CIVILIAN POWER REACTOR PROGRAM

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PART IV

*Plans for Development
as of February 1960*

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CIVILIAN POWER

REACTOR PROGRAM

PART IV

Plans for Development as of February 1960

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UNITED STATES ATOMIC ENERGY COMMISSION

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I. INTRODUCTION

The first phase of a continuing study to develop long range plans for the Civilian Power Reactor Program has been completed. Information developed in this study is included in a series of four reports. Additional reports on the results of the continuing study will be published as appropriate. Reports covering the first phase of the study are:

Civilian Power Reactor Program—Part I—Summary of Technical and Economic Status as of 1959.

Civilian Power Reactor Program—Part II—Economic Potential and Development Program as of 1959.

Civilian Power Reactor Program—Part III—Technical Status as of 1959.¹

Civilian Power Reactor Program—Part IV—Plans for Development as of February 1959.

In developing the program plans presented in this report, primary attention has been given to the technological development required to achieve economically competitive nuclear power. Consequently, prototypes for large central station power plants figure prominently in the program. This should not be construed as indicating a diminution of Commission interest in, or support of a small power reactor program directed to achieving economically competitive nuclear power in plant sizes below 50 MWE (electrical megawatts). A number of the reactors presently being built or planned will contribute to attaining this objective. As more information becomes available and is evaluated concerning these and other reactors, including military programs, additional prototypes of small power reactors will be considered for construction.

¹Titles of specific reports included in Part III and the document referenced in Part I are listed in Appendix A.

The current Civilian Power Reactor Program follows an orderly three-phase sequence for the development of individual reactor concepts. This sequence in general contemplates construction first of reactor experiments or experimental reactors, followed by prototypes and then by plants of commercial proportions. As a rule reactor experiments are built and operated by the Commission. Prototypes should be built and operated by publicly or privately owned utilities independently or in cooperation with the Commission. Under some circumstances, prototypes are built and operated by the Commission. The utility industry is expected to assume primary responsibility for large commercial size nuclear power stations; however, the Commission will consider possible assistance on initial plants in various concepts useful for demonstration purposes. It is important that the large plants and, as far as possible, the prototypes as well, be integrated into utility power grids in order to demonstrate load factors, dependability, and other operating characteristics which affect the economics of the plants.

Experimental and prototype reactors are constructed as a part of the Commission's program when the plans for experimental work indicate that the technical or economic information and operating experience to be derived from the facility is essential to the Commission, or to the power industry, in the efforts to reduce the cost of nuclear power. In the development, construction, and operation of prototype and full size power producing reactors, the Commission works cooperatively with reactor manufacturers and with publicly and privately owned utilities.

Any arrangements whereby the Commission provides significant financial support will in-

clude provisions to assure that an experimental testing program can be carried out with the reactor during its early operation. Such testing programs will vary with each project. When power generation is involved, this fact will be taken into account when establishing the testing program.

The Civilian Power Reactor Program will be continuously evaluated and reappraised. New

ideas and new technologies, including those developed in other countries, will be reflected in this continuing evaluation. Periodic program reviews will consider carefully the relative merits of various lines of development looking toward reduction or elimination of some efforts, and initiation of, or increases in others. Should information indicate that a concept is not useful in meeting our objectives, the concept will be dropped.

II. PROGRAM OBJECTIVES

In previous reports and testimony before the Joint Committee on Atomic Energy (February 1959 Hearings on the Development, Growth, and State of the Atomic Energy Industry), the Commission set forth the following five objectives for its civilian power program:

1. Reduce the cost of nuclear power to levels competitive with power from fossil fuels in high energy cost areas of this country within 10 years.
2. Assist friendly nations now having high energy costs to achieve competitive levels in about 5 years. This assistance is to be extended mainly through clearly defined programs of cooperation.
3. Support a continuing long range program to further reduce the cost of nuclear power in order to increase the economic benefits and extend these benefits to wider areas.
4. Maintain the United States position of leadership in the technology of nuclear power for civilian use.
5. Develop breeder type reactors to make full use of the nuclear energy latent in both uranium and thorium, recognizing that U-235 alone may not be sufficiently plentiful to meet our needs over the long range.

The first and third objectives are directly applicable to the development of central station power plants, and they have been used as the principal factors in establishing that part of the program outlined herein which deals with these plants.

In order to permit a more exact statement of the initial goal of the program, the first objective has been further defined as follows:

- a. The 10-year period is measured from 1958, when the objective was first stated. This es-

tablishes 1968 as the target date for achieving competitive power in high fuel cost areas.

- b. It is considered that competitive nuclear power will have been achieved when utility executives can decide to build nuclear stations based on economic considerations.

- c. High cost energy areas are considered to be those areas where fossil fuels presently cost 35 cents per million BTU or higher.²

No attempt has been made to assign a quantitative definition to the third objective either with regard to time or to the extent of the "wider areas". This objective is the basis for the longer range development program aimed at lowering the cost of nuclear power to a point where it is competitive with fossil power in ever increasing areas of this country.

The other three objectives are more general in nature. With the passage of time and events, conditions relating to two of the objectives have changed substantially.

The second objective relates to the achievement of economic nuclear power abroad. When this objective was first stated, it appeared that it could be achieved first in Western Europe in about 5 years. In the last 2 years the increased availability of fossil fuels and the drop in their shipping costs have brought the time table of achieving economic nuclear power in Europe closer to that of the United States.

The fifth objective recognizes the long-term importance of the development of nuclear power systems which can use a major fraction of the uranium and thorium available. At the present time it is not possible to make an accu-

² Conventional power costs in these areas are estimated to be about 7 mills per kilowatt hour for a 300 MWE single unit fossil fuel station using fuel costing 35 cents per million BTU (200 psia, 1,050° initial/1,000° F. reheat, 1½ inches of mercury back pressure), based on 1959 cost levels, no escalation, 80% capacity factor and 14% fixed charges.

rate prediction of the time when uranium shortages and rising costs associated with such shortages will make the more efficient use of source material a vital factor. However, the ultimate importance of conservation of nuclear fuel dictates a long-range program to develop the breeding potential inherent in both the ura-

nium 238-plutonium and the thorium uranium 233 fuel cycle.

