the problem of persuading the necessary scientific and technical staff to transfer to Oak Ridge was considerably simplified. The facilities were completed during the late summer and fall of 1943 and as rapidly as they were ready for occupancy staff were transferred.

The over-all staffing problem was further simplified since the duPont Company also tranferred to Clinton Laboratories many of their own technical and operating staff who were to be eventually assigned to Hanford. These personnel not only assisted in the Clinton operations but also received their preliminary training in Project operations prior to assuming their Hanford responsibilities. The new pile began operation in November, 1943 and operation of the chemical separations facilities was started in late December. Clinton Laboratories met their Project obligations on schedule. The required quantities of plutonium were produced, chemically separated and delivered to Los Alamos as promised. The necessary scale-up and process information needed by duPont for the Hanford design was obtained according to the established time table.

By the summer of 1944 the center of interest had definitely shifted to Hanford. The Metallurgical Laboratory had replaced the staff transferred to Clinton Laboratories and all of the Project installations were at full strength, actively engaged in working out final process details, estimating operating characteristics and desperately attempting to foresee all possible operating difficulties and devise methods for preventing or overcoming them. Then came the transfers from the Metallurgical Laboratory and Clinton Laboratories to Hanford for start-up. The first reactor began its operations in September of 1944 and the chemical separations plant began its delivery of pure separated plutonium to Los Alamos in January, 1945. The plant as a whole operated more successfully than could have been hoped for and the anticipated fatal difficulties failed to arise. The Project's task was completed.

Then followed the period of transition. The Project Office as an official administrative device ceased to function. As an advisory unit it remained until the reorganization of the Metallurgical Laboratory as the Argonne National Laboratory on July 1, 1946. Each of the Project units went its own way and attempted the solution of its own problems. Clinton Laboratories alone had a fairly clear continuing responsibility. In addition to the need for continuing process development studies in support of Hanford it had the facilities for large scale production of radioactive isotopes for research and industrial use. This was, however, primarily an industrial not a research objective and, therefore, outside the area in which the University of Chicago could continue to operate. The University asked to be relieved of its contractual responsibilities for the Clinton operations. The Monsanto Chemical Company agreed to assume the contractual responsibilities provided it could maintain a strong research and development program in support of its isotope production activities. This was approved and the contract was transferred from the University of Chicago to the Monsanto Chemical Company on July 1, 1945. The University had achieved another of its objectives and had brought to successful conclusion another of its contractual responsibilities.

In the meantime the Metallurgical Laboratory was attempting to chart its future course. As the result of an intensive study a proposal was prepared providing for its reorganization into a national laboratory under the sponsorship of all of the principal universities and research institutions of the Mid-West. This proposal was referred to a committee of leading scientists of the region who studied it in detail, made various modifications and recommended that the University of Chicago act only as one of the group of sponsors as far as determination of the scientific and technical programs and policies of the new laboratory was concerned, but that it be retained as the contractor as far as the business operations were concerned. They made their recommendations to the Manhattan District who obtained the agreement of the University of Chicago to serve in the capacity outlined. With this agreement the proposal was submitted to representatives of the universities and research institutions concerned and ratified by them. The necessary contractual supplements were arranged and Argonne National Laboratory began its official existence under the new organization on July 1, 1946.

There had been essentially no attempt during the period from the first organization of the Laboratory in January, 1942 until July, 1946 to really apply the principles of sound organization to the structure of the Laboratory. During the transition period the major administrative effort had to be expended primarily on a holding action. As little as possible in the way of reorganization with its attendant upset was attempted. However, the transfers of personnel to Hanford in the summer of 1944, a similar transfer that fall of a large number of physicists and chemists to Los Alamos, the transfer of another considerable group to Clinton Laboratories in July, 1945 when the future of that operation became stabilized together with the innumerable losses to universities and industry as a result of the uncertainties of the Metallurgical Laboratory's future did automatically rectify certain organizational problems. The establishment of Argonne National Laboratory consisted largely of the

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re-establishment of the old Laboratory organization under a new name. The traditions of the preceding four and one-half years were still too strong to be lightly set aside. Sufficient changes had been made during 1945, however, so that the remaining structure with minor changes which could be gradually achieved without serious disturbance would have provided a satisfactory organizational framework within which to operate had the original objectives of a laboratory primarily of research character been retained.

Such was not to be the case, however. On January 1, 1948 the Commission announced that it had designated the Argonne National Laboratory as its principal reactor development center. As part of this move certain reactor work was transferred bodily from Oak Ridge National Laboratory to Argonne. Cooperative responsibility and certain actual design work for the Materials Testing Reactor were thus transferred. The Naval Reactor group was transplanted en masse together with the responsibility for their successful operation on an important assignment. Once again the Laboratory was faced with a situation in which personnel problems were more vital than principles of sound organization. The continued active interest and initiative of this group was essential if the objective of the construction of a naval reactor were to be achieved on schedule. In order to maintain what was left of its badly shaken morale this group wereessentially occluded within the organizational structure of the Laboratory as a single unit. This had led once again to serious organizational anomalies, duplication of effort and inefficiency in the utilization of technical man-power. The ground-work for a non-disruptive change has now been laid and the Laboratory administration is now engaged in formulating a general plan of organization for the scientific and technical work of the Laboratory in order to eliminate the organizational irregularities still present. It is anticipated that this change will be completed by the end of the present fiscal year.