There has been no change in the fourth objective. The Commission has endeavored and will continue to strive to maintain the United States in a position of leadership in the use of atomic energy for civilian purposes.

III. SPECIFIC REACTOR PROGRAMS

Necessary congressional authorization will, of course, be required before proceeding with any of the new projects considered in the following concept-by-concept review.

A. LIGHT WATER-COOLED REACTOR PROGRAM

There is a relatively high probability that light water-cooled reactors in the reasonably near future can achieve competitive power in the high fuel cost areas of the United States where large single units are practical. In addition, water reactors also offer a longer range potential for being competitive in many other areas of the United States.

Over the next 4 or 5 years, Commission supported research and development work on water reactors will be aimed primarily at solutions of the problems of nuclear superheat, increased fuel life, decreased fuel costs, simplified fabrication techniques, fuel management, simplified and less costly containment methods and cheaper materials and methods of construction.

A major effort will be made to develop techniques for economically utilizing plutonium as a fuel material in water reactors.

The water-cooled reactor program is described under three categories: Pressurized Water, Boiling Water, and Nuclear Superheat.

1. Pressurized Water Reactors

The pressurized water reactor concept is technologically well advanced and is the concept with which we have had the most experience. This experience has demonstrated that pressurized water reactors are safe, dependable, and reasonably easy to control. Capital costs of a 300 MWE plant of this type, as quoted recently by the manufacturers on a fixed-price basis, when taken in conjunction with fuel

guarantees reported to the Commission by utilities and core manufacturers, indicate that the power produced from such a plant initiated now should be competitive over its life in high fuel cost areas of the United States where a plant of this size can be used.

a. Plans for Use of Existing or Authorized Facilities

(1) Domestic Civilian Power Program

The reactor at the Shippingport, Pennsylvania, Atomic Power Station will be modified to raise its power to 150 MWE equivalent. It will continue to be operated to demonstrate the life potential of the present rod type blanket elements. The present core will then be replaced by the newly developed 150 MWE high-power density flat plate oxide seed and blanket core. The reactor plant and its associated facilities will be used also to further demonstrate the technical and economic feasibility of the seed and blanket concept. The developmental cores to be installed at Shippingport upon completion of the PWR Core-2 lifetime will depend on the result obtained in the development, testing, and operation of the PWR Core-2. For example, consideration will be given to the installation of still higher power cores if feasible and/or the utilization of other fuel materials such as plutonium, uranium 233, and thorium in this developmental reactor facility.

The Yankee Atomic Electric Company plant at Rowe, Mass., is scheduled for criticality in 1960. It will operate initially at 110 MWE. Among the important new features to be tested in the plant are stainless steel clad slightly enriched uranium dioxide fuel elements and solution poison for shut-down control. Statistically important utility operating and maintenance experience will be gained from this relatively large scale reactor operating principally as a power producer.

Two pressurized water reactors are being built by private industry without substantial Government assistance. A 151 MWE reactor is being built by the Consolidated Edison Company of New York at its Indian Point, N.Y., plant which, with conventional superheat, will produce 255 MWE. It is scheduled to go critical in 1961. The Indian Point plant will provide important operating data for large water cooled reactor systems and technical data on the use of thorium-U-235 fuel mixtures. The Saxton Nuclear Experimental Corporation's 5 MWE reactor experiment will furnish steam to the Pennsylvania Electric Company's Saxton plant at Liberty, Pa., and is scheduled to go critical in 1962. These plants will add much information to the technology of pressurized water plants.

A 40 thermal megawatt process heat reactor is scheduled for construction. This reactor will explore the economics of reactors for production of low temperature, low pressure steam for use by the process industries.

A 16 MWE prototype with 6 MWE conventional superheat will be built primarily to demonstrate the economics of pressurized water reactors as small power reactors but it will also provide operating information important to the design of large pressurized water reactors. The feasibility of bulk boiling in pressurized water reactors will also be demonstrated in this reactor. Five proposals have been received for this reactor to be built under a second round type authority. The target date for criticality is 1962.

In addition to the work being done in this country, design, construction, and operating experience will also be obtained from SELNI in Italy and the BR-3 plant in Mol, Belgium.

(2) *Military and Maritime Contributions*

The Navy will put into operation a large number of nuclear powered submarines and surface ships in the next few years. The supporting research and development work for these reactors has contributed and will continue to

contribute significant data to the civilian reactor program as will the natural circulation prototype reactor which is to be built at the National Reactor Testing Station (NRTS).

The Army Reactor Program will develop much information of value to the Civilian Reactor Program. Civilian reactor development will benefit from the standardization of components and materials which will be a natural outgrowth of the Army program. The studies on use of reactors in remote military locations will be of particular importance in developing safe, reliable small nuclear power plants for use under a variety of climatic conditions in all parts of the world.

The pressurized water reactor installed aboard the N.S. *Savannah* should contribute important technology to the Civilian Reactor Program, and in particular to the future of maritime nuclear propulsion.

b. Future Plans

It is probable that at least one additional pressurized water prototype will be justified by research and development results and operating experience. Such a prototype would be designed to demonstrate improved technology growing out of the operation of the Shippingport, Yankee, and Indian Point plants, and out of development and design of the other reactors listed previously. This prototype, if justified by developments and analysis, would incorporate improvements in plant design, construction, containment, and components which would lead to lower power costs. Design of such a plant could be begun in 1962 with construction starting in 1963 or 1964.