Concurrently with its development of proposals for its future organization, the Laboratory began an analysis of its needs for future facilities. It could not remain in its campus laboratories because they were all situated either in University buildings which were required for normal University operations or in temporary structures which could not be maintained for any appreciable period of time. The possibility of permanent occupancy of the Palos Park site was explored with the Forest Preserve officials first by the Manhattan District and later by the Atomic Energy Commission and in each case the request was firmly rejected. A new site was then selected in duPage County some five miles from the Palos Park facilities and planning for the new buildings was started. This was a major task and has taken a significant fraction of the Laboratory's administrative effort. This planning had fortunately scarcely gotten underway when the decision to make Argonne the Commission's reactor center was made. One of the conditions which the Laboratory presented as essential if it were to serve in the newly designated capacity with any effectiveness was the provision by the Commission of permanent facilities really adequate to meet the needs of the Laboratory's greatly increased responsibilities. Such facilities were promised. In order to meet the immediate

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requirements involved in the transfer of personnel from Oak Ridge certain temporary structures were proposed which could later serve to supply the ever present demands for space for experimental engineering work. The Quonset buildings in the East Area of the duPage site were built to meet this requirement. In the meantime the design of the facilities for the West Area was continued, necessary architect engineer work carried out and the site preparation and building construction undertaken. The East Area structures were occupied during the fall and winter of 1948-49 and occupancy of the permanent West Area buildings is underway at the present time. By summer of 1952 all of the activities of the Laboratory will have been moved to the duPage site with the exception of the experimental work utilizing the old Palos reactors which cannot be transferred until the new research reactor is completed sometime late in the fall of 1952.

The development of the service and business administration of the Laboratory has paralleled that of its technical organization. Immediately upon its organization in January, 1942, the Laboratory assumed the responsibility for handling its own technical information activities. It likewise assumed responsibility for its personnel operations at an early date. Shortly thereafter with the assistance of the University it established its own procurement service. At the start its accounting was all handled directly by the University but as the Laboratory grew the volume of work increased to the point that it was necessary for the Laboratory to establish its own accounting department operating under the control of the University. It then took over the responsibility for the supervision of its own guard force. The next expansion in operating activities came with the Laboratory's acceptance from the Manhattan District of the responsibility for motor pool operations and for the maintenance of all property records. One after another all of the business activities essential to the Laboratory's operations have been taken over until at the present time the Laboratory has become essentially self sufficient in the business area.

As long as the Laboratory maintained the status of a "renter" its requirements for plant assistance were modest. The first break in the "renter" role came with the establishment of the original Argonne laboratory in Palos Park. Here for the first time the need arose for full plant service. In this case the requirements were on a relatively small scale because the unit was small and consequently they were readily absorbed within the structure of the business and service organization. Then came the design and construction of the new facilities to be situated on the new site in duPage County. Here the responsibility for establishing the design requirements fell in general on the technical staff. As construction nears completion, however, the necessity for operation of the new structures has fallen directly upon the plant department of the Business Manager's Office. With the transfer to the duPage site nearing completion the full magnitude of the load upon plant operations is developing, including the actual building maintenance, the utilities management, the steam plant, water plant and sewage plant operations together with road and 3700 acres of grounds maintenance. Except for acute man-power shortages arising from inexperiencein estimating operating requirements two years ago when the budget was established, the new responsibilities have been assumed smoothly and effectively. The move to the duPage site has coincided with increased emphasis on the developmental program of the Laboratory which in turn has placed still further increased demands on the plant department for the continual plant change and minor construction operations characteristic of such activities making the severe plant department man-power shortages even more acute. A similarly increased load has been experienced in the central shops due to this increase in developmental work.

Finally, the move to the new site has markedly increased the load on the transportation and commissary departments, responsibilities again taken in stride. With each assumption of new administrative or service functions the ratio of scientific and technical staff employees to service and administrative employees decreases. The requirement for isolation with attendant complete self sufficiency inevitably results in such a lowered ratio with consequent high overhead. The security requirements make this even more true by largely eliminating the possibilities of obtaining temporary help. The occupancy of the new facilities and the move to the new site from the University campus is now at its peak and the re-adjustments of the administrative staff to meet the requirements of operations under the new conditions are presently at maximum flux. The change in status of the Laboratory from that of "renter" to that of "householder" with its attendant multiplication of administrative problems has been carried out so far successfully by the contractor and the Laboratory within their own resources. Further changes will be required before a stable organization is achieved and certain of these are now in process.

As an indication of the magnitude of the administrative responsibilities involved the following review of personnel statistics for the Project is of interest. The figures are only approximate, but are the best readily available. In March of 1942 the total personnel at the Laboratory numbered about 50 individuals of whom some 30 were scientific staff. By January of 1943 there were about 500 people on the payroll of whom roughly half were scientific staff. During the early summer of 1943 the total payroll had increased to a figure in the neighborhood of 1500 with some 500 of these being scientific staff members. During late summer and autumn of 1943 the Laboratory transferred a large number of staff from all of its divisions to Oak Ridge to serve as the nucleus of the technical staff for the Clinton Laboratories. By November of 1943, therefore, the staff of the Laboratory had decreased to approximately 900 persons on the payroll of whom roughly 450 were technical staff. The Laboratory again began rebuilding its forces and by July of 1944 the total number of individuals in the Laboratory was approximately 2000 of whom 600 represented scientific staff. During the summer and fall of 1944 the Laboratory transferred a fairly large number of its staff to the duPont organization at Hanford to assist in the start-up of the Hanford operations. Furthermore, in the fall of 1944 a considerable group of the remaining scientific staff were transferred to Los Alamos at its urgent request to aid in the final stages of the bomb program; this left the Laboratory on January 1, 1945 with approximately 1500 on the payroll of whom 400 were scientific staff. The decrease in Laboratory staff continued throughout 1945 and the first half of 1946 until the total number of personnel as of July 1, 1946 was approximately 1200 of whom in the neighborhood of 250 represented scientific staff. At this time the Metallurgical Laboratory was reorganized as the Argonne National Laboratory with a permanent status and the personnel has increased since that time until September of 1951 when the total number of personnel on the payroll is 2900 of which roughly 600 are scientific staff. Clinton Laboratories starting with the initial staff transferred from the Metallurgical Laboratory and supplemented by personnel loaned by duPont grew to its maximum size of some 2500 persons on the payroll in the late summer of 1944. In addition to the staffs at the Metallurgical Laboratory, the Argonne Forest Laboratory and the Clinton Laboratories there were some 200-300 scientific staff engaged on project work in the laboratories at the University of California, at Iowa State College, Ames, Iowa, at Battelle Memorial Institute, Columbus, Ohio, at Massachusetts Institute of Technology and in several small groups at various other universities. One item of particular interest should be especially noted. Due to the many mass transfers of personnel from the Laboratory there is scarcely a single major atomic energy installation which does not number several staff members in key positions who received their introduction to and their basic training in the atomic energy business at the Metallurgical Laboratory. This service in itself has provided a major contribution to the over-all atomic energy program. With the Laboratory's "loaned employee" training method this is also a continuing product of the Laboratory's normal operations.