If the development work on the spectral shift³ variation of pressurized water systems is successful, and the idea still appears promising, construction of another prototype reactor, pos-

³ The spectral shift reactor is one in which heavy water is added to the light water coolant. Initially a high concentration (75% to 80%) of heavy water is used. As the fuel burns the concentration of heavy water is reduced (to about 25%) in order to decrease the neutron diffusion rate which increases reactivity and extends fuel life.

sibly 50-100 MWE, to demonstrate this technology and its economics would be started in the early 1960's.

Information submitted to the Commission by reactor manufacturers indicates that utility managements may be in a position to make a decision now to build large pressurized water plants in high fuel cost areas in which large plants are practical, basing their decision on economic considerations. The construction and operation of one or more such plants as a part of utility systems located in such areas would play a valuable role in the development of economic large central station nuclear power plants.

The studies which are currently being made with respect to the feasibility of reactor generated power in remote locations together with the technical information developed in Army and Navy reactor programs may indicate the desirability of initiating in 1962 a small power reactor prototype (20 to 30 MWE) at some installation which would offer a test of reliability under varying conditions.

2. Boiling Water Reactors

The technical feasibility of boiling water reactors has been successfully demonstrated by the BORAX experiments at the National Reactor Testing Station in Idaho, the Experimental Boiling Water Reactor at Argonne National Laboratory, and the Vallecitos Boiling Water Reactor in California. Based on currently available information, there is every reason to believe that the large Dresden plant now undergoing startup tests, the Humboldt Bay plant, and the Rural Cooperative Power Association Elk River plant, all using boiling water reactors of varying size and design, will operate successfully and will furnish valuable information.

a. Plans for Existing and Authorized Facilities

Domestic Civilian Power Program

The modifications now under way on the Experimental Boiling Water Reactor, which will

raise its power to 100 MWT, will be completed and the experimental program of study of the behavior of the boiling water system will be resumed. The modified reactor will be used initially to demonstrate the stability of a boiling water reactor at higher power density, and it will serve as a boiling water fuel element test facility. Plutonium fuel development and water chemistry will be studied in this reactor.

The 16 MWE indirect cycle boiling water Elk River plant, which has an additional 6 MWE from conventional superheat, is scheduled for criticality in 1960. This reactor is primarily of interest in the small power plant program. Experience gained from it will also aid in the evaluation of certain variations in boiling water reactor design of possible interest to larger plants. These variations include use of mixed thorium oxide and uranium oxide fuels and of an intermediate heat exchanger in a boiling system.

Three boiling water reactors have been built, or are being built, by private industry without substantial Government assistance. General Electric's 20 MWT (5 MWE) Vallecitos Boiling Water Reactor near Pleasanton, Calif., is being modified to provide for forced circulation and to insert a UO_2 core. This plant is expected to resume operation in May, 1960. Commonwealth Edison Company's 180 MWE Dresden Nuclear Power Station at Morris, Ill., has gone critical, and the 48 MWE Humboldt Bay (California) Reactor of the Pacific Gas and Electric Company is scheduled to go critical in 1962. The experimental and operational data from these reactors will add much information on the technology of boiling water reactors and the latter two will provide valuable statistical operation and maintenance data for water cooled reactor systems. The programs of these reactors will supplement the work being carried out in plants built with Government support, and will be an important part of this country's overall program for the development of boiling water reactors.

Construction of a 50-75 MWE high power density boiling water prototype is planned to

begin in 1960 with criticality scheduled for 1963. This plant will be designed and operated in such a way as to provide technical and economic information on operation at power densities of the order of 60 kilowatts per liter and at fuel lifetimes similar to those experienced at lower densities. Negotiations are currently underway between the Commission, the Consumers Power Company of Michigan, and the General Electric Company to develop a mutually satisfactory cooperative program for this reactor. Information from this program will be of value to both large and small power stations.

A simplified 50 MWE boiling water prototype reactor will be constructed to demonstrate design improvements which will reduce the size, complexity, and cost of boiling water reactors. Such features as improved control methods, simplified containment, elimination of high risers, and increased power output per unit of water flow will be incorporated in the design. Invitations have been issued for proposals from interested utilities. It is expected that construction will start in 1960 or early 1961. The target date for criticality is 1964. While this reactor will be primarily a prototype for future large reactors, the engineering improvements made will, in general, be equally applicable to small reactors.

In addition, Italy will build the 150 MWE SENN reactor. It will contribute experience in design, manufacturing, operating, and maintenance for a large boiling water reactor plant. Information developed will be available to the Commission and to industry through an exchange program.

b. Future Plans

Aside from developments involving nuclear superheat, which are described elsewhere in this report, most of the currently foreseen developments in boiling water technology probably will be demonstrated with reactors currently in operation, being built, or authorized. When operating experience is available from these

reactors, in 1963 or 1964, it will be possible to determine what, if any, additional experimental or prototype reactors are needed to achieve competitive power in large reactors. Until such a determination is made, no further construction of large boiling water experimental or prototype reactors is contemplated by the Commission.

In the small reactor fields, results from such projects as Elk River, Humboldt Bay, and the simplified reactor project discussed earlier may indicate in 1963 or 1964 the need to initiate construction of a small (20–30 MWE) prototype.

As in the case of pressurized water reactors, we have been advised by a manufacturer that a 300 MWE boiling water plant can be built now on a fixed-price basis, with certain fuel cost guarantees, which may produce power competitive with conventional power in certain high cost fuel areas of the United States. The Commission considers that the construction of one or more boiling water plants by utility companies in high cost areas where plants of this size may be practical would make a significant contribution to the development of economic power.

3. Nuclear Superheat Reactors

Nuclear superheat can be applied to both direct and indirect cycle boiling water reactors, and to indirect cycle pressurized water reactors. In direct cycle boiling water reactors, nuclear superheat may be integral. In indirect cycle reactors, whether boiling or pressurized, what is essentially a separate steam-cooled reactor would be required to obtain nuclear superheat.