To summarize its administrative achievements under the sponsorship of the University of Chicago, the Project began its operations January of 1942 with a group of some 50 physicists, highly competent but with widely diverse points of view and bound together only by an unshakable belief in the urgent necessity of achieving success in the development of an atomic weapon before the enemies of the Nation had attained a similar objective. An organization designed primarly to accommodate the personalities of the scientific staff involved was developed and the additional staff required to carry the Project to a successful conclusion was procured. A technique of project operations as contrasted with the central laboratory operations was devised and man-power and facilities otherwise unavailable placed into active and productive service. To meet the requirements for experimental quantities of plutonium a pilot plant type of reactor and the associated chemical separation processes were designed, a new site at Oak Ridge, Tennessee was selected, final construction design was completed in collaboration with the duPont Company, the facilities were built, and a new Laboratory installation, Clinton Laboratories, was organized and placed in operation. The drain on the Laboratory's personnel was replaced and its responsibilities in connection with the design of the production facilities at Hanford were carried to a successful conclusion. The final step in this operation was the transfer of trained personnel to the duPont Company at Hanford for assistance with the actual start-up of the production operation. Shortly afterward, additional trained personnel were transferred to Los Alamos to assist in the final stages of the bomb design work. During the unsettled period from January of 1945 until July 1, 1946 the Laboratory was held together pending final decision concerning its future. The total personnel involved in the Project operations increased from some 50 in March of 1942 to a total of approximately 5000 under the direct administration of the University in the summer of 1944. This number decreased rapidly with the above transfers both from the Metallurgical Laboratory and from the [illegible] Clinton Laboratories. On July 1, 1945 the Clinton

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Laboratories were turned over to an industrial operator, the Monsanto Chemical Company. In July of 1946 the University accepted the responsibility for the business administration of Argonne National Laboratory, the newly reorganized successor of the old Metallurgical Laboratory. In the Plan of Organization and Statement of Operating Policy of Argonne National Laboratory adopted at that time, it was clearly indicated that the University's activities were to be confined to purely administrative matters. A Board of Governors elected by Participating Institutions was to have the responsibility for the scientific and technical guidance of the Laboratory. The Commission action on January 1, 1948 designating the Laboratory as its principal reactor center changed the responsibilities of the Laboratory significantly. The reactor development activities were expanded many fold and two groups of personnel were transferred to the Laboratory from Oak Ridge National Laboratory. The first of these was a small group associated with the Materials Testing Reactor work for which the Laboratory assumed a cooperative responsibility with Oak Ridge National Laboratory. The second was the major group associated with the Naval Reactor project for which activity the Laboratory assumed full responsibility. The growth of its responsibilities for the prosecution of major development activities so changed the character of the Laboratory's operations that its organizational superstructure, in particular the role of the Board of Governors became obviously inoperable and as a result was subjected to critical review during 1950-51. This restudy resulted in pointing out the impossibility of the Board's playing a definitive role in determining the over-all Laboratory program. At the same time it clarified the area of active Participating Institution interest and defined the function of the former Board in this new relationship. A document was prepared and approved by the representatives of the Participating Institutions formalizing this new agreement in May, 1951. At present, therefore, the University of Chicago holds full contractual responsibility for the operations of the Laboratory for the first time since its reorganization in 1946. In spite of the problems created by the uncertainties of the transition period, by the sudden increase in program responsibilities due to its designation as principal reactor center, by the heavy load of additional responsibilities entailed in the Laboratory's major construction program, and by the existence of the inoperable organizational superstructure in which primary administrative responsibilities were assigned to an advisory board, the Laboratory has grown not only in numbers but more significantly in the scientific and technical competence of its staff during the past five years. It has grown from a total payroll of some 1100 in July of 1946 to approximately 2900 at the present time, with the technical staff increasing from some 250 to approximately 600. Of particular importance is the fact that it has been possible to recall many of the strongest members of the technical staff who left the Laboratory during 1945 for university and industrial positions and equally important that it has also been possible to attract new leadership of the very highest ability. The Laboratory has evolved into a closely knit, well coordinated and extremely competent research and development team capable of meeting any problem in the area of its scientific and technical responsibilities with confident effectiveness. While still requiring increased strength in a few areas in order to attain proper balance, the Laboratory is none the less capable of assuming major undertakings and discharging its responsibilities rapidly and

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and successfully. It has demonstrated, in addition, its ability to work effectively on cooperative projects with industrial co-partners where the Laboratory's responsibility lies in the origination and basic design of new projects while the industrial contractor is responsible for the detailed engineering, construction and operation of the resulting facilities. It is a far cry from the small disorganized and administratively inexperienced group which constituted the Project on January 1, 1942 to the assured effectiveness of Argonne National Laboratory in 1951. Only the unquenchable enthusiasm of the staff and its unshakeable belief in the over-riding value of ideas have remained unalterable throughout the history of the Laboratory. Far beyond matters of organizational structure, administrative effectiveness, adequacy of facilities, etc., it is these qualities, increasingly apparant and increasingly vital as the Laboratory has gained the strength and stability of maturity, that combined with high scientific and technical ability provide the Commission with its best guarantee of continuing achievement on the part of Argonne National Laboratory.