Nuclear superheat would make possible production of steam at temperatures and pressures used in modern conventional power plants of high efficiency. Development work and design studies have been underway for some time, concentrating chiefly on the superheat fuel element. Data from these programs are applicable to both direct and indirect cycle reactors. Design studies and evaluations have been made on in-

tegral superheat systems, and soon will be initiated on separate superheat systems.

a. Plans for Existing and Authorized Facilities

Domestic Civilian Power Program

The fifth Boiling Reactor Experiment (BOR-AX-5) is under construction at the National Reactor Testing Station and is scheduled to go critical in March 1961. The reactor will be operated initially with a limited number of test channels producing superheated steam and will be converted gradually into an integral nuclear superheat reactor. Flexibility designed into the system will permit investigations of nuclear stability problems associated with various fuel and coolant arrangements.

The Northern States Power 62 MWE Plant near Sioux Falls, S. Dak., is under construction and is scheduled for criticality in 1962. This reactor will provide test and operating data on a high density, integral nuclear superheat core. Development work leading to reduction in the enrichment of fuel in the superheat section of the core will continue.

A contract has been signed with the Puerto Rico Water Resources Authority for construction of a 16 MWE Boiling Nuclear Superheat Reactor (BONUS). This reactor will provide information on the practicality of an integral nuclear superheat design for small reactors, and will assist in the evaluation of nuclear superheat in large plants. The target date for criticality is early 1963.

b. Future Plans

If the technical and economic information obtained from these projects confirms the prediction that nuclear superheat can substantially lower power costs in boiling water reactors, a 100 MWE prototype would probably be required to exploit the full potential of the system. Such a prototype, if justified, probably would be initiated in 1963.

If this program proves successful, it is anticipated that by 1968-69 sufficient technical and

economic information will be available to permit utilities in certain areas of the country to decide, on economic grounds, to construct a large (300 MWE) integral superheat plant.

B. ORGANIC-COOLED REACTOR PROGRAM

There is a relatively high probability that organic-cooled reactors can achieve competitive power in high fuel cost areas of the United States by the middle 1960's and in the longer range over many other areas. Because of the experience in operating the Organic Moderated Reactor Experiment (OMRE) and in other research and development work already done, because of the relative simplicity of the system, and because of the direct applicability of much of the technology developed in water reactor programs, it is believed that this concept can achieve its early potential with less research and development and construction of experimental and prototype plants than are required for other reactor concepts.

Organic-cooled reactors operate at higher temperatures and lower pressures than water reactors, and have no major corrosion problems. These characteristics facilitate the construction of plants having lower capital costs. However, high costs for replacing decomposed coolant are an economic disadvantage. Organic coolants also have poor heat transfer characteristics and require fuel elements with extended surfaces and high conductivity cladding. Since a longer-lived fuel must be developed, research and development work at present is primarily on aluminum-aluminum oxide claddings for uranium oxide and uranium alloy fuel materials. Research and development work also is directed toward lower organic makeup costs and improving organic fluid flow and heat transfer characteristics.

In the longer range, the research and development program will be directed toward utilizing plutonium as a fuel in organic reactors.

a. Plans for Use of Existing or Authorized Facilities*Domestic Civilian Power Program*

The 5 to 15 MWT Organic Moderated Reactor Experiment at the National Reactor Testing Station is being modified to make it a more suitable test facility and to reduce its cost of operation. It will continue to be used as a fuel test facility, for determining coolant decomposition rates, and for conducting heat transfer and surface fouling tests.

The 40 MWT Experimental Organic-Cooled Reactor (EOCR) is presently being designed with construction scheduled to start this year at NRTS. It is scheduled to be critical in 1962. This facility will have more flexibility than the OMRE. It will allow an acceleration of the rate at which alternative fuels, coolants, moderators, and operating conditions can be investigated, and it will give greater assurance that improvements will be available for organic reactors that might be built in the future.

The 11 MWE organic cooled and moderated reactor being built for the City of Piqua, Ohio, is scheduled for criticality in 1961. It is of primary importance as a prototype for small nuclear power plants, and it will make possible a reasonable analysis of the potential of the organic concept in this size. It will also provide operation data that can be extrapolated to larger plants.

A 50 to 100 MWE organic-cooled prototype is planned for construction. Its primary purpose will be to provide data on use of an improved fuel such as aluminum cermet clad uranium dioxide. An invitation for proposals to build this reactor has been issued under the fiscal year 1960 authorization. Should no acceptable response be received to the invitation, and if research and development results continue to be favorable, the Commission proposes to start construction with funds included in the fiscal year 1961 appropriation request. The target date for criticality of this reactor is 1964. It is primarily a prototype for future large scale power reactors, but the basic fuel element information which it will develop will be im-

portant for process heat and small power reactor systems.

b. Future Plans

Assuming success in operation of the 50-100 MWE prototype and in other research and development, it is anticipated that by 1965 or 1966 sufficient information will be available to permit utilities to decide on economic grounds to construct a 300 MWE organic-cooled reactor in a high fuel cost area and later in wider areas.

In the middle 1960's continuing research and development, if successful, should indicate further improvements possible in organic-cooled reactors. A 50-100 MWE prototype may be justified to demonstrate these features.

C. LIQUID METAL-COOLED REACTOR PROGRAM

Liquid metal-cooled reactors, particularly those cooled with sodium, appear to have a high potential for achieving competitive power in large areas of the United States in the late 1960's or early 1970's.

Sodium has many attractive features as a reactor coolant. It is liquid at relatively low temperatures, has a very high boiling point, reasonably low neutron absorption cross section and excellent heat transfer and heat transport qualities. These characteristics make possible very high steam cycle efficiencies. Because of the negligible pressure required for sodium systems, very large sized (500 MWE and larger) reactors are practical. This is an advantage since unit power costs generally decline with increased plant size. The Experimental Breeder Reactor No. 1, the Sodium Reactor Experiment and the submarine Seawolf and its prototype reactor have demonstrated that sodium-cooled reactors can be operated safely. However, there still are problems with fuel elements and components which must be solved before these systems can achieve their full potential.