SUMMARY OF SCIENTIFIC AND TECHNICAL ACHIEVEMENTS

It is not the intention to present in this report a complete scientific and technical record of the Laboratory. Such a presentation would require detailed discussion of the technical interpretation and significance of the results of literally hundreds of research and developmental programs. As indicative of the magnitude of the Laboratory's accomplishments one need only refer to the Plutonium Project Record which presents the results of some of the research conducted on the Metallurgical Project through 1945. The nine volumes which have been issued to date consist of 7,151 pages of unclassified and 951 pages of classified research papers and research summaries. A majority of these papers are devoted to research conducted at the Laboratory. Nor does this represent the sum and substance of the Laboratory's efforts, for many of the research programs and most of the development and engineering projects are not covered in the Plutonium Project Record, and, furthermore, the work of the Laboratory since 1945 is not touched at all. It is therefore the intent, in this necessarily limited summary, to present a broad picture of the work of the Laboratory with emphasis on those programs which have contributed materially to the solution of specific needs of the Nation's atomic energy program. For additional information reference should be made to the Plutonium Project Record, to the several thousand Laboratory reports and to the hundreds of open literature publications.

For the present purpose it is convenient to divide the work of the Laboratory into the following categories: reactor development, materials development, separation process development, basic and applied research in the physical sciences, basic and applied research in the biological sciences. Of course, any such division is somewhat arbitrary as it must be in any large and organic research and development program. As the objectives of any program are changed or modified by additional knowledge, what is nominally basic research one moment may become development work or even a production activity the next.

Reactor Development

From its inception in January 1942 the Metallurgical Laboratory had as its primary responsibility the research and development pertinent to the Nation's reactor program. The Argonne National Laboratory which succeeded the Metallurgical Laboratory has continued to carry this responsibility, being designated by the Commission in January 1948 as its principal reactor center. As evidence for the success of the reactor program initiated under the one and continued by the other it is only necessary to cite the fact that these Laboratories have played a major role, in some instances an exclusive role, in the work leading ultimately to the construction of a majority of the existing reactors in this country; the remainder have all been designed and constructed under the direction of personnel who acquired their reactor experience on the Metallurgical Project. Even today when the Nation's reactor program has been expanded to include many new organizations working on a number of new reactors, the Laboratory is directly responsible for or associated directly with a majority of the reactor projects approved for construction. Of the reactors in the study or preliminary design stage several are assigned directly to the Laboratory's own program and it is acting as consultant to several of the remaining projects. With no intent to belittle the major contributions made by other AEC installations, it is still true that up to the present time the Nation's reactor progress has been largely a reflection of the progress achieved by the Metallurgical Laboratory and by the Argonne National Laboratory.

The First Chain Reacting Pile (CP-1). The only possible experimental approach to the first practical demonstration of a self-sustaining chain reaction was through the medium of intermediate exponential experiments involving the use of an auxiliary source of neutrons. These exponential experiments made it possible to estimate the magnitude of the various parameters affecting the "multiplication constant", the factor which most conveniently represents the ability of a reactor to become self-propagating. After preliminary experiments at Columbia in 1941, an intensive program of experiments of this nature was carried out at Chicago. The end result was that in June of 1942 a "multiplication constant" slightly greater than 1.0 was observed at Chicago, thus indicating, for the first time in history, that a self-sustaining chain reaction was scientifically possible. The problem then became one of obtaining adequate quantities of sufficiently pure materials to construct a unit which would be large enough to become completely self-sustaining. December 2, 1942 marked the date that the first self-sustaining pile, CP-1, (Chicago Pile, number one), first began operation in the West Stands of Stagg Field on the University of Chicago campus. On this date atomic energy officially came of age. (Subsequently CP-1 was moved to the Argonne site and given the designation CP-2. It is still in operation and is continuing to play a vital role in reactor development.)

The Clinton and Hanford Reactors. The existence of the CP-2 reactor, an experiment itself, made possible the appropriate experiments necessary to lay the foundations of reactor theory and reactor technology. With the experience gained from CP-2 as background, the Metallurgical Laboratory at Chicago began almost simultaneously the design of the production piles at Hanford and the smaller pile at Clinton Laboratories which was to serve as a training facility for the Hanford reactor personnel as well as to produce the first few grams of plutonium vitally needed for chemical and physical studies. The graphite-moderated, air-cooled pile at Clinton was constructed by the duPont Company on the basis of designs developed at Chicago, and the pile was operated by Chicago personnel transferred to the Clinton Laboratories at Oak Ridge. The Metallurgical Laboratory at Chicago was responsible for all the research and development work, for most of the basic engineering studies, and for much of the basic design information attendant to the construction of the graphite-moderated, water-cooled plutonium production piles at Hanford constructed and subsequently operated by the duPont Company. These piles are still in full production and, together with the two essentially similar reactors which were subsequently constructed by the General Electric Company at Hanford, have produced greater than 99% of the Nation's plutonium supply.

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The First Heavy Water Pile (CP-3). In order to obtain experimental facilities necessary for further studies pertinent to reactor theory and nuclear science, and to investigate the technological features of a heavy-water pile, the first heavy water-moderated and cooled pile (CP-3) was designed and constructed completely by Chicago personnel at the Argonne site in 1944. This pile, which in itself was a reactor experiment, was used for thousands of nuclear experiments between 1944 and 1950. In addition basic reactor engineering data were obtained on the characteristics of a heavy water pile. In 1950 the natural uranium fuel was replaced with enriched uranium to give higher neutron fluxes and the pile (CP-3') is once more in operation.

The Experimental Breeder Reactor (CP-4). In 1945 - 1946 the Laboratory initiated the research and development work which ultimately led to the design of the Experimental Breeder Reactor, the first reactor designed to demonstrate the feasibility of producing more fissionable material than is consumed in the chain reaction. This reactor is designed to operate in the fast neutron region in distinction to all other existing and contemplated reactors with the exception of the small Los Alamos fast reactor. One other important and novel feature is the use of liquid sodium-potassium alloy as the coolant. This reactor has been built at Argonne and installed by Argonne personnel at the Arco Reactor Test Station. It has recently been brought to criticality and should be in operation very shortly by Argonne as a reactor experiment to investigate the potentialities of breeding and of the use of liquid-metal pile coolants. The actual demonstration of breeding would be the most important event of long range significance in the Nation's reactor program since the first self-sustaining chain reaction was demonstrated in Stagg Field. The experience gained with liquid metals will be of great importance to the reactor power program since several of the power reactors under consideration for the future contemplate the use of liquid metal coolants, a feature which was first suggested and investigated by Metallurgical Laboratory personnel in 1942 and later reduced to full engineering practice by the original Argonne Laboratory group.