Since liquid sodium is not in itself a moderator, systems which use this material as a coolant

can operate over a wide neutron energy spectrum, depending upon the presence and characteristics of moderating material. In fast and possibly in epithermal systems, sodium-cooled reactors are capable of breeding. Sodium-cooled reactor systems can also operate with uranium 238-plutonium fuel systems or with thorium-uranium 233 systems.

The Commission's program for sodium-cooled reactors is presented below under two headings—fast reactors and thermal reactors.

1. Sodium-Cooled Fast Reactors

Most of the technical and economic advantages which are inherent in the use of sodium as a reactor coolant apply to fast systems. They have an additional advantage in their ability to achieve high conversion ratios or to breed.

The research and development program for fast or epithermal liquid metal-cooled reactor systems is long range in nature and is expected to yield significant results in the late 1960's. In its initial stages, it will concentrate on the development of a satisfactory, long life, high burnup fuel material; on the utilization of plutonium and uranium 233 as fuels and of uranium and thorium as fertile materials; on the development of reliable and less expensive sodium components; and on the development of efficient and rapid fuel recycle methods.

a. Plans for Use of Existing or Authorized Facilities

(1) Domestic Civilian Power Program

Operation of the first Experimental Breeder Reactor (EBR-I) at NRTS will be continued. Upon completion of the current safety experiments, a plutonium cermet core will be installed.

The second Experimental Breeder Reactor (EBR-II) at NRTS is scheduled for criticality in late 1960. The first core for this reactor will utilize U-235 fuel. The subsequent core will be fueled with plutonium. This plant will incorporate on-site pyrometallurgical fuel processing.

The 94 MWE Enrico Fermi Plant at Monroe, Mich., is scheduled for criticality in 1960. Test

information on the uranium 10 weight percent molybdenum fuel performance, on fuel rotation, on fuel processing, on core physics and on overall plant performance will be important to the advancement of fast reactor technology.

Work being undertaken abroad also will contribute information of value to our program. The United Kingdom's Dounreay reactor is an experimental facility similar to a large EBR-I; they plan later to build a large fast breeder prototype. The French are planning a 10 MWT advanced fast reactor using plutonium as fuel.

(2) Military Contributions

Various military research and development efforts will contribute significant data on fast breeder systems. The development work on the SNAP reactors (Systems for Nuclear Auxiliary Power) will result in the construction of small sodium-cooled reactors which will provide information on the performance of fuel elements, moderators and structural materials, operating at high temperatures in a fast neutron spectrum. The aircraft program includes the construction and operation of an experimental liquid-metal cooled intermediate reactor. This facility will provide useful data on high temperature fuel element performance and on the behavior of other materials in a liquid metal environment.

b. Future Plans

A 100 MWE prototype sodium-cooled fast or epithermal reactor will be constructed if the results from existing or planned reactors provide a basis for improved design. Two years of operating experience on these plants should be available before starting the new prototype. Detailed design and construction could start in 1963 or 1964. The primary purpose of this reactor will be to incorporate the improvements in design arising out of the operation of prior plants, and to demonstrate a plutonium-fueled core optimized for lowest power costs.

With the successful completion and operation of the above prototype and with data from other

plants, it is believed that, by the late 1960's, enough information will be available to permit utilities to decide on economic grounds to construct large sodium-cooled fast breeder plants in many areas.

2. Sodium-Cooled Thermal Reactors

Sodium-cooled thermal reactors have the potential of achieving economic power in high fuel cost areas of the United States. These reactors can be operated at high temperatures and low pressures. However, to obtain full benefit from these characteristics, a greatly improved fuel element must be developed: one capable of long life in the high temperature environment. For this reason it is unlikely that this potential can be achieved at an early date.

Since sodium-cooled fast reactors offer most of the advantages of the sodium-cooled thermal systems and in addition, offer the possibility of lower fuel costs through breeding, work on sodium-cooled thermal reactors, would not be expanded until operating results from the Hallam reactor, now under construction, can be evaluated. Research and development for sodium-cooled thermal systems will concentrate on uranium carbide fuel development and on major improvements in the design, efficiency, and performance of the sodium components. In carrying out this program, full consideration will be given to the points of similarity between thermal and fast cooled systems and the work will be directed in such a way as to achieve maximum benefit to both.

a. Plans for Use of Existing or Authorized Facilities

Domestic Civilian Power Program

The Sodium Reactor Experiment (SRE) in California will be returned to operation. For the next several years, its use will be limited to testing of advanced fuels and other work in support of the Hallam plant. When this work is completed, and if the potential of the concept shows continued promise, the SRE will be reassessed as to its suitability for conversion to

a high temperature fuel test facility, or to an advanced experimental reactor to demonstrate improvements in thermal sodium-cooled systems.

The Hallam Nuclear Power Facility is scheduled to reach criticality earlier in 1962. Operational plans for this 75 MWE plant include continued testing and evaluation of promising fuels, with the objective of reduced fuel cycle costs. Operating experience and tests with the plant are expected to yield valuable technical information regarding all sodium-cooled reactor plants, including those to operate with neutrons in the fast and intermediate energy spectrums.

b. Future Plans

If evaluation of the operation and tests of the Hallam reactor show a more favorable potential than had been foreseen for this concept, consideration will be given to the construction of experimental or prototype plants to exploit potential improvements. Such additional facilities will not be considered, however, until operating experience is available and therefore would not be initiated before 1963 or 1964.

D. ENRICHED GAS-COOLED REACTOR PROGRAM

Enriched uranium gas-cooled reactors have the potential of producing superheated steam of the quality currently in use in large conventional central station power plants with the resulting high efficiency. Gas-cooled reactors can operate at low pressure and therefore can be built in very large sizes.

The Commission has two approaches to the gas-cooled reactors program, exemplified by the 22.3 MWE net (or 25 MWE gross) Experimental Gas Cooled Reactor (EGCR) now under construction at Oak Ridge, Tenn., and the Philadelphia Electric Company's 40 MWE (28.5 MWE with metal-clad fuel) High Temperature Gas-Cooled Reactor (HTGR). The HTGR will employ a core utilizing a graphite-clad fuel consisting of fully enriched uranium carbide and thorium carbide dispersed in

graphite. The EGCR is a reactor utilizing stainless steel-clad, slightly enriched UO_2 fuel. In the case of both reactors, heat is removed from the fuel by the helium coolant and is transmitted to a heat exchanger where steam is formed to drive the turbine. The graphite-clad system shows greater economic potential than the metal-clad system, but presents more difficult development problems.

The present and immediately foreseeable research and development program is concerned primarily with the design and construction of the EGCR and HTGR. Their construction and operation will make possible a more comprehensive evaluation of the potential of the gas-cooled reactor system. The program also will include investigations of fuel and cladding materials suitable for high burnup at fuel surface temperatures of $1,700^\circ\text{F}$. and higher and of alternate coolants.

a. Plans for Existing and Committed Facilities

(1) Domestic Civilian Power Program

The 22.3 MWE Experimental Gas-Cooled Reactor (EGCR) at Oak Ridge is scheduled for criticality in 1962. This power-producing prototype will furnish statistically significant economic data on operation of gas-cooled reactors. It will be used as a flexible test facility which will permit the testing of advanced fuels, materials, and components suitable for use in future gas-cooled power reactors. Work on this project will be carried out in close cooperation with work of the United Kingdom on its Advanced Gas Reactor (AGR).

The Philadelphia Electric Company's High Temperature Gas-Cooled Reactor (HTGR) is being designed and is scheduled for criticality in 1963. The work supporting this project includes development of impervious graphite, uranium carbide-thorium carbide fuel dispersed in graphite, high temperature components, and auxiliary systems including methods for trapping fission products which may get into the gas coolant.

In addition, much valuable information also will be obtained from our cooperative arrangements with the United Kingdom on the DRAGON project. This is a high temperature gas-cooled reactor to be built in the United Kingdom as a cooperative project with the Organization for European Economic Cooperation.

(2) Military and Maritime Contributions

The Commission's aircraft nuclear propulsion direct cycle program is continuing to utilize the Heat Transfer Reactor Experiment No. 3 (HTRE-3) at NRTS. Present work is being concentrated on the review of HTRE-3 reactor design and its control system. Expansion of in-pile component testing is underway at the Engineering Test Reactor (ETR). High temperature information developed by HTRE-3 will provide valuable information on fuel elements for gas reactor systems.

The Gas-Cooled Reactor Experiment being conducted for the Army Nuclear Power Program will begin operating this year. This facility will provide important data on core performance, particularly on small water moderated stainless steel clad uranium dioxide cermet fuel cores and water moderated uranium dioxide or uranium dioxide-beryllium oxide pellet cores. The use of nitrogen as coolant will be investigated. Closed cycle gas turbine machinery will continue to be developed and tested.

Development work on gas-cooled reactors for other special purposes, such as maritime propulsion, will continue to provide information important to the evaluation of the potential of gas-cooled reactor technology for large central station power plants.

b. Future Plans

Evaluation of EGCR and HTGR operating experience will determine which of the two approaches has greater economic potential for central station power plants. Assuming successful operation of these plants, a 100 MWE

prototype to demonstrate advanced gas-cooled reactor features will be initiated. It is expected that design and construction of this prototype could be initiated in the middle 1960's.

By the early 1970's, after operating experience is gained from the programmed reactors, sufficient information should be available to permit utilities to decide, on economic grounds, to construct in high fuel cost areas a 300 to 500 MWE gas-cooled reactor using enriched fuel.

C. HEAVY WATER REACTOR PROGRAM

Heavy water moderated, natural uranium fueled reactors have a number of unique advantages. For example, they eliminate dependence upon diffusion plants in the fuel cycle, they have high neutron economy, and they require relatively small quantities of uranium ore per unit of power produced. On the other hand, these reactors are physically large with consequent high capital costs. Also, the reactivity lifetime of the natural uranium fuel is more limited than that of enriched uranium fuel.

Several prototypes of natural uranium heavy water-moderated reactors are planned or are under construction in the United States. Also, the Canadians are planning construction of both a 20 MWE prototype, the NPD, and a 200 MWE natural uranium heavy water-moderated plant, the CANDU. These plants are scheduled for criticality in 1961 and 1964, respectively. Negotiations are currently underway with the Canadians looking toward an expanded program for cooperation in the development of heavy water reactors. Close cooperation under this agreement will be mutually beneficial and, in addition, will serve to assist the Commission and United States industry in determining the future role of heavy water reactors in this country.

The United States research and development program will be directed toward those problems which are critical to the evaluation of heavy water moderated systems. To the fullest extent possible, it will use pertinent information

being developed in other programs and in other countries. The critical problems are those associated with reactivity limitations on fuel lifetime (including fuel management techniques for extending these limits), minimizing loss of heavy water, and techniques for fabricating components of pressure tank systems. One difficult design objective is to obtain the high coolant temperature needed for high thermal efficiency while maintaining the cool moderator necessary for long fuel-reactivity lifetime. The research and development program and cooperation with other countries will be planned so that the combined results will provide a sound basis for evaluation of this class of reactors, including designs which use coolants other than heavy water, (e.g., organic and gas).

a. Plans for Existing and Authorized Facilities

Domestic Civilian Power Program

The Heavy Water Components Test Reactor (HWCTR) is scheduled for criticality in 1961 at the Commission's Savannah River Plant. This reactor will be used to obtain operating information on a heavy water-moderated system under conditions similar to those that might be suitable for power production. It will provide irradiation tests on fuel elements being considered for heavy water-moderated systems and will provide tests of other components such as pumps, valves, and instrumentation.