The Naval Reactor (Shipboard Thermal Reactor, Mark I, II, and III). In 1948, the Laboratory was asked to assume the responsibility for the basic research and development leading to the conceptual design of a prototype power reactor for submarine use. The inherent requirement of producing useful power presents many new problems never before encountered in the previous reactors which were intended solely for plutonium production. Higher reactor power levels, and therefore neutron fluxes, and much higher heat fluxes are involved. In addition to the power demands, the space restrictions in a submarine also pose many new problems. In order to meet the very stringent operating characteristics desired, it has been necessary to develop a completely new type of fuel element which consists of a zirconium-clad uranium alloy. The development work at the Laboratory has led to the Shipboard Thermal Reactor, Mark I, which is now under construction at the Arco Reactor Test Station by the Westinghouse Electric Corporation. This specific reactor has been a cooperative project in which the Laboratory has had the responsibility

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for the necessary research and development, many of the engineering studies, and the conceptual and preliminary design. Westinghouse has had the responsibility for the detailed design, the heavy engineering, and the construction and operation of the reactor.

At the present time the Laboratory is proceeding with the investigation of the additional problems faced in the Mark II reactor, the first reactor specifically intended for an operating vessel. The Laboratory will carry out any necessary research and development and will analyze the results of Mark I operation in terms of Mark II requirements. At the same time the Laboratory is devoting as much effort as it can spare to the investigation of radically improved reactor designs for light and heavy water mobile power reactors, one feature of which may involve the use of thorium as fertile material.

The Materials Testing Reactor. In 1948 the Laboratory was also asked to cooperate with the Oak Ridge National Laboratory in the design of the Materials Testing Reactor, a high neutron flux reactor intended to serve as a facility for testing reactor materials and components. The Laboratory has been responsible for the design of the reflector, shield, experimental facilities, and associated operating plants. This design work has been completed and turned over to Blaw-Knox which is responsible for the detailed engineering design and to the Bechtel Company which is responsible for the construction of the reactor. The reactor is now under construction at the Arco Reactor Test Station where it will subsequently be operated by the Phillips Petroleum Company.

Research Reactor (CP-5). In 1949 the Laboratory began the design of a research reactor for its permanent site as a replacement for the original graphite pile (CP-2) and the heavy water reactor (CP-3') at the Palos Park site. This reactor is to provide a high flux and a large experimental volume at a low power level. This reactor will use U^{235} alloyed with aluminum or zirconium as the fuel and will use heavy water as moderator, coolant, and reflector. The conceptual design and the engineering development are essentially complete, and the detailed design has begun. Since this is solely an experimental facility, this reactor will be constructed by the Laboratory and should be in operation within the coming year. Recently the Laboratory has been asked by the Commission to investigate the application of this type of reactor to the production of initiator materials and preliminary design and analysis is now under way. Many of the features of this type of reactor would make it ideal for this purpose.

Neutron Producer Reactors (CP-6). Late in 1949 the Laboratory began the conceptual design of a reactor for plutonium and tritium production. On the basis of these preliminary investigations, on the Laboratory's experience with heavy water reactors, and on the Laboratory's record of successful cooperation with industry, the Laboratory was asked to cooperate with the duPont Company in the design of the Neutron Producer Reactors (CP-6) for

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plutonium and tritium production. The Laboratory has its customary role of providing preliminary design and any experimental and theoretical support needed by the duPont Company which has the responsibility for the detailed design and construction of the reactors at Savannah River. These reactors will be the first heavy water-moderated and cooled reactors in this country designed for plutonium and tritium production and are based on the conceptual designs begun by the Laboratory in 1949. To date the Laboratory has carried out much of the experimental and development work needed for the specific design of these reactors.

Other Specific Reactor Studies. In addition to the above specific reactors which have either been constructed or authorized for construction, the Laboratory has carried out many other development programs on reactors. The first engineering study of a gas-cooled, graphite-moderated production pile was made in 1942-1943. The first investigations of a liquid metal (bismuth, sodium, etc.)-cooled pile were made during the early days of the Laboratory. Considerable development work was done on a quasi-homogeneous pile (the slurry pile) in 1943-1944 and the first detailed investigation of a power pile using beryllium oxide as the moderator and graphite impregnated with uranium as the fuel was carried out in 1945 and 1946. The Laboratory has done and is continuing development work on a natural uranium reactor for central station power production and at the present time is beginning a development program and feasibility study on a pressurized, heavy water-moderated and cooled, plutonium- and tritium-producing reactor (CP-7) which will also yield useful power.

General Reactor Development. Through these specific pile development programs, and through the more general reactor programs, the Laboratory has made a major contribution to the general field of reactor technology upon which all reactor work in this country is based. Very significant contributions have been made to reactor theory, to methods of reactor calculations, to the use and interpretation of exponential and zero-power experiments, to methods of reactor control and of heat removal, to the development of appropriate metallurgical techniques for the many unusual materials needed for reactors, and, in fact, to virtually every factor involved in reactor development.

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Materials Development

Despite the demonstration of the scientific feasibility of a self-sustaining chain reaction, the entire reactor program would have been impossible without the development and procurement of suitable materials for the various reactor components. One of the most serious sources of neutron loss is their absorption in the various pile components, such as the fuel, the moderator (in thermal neutron reactors), the structural materials, the coolant, etc. Although the element uranium, either natural or enriched, has the appropriate nuclear characteristics for the fuel, every effort must be taken to eliminate foreign impurities, especially those having high neutron absorption cross-sections. The most appropriate substances for moderators are those of low atomic weight, high scattering cross-section and low neutron absorption cross-section. This largely limits the choice of a moderator to heavy water, beryllium, beryllium oxide, beryllium carbide, or carbon probably in the form of graphite. The problem then becomes one of obtaining large quantities of moderator material purified to an extent never before encountered in industrial usage. The structural elements and the coolants again are essentially limited to materials having low absorption cross-sections, and again the problem may become one of purification.

One of the most vital accomplishments of the Laboratory has certainly been its contribution to the materials program. It has pioneered in investigating the nuclear and physical properties of various appropriate materials, it has developed methods of purification and methods of fabrication and it has been instrumental in seeing that these methods are applied to industrial production and that production requirements are met. In addition, it has sponsored numerous development programs by private industry in order to encourage the application of industrial know-how to the various materials problems. Some of the more significant accomplishments of the Laboratory's materials program are noted in the following paragraphs.

Uranium. At the beginning of the Project the problem of procurement of pure uranium was a prime responsibility of the Laboratory and the establishment of the first uranium production facilities was accomplished under Project direction. It was a direct result of the Laboratory's efforts that the first uranium purification process was installed at the Mallinckrodt Chemical Company. In this connection the Laboratory pioneered in the development of analytical techniques for uranium. The Laboratory has carried out almost all of the work on the development of appropriate metallurgical techniques for the fabrication of uranium. Methods of extruding, casting, and rolling uranium metal were first developed at the Laboratory and the extremely difficult problem of developing an adequate coating for the uranium was first investigated and solved at the Laboratory. Continued research on the properties of uranium has led, as an example, to the elucidation of the exceedingly troublesome radiation-growth problem first observed at Hanford, and methods of minimizing this effect have been suggested and tested. The Laboratory now has the prime responsibility for recommending the fuel elements for the Neutron Producer Reactors. The fabrication techniques selected in cooperation with the duPont Company was first suggested at the Laboratory several years ago as one which should minimize the growth problem.

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In connection with the uranium studies it is interesting to note an excellent example of the value of contined basic research and development. On the basis of experimental work associated with a completely different program, an ion exchange process was suggested as a means of recovering uranium from low grade ore. This process, based on Laboratory patents, is at present being given serious consideration as one method of alleviating the Nation's critical uranium raw materials problem.

Graphite. In 1942 the Laboratory assumed the direct responsibility for seeing that adequate facilities were made available for the production of very large quantities of purified graphite for the Hanford reactors. In addition to extensive laboratory research on the problem the Laboratory cooperated with the National Carbon Company and the Speer Graphite Company in devising means for improving the purity and increasing the density of their product. The Laboratory also developed methods for analyzing graphite for extremely small traces of impurities, and developed the functional tests which measure the total amount of neutron absorbing impurities. The entire program was eminently successful and an adequate production of amazingly pure graphite for Hanford and future reactors was assured.

The Laboratory has been the only organization which has maintained a continued program on the investigation of the nuclear, physical, and chemical properties of graphite. One result of this program has been the suggestion of various means of minimizing the deleterious effects of pile radiation on the physical properties of graphite. Certain of these techniques have been applied at Hanford with significant success. The first experiments on the use of graphite containing uranium oxide or carbide as a fuel element were carried out by the Laboratory. The recently adopted high temperature fluorination process for the purification of graphite was also first suggested by the Laboratory in 1943.

Heavy Water. A continued interest in the production of heavy water has been maintained. It was the direct result of the Laboratory's recommendation that certain of the heavy water production facilities were maintained after graphite had been chosen for the moderator in the Hanford piles and the Laboratory has continually advanced the case for the heavy water reactor. Methods of maintaining heavy water purity and of preventing difficulities due to radiation-decomposition have been under continued study at the Laboratory with the heavy water CP-3 reactor.

Beryllium. The Laboratory has probably also been instrumental in maintaining the production of beryllium and beryllium oxide in this country. It has sponsored research and development contracts with the various manufacturers and has cooperated with them in the development of methods for the production of sufficiently pure material to meet reactor requirements, and in the development of methods for the production of beryllium oxide shapes. The Laboratory itself has pioneered in the development of metallurgical techniques for the fabrication of beryllium metal and has maintained a continuing program on the investigation of the properties of beryllium ceramics. The possible application of beryllium to future reactors is under continuing study.

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Zirconium. Zirconium has been found to have an excellent combination of the physical and nuclear properties necessary for structural and cladding purposes in reactors and it is certain that it will play an increasingly important role in reactor technology, especially where higher temperatures are involved. The Laboratory has had a major role in the development of zirconium for such uses and has been the first to use zirconium in an actual reactor. It developed the first workable process for the purification of zirconium with respect to hafnium, and it has pioneered in the development of appropriate metallurgical fabrication techniques. It is largely through the Laboratory's continued interest that adequate quantities of zirconium suitable for reactor use are now available.

Liquid Metal Coolants. The Laboratory was the first to investigate the potentialities of sodium-potassium, sodium, lithium, bismuth and other liquid metals as reactor coolants. These numerous studies led directly to the adoption of sodium-potassium alloy as the coolant in the Experimental Breeder Reactor and to the use of other liquid metals in several of the reactors presently proposed or under study.

Plutonium. The Laboratory carried out the first preparation of plutonium metal and performed the first density, hardness and other physical measurements on microgram quantities of the metal. The methods now used for metal production are based essentially on the early research and development done at the Metallurgical Laboratory.

Separation Processes

Since the primary purpose of the reactor program, at least until recently, has been the production of plutonium, equally important with the development of suitable reactors is the task of separating plutonium from uranium and the highly radioactive fission products. In addition it has proved necessary to devise separation processes for the recovery of other radioactive elements of importance to the atomic energy program. The Laboratory has pioneered in the development of appropriate separation processes and has been responsible for, or involved in, the development of almost every process now in use.

Plutonium. A prime responsibility of the Laboratory was the development of a plutonium separation process for use with the Hanford reactors. Appropriate studies began in 1942 and almost every conceivable type of process was investigated, including specifically, precipitation, solvent extraction, adsorption, volatility, and electrolytic methods. Although most of these processes were carried to the point where scientific and engineering feasibility seemed probable, the decision was made to concentrate on a precipitation process since there appeared to be less engineering risk in scaling up this process from the experiments on microgram quantities to the gram quantities involved at Hanford.