Research and development on a cooperative basis in support of the 50 MWE reactor of the East Central and Florida West Coast Nuclear Groups will continue, looking toward an early evaluation, in accordance with the terms of the contract, and a determination as to whether or not the project will proceed with plant construction. If built, the reactor is scheduled for completion in 1963.

A heavy water-moderated and cooled pressure tube reactor of 17 MWE capacity is being designed and is scheduled for criticality in 1962 in accordance with a contract between the Commission and the Carolinas-Virginia Nuclear Power Associates, Inc. This reactor will

provide additional data on the performance of heavy water reactors.

The Plutonium Recycle Test Reactor (PRTR) is scheduled for criticality in 1960. The purpose of this experimental reactor facility is to investigate the economic feasibility of plutonium recycling. However, the fact that it uses heavy water as a coolant and moderator, incorporates a pressure tube design, and operates at power reactor temperatures, makes it an important source of additional information and technology.

b. Future Plans

When operating and cost data are available from the United States and Canadian heavy water reactors, there should be sufficient information to determine whether or not construction of a large heavy water reactor is economically justified in high fuel cost areas of this country. It is expected that such an evaluation can be made by 1966 or 1967.

F. AQUEOUS HOMOGENEOUS REACTOR PROGRAM

The aqueous homogeneous reactor offers many advantages for production of power since it operates with a solution fuel, incorporates continuous fission product removal, and is largely self-regulating due to its large negative temperature coefficient. It further offers the possibility of breeding when operated on a thorium-uranium 233 fuel cycle. Major technical problems are associated with the corrosive nature of the fuel, stability of the fuel solution under irradiation, the maintenance problem associated with the radioactive primary loop, and the limited operating temperatures with the attendant low steam cycle efficiencies.

It is still too early to determine whether the simplicity of the fuel cycle and potential breeding will be more than offset by technical complexities and temperature limitations. Because of the special advantages research and development will be continued on the technical problems on a long range basis.

a. Plans for Use of Existing Facilities

Domestic Civilian Power Program

Research and development work will concentrate on understanding and solving the fuel stability and corrosion problems in the core and on development of a suitable blanket material. Future operation of the Homogeneous Reactor Experiment (HRE-2) facility will be directed toward the solution of the fuel stability, remote maintenance and other basic problems.

b. Future Plans

The outcome of the research and development work will determine whether or not a third aqueous homogeneous reactor experiment should be constructed. If deemed advisable, design and construction of this experiment would be initiated in 1962-63 and would demonstrate breeding, or, as a minimum, a high conversion ratio. If this experiment (HRE-3) proves successful, a 50 MWE prototype may be initiated in the late 1960's.

G. NEW REACTOR CONCEPTS PROGRAM

Reactor technology is developing rapidly in many directions. The Commission is alert to evaluate new reactor concepts as well as new ideas for major improvements in existing reactor types. However, a decision to proceed with the development of design alternatives representing major technological advances depends upon an evaluation of the advantages expected. Such evaluation is difficult even when considerable technical data exists.

Early construction of inexpensive reactor experiments may be justified to help determine the technical feasibility of advanced designs which look promising. The Boiling Reactor Experiment (BORAX), the Organic Moderator Reactor Experiment (OMRE), and the Los Alamos Power Reactor Experiment (LAPRE) are examples of reactors built in minimum time at low cost to provide answers to specific questions regarding technical feasibility.

The following reactor concepts or reactor modifications are typical of those currently being investigated. In several cases, specific research and development is being carried out in areas critical to the evaluation:

Fused Salt. This is a fluid fuel reactor design based upon the use of a mixed salt solution of fissionable and fertile materials which is circulated from the reactor through an external heat exchanger. Potential advantages of this system are high thermal efficiency, low pressure, and simplified fuel reprocessing.

Fluidized Bed. This design is based upon maintaining a bed of fissionable and fertile material in a fluidized state under turbulent flow conditions. Organic material or water are considered as possible fluidizers and coolants. High power density and ease of charging and discharging fuel are potential advantages of this system.

Paste or Suspended Fuel. This design is similar to the fluidized bed concept except that the bed is maintained in a laminar, nonturbulent condition, and is internally cooled by a separate coolant. Many of the potential advantages of the fluidized bed are retained. In addition, because of the nonturbulence, particle attrition is reduced and reactor control may prove to be easier.

Supercritical Water Cooled. A reactor based upon this concept would operate at extremely high pressure, avoiding the phase change of water associated with boiling, yet permitting the generation of superheated steam external to the reactor. High thermal cycle efficiency is the potential advantage of this system.

Slurry. This design is based on a fluid fuel system in which the particle size of the fissionable or fertile material is so small that it forms a suspension under operating conditions. The reactor may be cooled externally or internally. The carrier fluids undergoing most active investigation are water and liquid metals. The potential advantages of this concept are similar to those cited for other fluid fuel reactors.

Advanced Epithermal. A compromise design between sodium-cooled fast reactors and

sodium-cooled thermal reactors may have advantages over either, particularly for the thorium fuel cycle. This design would include some moderation by graphite or beryllium, optimized for high conversion ratio with uranium 233 fuel consistent with economic promise. High thermal efficiency and low pressure characteristics of a sodium-cooled system would be retained.

Pebble Bed Gas Cooled. In this concept a stationary bed of balls (or pebbles) containing the fissionable, fertile, and moderator materials is cooled by a gas. Potential advantages are in the area of low fuel cycle costs, and high thermal efficiency.

Solid Moderated, Steam-Cooled Reactor. In this concept, heat from the fuel is radiated to the moderator (graphite, beryllium oxide, zirconium hydride, etc.) which in turn is cooled by water or steam. High thermal efficiency is the principal potential advantage.

Alternate Coolant Fast Reactor. This design is similar to the sodium-cooled fast reactor except that alternate coolants are being considered including mercury, lead, lithium, sulfur, and other materials. It is believed that with certain of the alternate coolants increased efficiency and reduced costs may be attainable.

a. Plans With Respect to Existing or Authorized Facilities

Domestic Civilian Power Program

The Los Alamos Molten Plutonium Reactor Experiment (LAMPRE) is under construction at the Los Alamos Scientific Laboratory (LASL). It will be operated to demonstrate the technical feasibility of a fast reactor using a fluid or molten fuel.