At the beginning of 1943 the so-called bismuth phosphate process for the separation, decontamination, concentration and isolation of plutonium was selected as the most promising of the several precipitation processes investigated. The Laboratory was completely responsible for the conception, laboratory research, and laboratory and semi-works development of this process. The process was subsequently installed at Hanford by the duPont Company and has proved eminently satisfactory. To date it has been used for the separation and isolation of virtually 100% of the Nation's plutonium supply.

Beginning in 1944 the Laboratory was responsible for the conception and all the laboratory and small-scale pilot plant studies leading to the development and the demonstration of the feasibility of the Redox process. This solvent extraction process was selected by the Commission to replace the bismuth phosphate process since it not only recovers plutonium more effectively but also recovers the uranium and substantially reduces the waste volume. The Redox process is expected to be in production use at Hanford by the end of this year. The demonstrated feasibility of the Redox process and the very encouraging engineering performance of the attendant continuous solvent extraction equipment have been definitely responsible for the widespread consideration of such processes by various other AEC sites for Project applications. Specific examples which can be cited are the Purex process for the Savannah River project and the "25" process for the central chemical processing plant at the Arco Reactor Test Station.

The possibility of a fluoride volatility process was first suggested at the Metallurgical Laboratory and preliminary experimental work was carried out in 1943. Recently a volatility separations process which employs interhalogens for fluorination and fractional distillation as a means of separating the constituents has been under investigation at the Laboratory. This process appears thus far to be the most promising separations process yet conceived and it may well prove to be a very important step in the economics of power production.

It is interesting to note that the early investigation of an ion exchange process for plutonium separation led to the development of ion-exchange processes for the separation of the rare earths (at other laboratories), and, subsequently, to its application to heavy element separation, and, eventually, to its present widespread application to many inorganic separations.

Uranium 233. Development work on a continuous solvent extraction process for the separation of U^{233} from thorium irradiated in a reactor was begun in 1944. This work subsequently led to the production of the first milligram and gram quantities of U^{233} from which most of the present knowledge of the nuclear characteristics of this fissionable isotope were obtained. This work is of great importance in connection with the future utilization of thorium in converters.

Neptunium. The Laboratory developed the recovery process which resulted in the isolation and purification of the first milligram and then gram quantities of neptunium 237.

Effluent Processing. The Laboratory has been very active in the vexing problems of effluent processing and control in the Commission's various operating sites. In addition to conducting process and equipment development aimed at the long-range handling of the effluents resulting from Laboratory operation, the Laboratory has engaged in the effluent processing problems encountered in connection with the Savannah River operation.

The general problem has long been of interest to the Laboratory and it has pioneered in the modification of separation processes to reduce the waste effluent problem to a minimum. Currently, the investigation of methods for the "fumeless" dissolution of uranium have an important bearing on some aspects of the problem.

<u>Tritium.</u> In order to obtain sufficient quantities of tritium for research purposes the Laboratory began in 1945 the development of a process for the production and extraction of tritium from irradiated lithium. In fact, until 1949, all the tritium produced in this country was processed at the Laboratory. The present process used at Hanford was developed completely at the Laboratory and the process which will be used in connection with the Savannah River reactors is the direct result of Laboratory development. The method now used at Los Alamos for the storage and purification of tritium was developed by the Laboratory.

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Research in the Physical Sciences

As an essential adjunct to the development programs vital to the success of the Nation's atomic energy program, the Laboratory has continually sponsored research programs consonant with its programmatic responsibilities. Development work cannot really flourish unless attention can be paid to the corresponding research progress in the appropriate fields. At various phases in the Laboratory's history, this research work has been directed toward very specific programmatic goals, as for example, during the last war. At other times it has been possible to carry out some research in which no such restriction was necessary, the only constraint being that the research should be in the general fields pertinent to the atomic energy program. The Laboratory's very many direct contributions to the atomic energy program are due in large part to the continued vitality of the Laboratory's research program.

A complete record of the research accomplishments of the Laboratory would be impossiby long for this presentation. Instead, a number of representative examples of the type of research done or of highlights of results obtained will simply be noted without any particular regard as to order or as to complete coverage of the program. This representative list follows.

Study of the Fission Process. The Laboratory has made many contributions to the elucidation of the fission process. It has investigated the energy spectrum of fission neutrons, investigated delayed neutrons from fission, established the existence of spontaneous fission, and determined the power and product yield per fission. The Laboratory made the first accurate measurements of the fission yields in U^{235}, Pu^{239}, and U^{233} and has characterized, for the first time, many of the nuclides produced in the slow neutron fission of U^{235}. This includes the determination of decay schemes, genetic relationships, half-lives, and mass assignments of the isotopes produced in fission, and the measurement of some of the absorption cross-sections. The Laboratory also performed most of the original measurements of the fundamental reactor constants, as for example, the number of neutrons released per fission and the ratio of neutron capture to fission for U^{233}, U^{235}, Pu^{239} and other fissionable isotopes. On the basis of experimental work of this nature not only have significant contributions been made to the theory of the fission process itself, but also the understanding of the chain reaction has been significantly improved in terms of analytical precision.

The Effects of Radiations on Materials. The Laboratory carried out the first theoretical and experimental investigations on the effects of fast neutrons and fission recoils on the properties of solids such as graphite, uranium, beryllium oxide and many other materials. Current theories as to the mechanism of radiation damage in graphite are to a large extent the result of the Laboratory's research. Stored energy in graphite was first predicted, experimentally verified and its possible consequences studied at the Laboratory. The research on uranium, especially on the dimensional instability

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of uranium and its alloys, has contributed considerably to the elucidation of the mechanism and to the development of means of minimizing the growth observed under pile irradiation.

The first investigation of the effects of pile radiations on the decomposition of water was made at the Laboratory and current theory as to the mechanisms involved stem directly from this research.

Chemistry of the Elements. An exhaustive investigation of the solution and dry chemistry of plutonium has been in progress at the Laboratory beginning with the first micrograms produced by cyclotron irradiation in 1943. This program has resulted in the first preparation and x-ray characterization of most of the known plutonium compounds, the determination of the valence states of plutonium in solution, the discovery and isolation of microgram quantities of naturally occurring plutonium in uranium residues, and many other accomplishments. In fact, the work at the Laboratory is, to a large extent, responsible for the present state of knowledge of the chemistry of plutonium.

Similar studies have been made on neptunium, actinium, and protactinium. The Laboratory was responsible for the isolation of the first relatively large amounts of these elements in a pure form and again has been almost solely responsible for the study of their chemistry. In connection with separations studies the Laboratory discovered and first isolated americium and curium, elements 95 and 96, and made some preliminary studies of their chemistry. Also in connection with the separations and fission product studies, the Laboratory has made many contributions to the knowledge of the chemistry of the rare earths.

One of the more recent and most spectacular accomplishments has been a thorough investigation of the low temperature physical properties of $helium^3$, including its first liquefaction. The preparation of tritium compounds and their properties have been investigated.

The atomic spectra of many of the heavy elements and of other elements of interest to the atomic energy program have been investigated. The first measurements of the atomic spectra of Pu^{239}, Ac^{229}, Np^{237} and He^3, and of the molecular spectra of T_2, HT, DT, were made at the Laboratory.

Neutron Physics. The first studies on the reflection and refraction of neutrons were made at the Laboratory and new approaches were made to the problems of neutron polarization. Theoretical and experimental studies of the neutron slowing down process and of neutron temperatures have been made. The properties of essentially monoenergetic neutron beams have been studied. Studies of this type are made possible by the development at the Laboratory of the first velocity selector employing revolving shutter and time-of-flight techniques and the construction of the first neutron beam crystal spectrometer. One of the factors most vital to the field of neutron physics in which the Laboratory has been active has been the development of appropriate techniques for measuring neutron fluxes.

Metallurgical and Ceramic Studies. Many significant metallurgical and ceramic studies have been made at the Laboratory. Detailed investigations of the physical properties of various ceramics, metals, and metal alloys and of the effects of pile radiations on their properties have been carried out. In particular the first spectroscopically pure uranium was produced at the Laboratory. The investigation of the dimensional instability of uranium and the thermal cycling technique for studying this phenomenon were first carried out at the Laboratory. The phase relations in uranium and uranium alloys were first investigated at the Metallurgical Laboratory. The mechanism of corrosion for many of the elements pertinent to the atomic energy program have been investigated and means of minimizing such corrosion have been recommended on the basis of these studies.

Nuclear Properties of Other Elements. In addition to the investigation of the nuclear properties of the specific fission product nuclides the Laboratory has maintained a broad program on the investigation of the nuclear properties of other nuclides either of specific interest to the atomic energy program, or else of general interest to the development of nuclear science. This has included the measurement of innumerable neutron cross-sections for various nuclear processes on various elements and isotopes. Physical, radiochemical, and mass spectrographic techniques have been employed in such measurements. Perhaps one of the most important results of this program has been the development of the pile oscillator technique for cross-section measurements. The studies have been of great importance to specific reactor problems and, at the same time, have furnished the basic data from which "magic number" relationships have been derived.

The half-lives, decay schemes, genetic relationships, and nuclear moments of many radioactive species have also been determined. The first careful measurement of the tritium half-life and perhaps the most accurate determination of the C^{14} half-life were made at the Laboratory. The investigation of the nuclear properties of the heavy elements led to the discovery of the $4n + 1$ disintegration series. The first measurements of the nuclear moments of tritium and He^3, and the most accurate determination of the deuteron moment were made at the Laboratory.

Instrumentation. Many of the developments in the field of radiation detection have been based on the work of the Laboratory. The development of compact, rugged, accurate instruments for health monitoring has been a prime concern of the Laboratory since 1942. Many contributions have been made to the development of detecting devices for research use, including for example the development of proportional counters, alpha pulse analyzers, boron counters for neutron detection, etc. The Laboratory was responsible for the development of the present commercial model of the vibrating reed electrometer and for many instrumental developments in the field of microchemistry. It has also pioneered in the development of remote control equipment including shielding devices, manipulators, and optical and electronic viewing systems.

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Research in the Biological Sciences

From its inception the Laboratory has maintained a strong biological and medical program integrated with its research and development work on all phases of nuclear energy. This was the first laboratory in which the problem of monitoring for the control of radioactive hazards and for the prevention of radiation exposure had to be met on a large scale. The early work at the Laboratory had much to do with the subsequent success of the atomic energy business from the standpoint of industrial health.

Specifically the Laboratory developed most of the present methods of determining radioactive elements in human excreta and made an exhaustive study of the changes in the blood and skin that follow irradiation of the body. The first and, in most respects, only complete studies of the deposition in the body of plutonium, and of radioactive strontium, barium, lanthanum, cerium, and yttrium were made at the Laboratory and the principle of metal displacement from bone was established by demonstrating that zirconium will displace plutonium from the skeleton. The tolerance levels for plutonium, tritium, carbon 14 and other activities were established on the basis of the Laboratory's investigations.

Many investigations have been carried out on the factors involved in radiation sickness and chemical means of protecting against radiation sickness were first demonstrated in this Laboratory.

The toxicities of other non-radioactive elements pertinent to the atomic energy program have been investigated. As an example, such studies have led to a therapeutic agent against beryllium poisoning.

Many other related basic and applied studies have been carried out. As one specific example, the artificial blood plasma, dextran, was synthesized from plants grown in a carbon-14 atmosphere. This provided a "tracer" dextran with which it was possible to prove in an experiment of one week duration that this substitute was metabolized completely by the body, a proof which would have otherwise required years of clinical investigation. As a result it was possible to proceed to immediate production of this vitally needed substance by the Commercial Solvents Corporation which brought the problem to the attention of the Laboratory for its assistance.

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