The high temperature gas-cooled reactor experiment (TURRET), being designed by LASL and scheduled for the initiation of construction in August 1960, would establish the feasibility of operation with a gas coolant at temperatures above 2,000° F. An attempt will be made to handle a very radioactive primary

system. This reactor might have direct application in supplying process heat to the chemical and metallurgical industries.

b. Future Plans

Engineering studies, research and development, and evaluation of new reactor concepts will continue to the point where a decision can

be reached, either to build a reactor experiment or to terminate the work. During the next few years it is probable that three to five of these concepts will have reached a point where construction of a reactor experiment will be justified. Subsequent evaluation of the results from these experiments may justify the construction of several prototypes.

IV. NUCLEAR TECHNOLOGY PROGRAM

In addition to the specific work carried on under individual power reactor projects, there is an area of more broadly based nuclear technology development. The general objectives of this program are to provide basic data on reactor systems and related problems, to carry out engineering development of a general and fundamental nature, to investigate the feasibility and potential of new methods for improving reactors, and to provide tools, such as test and research reactors and remote handling devices, for use in reactor research and development.

Developments in this area should help to lower the cost of nuclear power generation through improvements affecting many types of reactors and through reductions in the overall cost of the reactor fuel cycle.

A. FUELS AND MATERIALS

Research in this category is directed toward evaluating the potential of materials for reactor applications, determining their basic properties and developing engineering design information on nuclear fuels and reactor materials. This work will result in more efficient utilization of nuclear fuels and reactor materials in reactor cores.

In this field, the *Fuel Cycle Development Program* was established to concentrate research effort on reduction of nuclear power costs through improvements in fuel performance and reductions in fuel costs. During fiscal year 1959, 24 research and development proposals submitted by 18 industrial organizations in response to public invitation were accepted. Additional work was assigned to National Laboratories and the research effort of other contractors was increased. Research necessary to reduce the overall fuel cycle cost includes an intensive effort to increase reactor core life and

fuel burnup, increase the irradiation stability of nuclear fuel, reduce fuel fabrication costs, and attain higher temperature operation of fuel assemblies. Specific plans include:

1. Developing basic engineering information concerning alloys of fissionable elements, uranium oxide, uranium carbide, and plutonium- and thorium-bearing ceramic fuels. In particular, additional data are required on the properties of materials at the maximum temperatures contemplated for their use.
2. Determining the effect of radiation upon the properties and performance of reactor materials. Particular attention will be given to the effects of long-term irradiation.
3. Developing improved fuel fabrication methods and simplified fuel element concepts to reduce fuel element fabrication costs and thus facilitate overall reductions in fuel cycle costs.
4. Conducting research directed toward understanding the mechanisms of release or retention of fission gasses in the hope of extending the useful reactor life of nuclear fuels and achieving higher fuel temperatures.
5. Conducting research on the behavior of oxide fuel elements under irradiation at temperatures that result in central melting, or vapor phase movement of the fuel, in order to establish the feasibility of reactor operations under these conditions.
6. Conducting research on nondestructive testing techniques and on the development of improved nondestructive testing equipment.

B. FUEL REPROCESSING

This effort places principal emphasis on reducing the cost of reprocessing current reactor fuels and on developing techniques for processing advanced fuels in proportion to their poten-

tial. These objectives include the development and demonstration of methods for power reactor fuel reprocessing which will make possible the eventual entry of private industry into this area. At this time, proven technologies do not exist for many fuels. The demonstration program now planned will define these technologies more clearly while exploring promising alternatives.

The program in the closed fuel cycle concept, consisting of low decontamination processing and remote refabrication, presently emphasizes pyrometallurgical techniques. It is being carried out partly as backup to the EBR-II concept, and partly in exploration of the degree to which this radical new approach to the entire fuel cycle will find application in other power reactor systems. The increasing importance of high burnup lessens the significance of fission product poisoning; at the same time direct handling of recycled fissionable materials becomes more difficult due to gamma and beta active isotopic contamination. If economics can be favorably demonstrated, the closed cycle approach will be more compatible with these developments than the conventional direct fabrication cycle, and in addition will offer the possibility of reducing external fuel inventory charges.

C. ENVIRONMENTAL INVESTIGATIONS AND WASTE DISPOSAL

The principal objective of this program is the engineering development of practical systems for the safe handling and disposal of the wide variety of radioactive wastes evolved from nuclear energy activities. This objective requires the accumulation of quantitative information obtained from a broad program of both laboratory and field investigations ranging from an evaluation of the behavior and fate of radioactive materials that may be dispersed in specific environments (air, ground, and water) to the development of techniques and systems for concentrating and fixing large quantities of radioactive materials in solid form suitable for

ultimate, long-term disposal in specially selected locations.

Accordingly, the projects in this program include specific river, atmospheric, marine, and hydrogeologic studies on a wide geographic scale; laboratory and pilot scale studies of waste fixation schemes; and supporting laboratory investigations. The transition to prototype field and engineering projects will continue to be a significant feature of the program in the future. The results of this work are also essential for developing data related to the environmental aspects of the location, design and operation of nuclear reactors and associated facilities.

D. PHYSICS

The physics program will be directed toward the development of such fundamental physics data on reactor materials as cross-section measurements, physics experiments aimed at improved core design and better reactivity control, and other fundamental studies to improve reactor design. This work will include research on the isotopic composition of high burnup fuel and on the effect on reactivity lifetime of fissionable isotopes and fission produced poisons generated during long-term exposure.

E. REACTOR COMPONENTS AND ASSOCIATED EQUIPMENT

The reactor components program is directed toward the solution of fundamental engineering problems applicable to all reactor concepts and toward the development of components generally useful in power reactors. The program includes the development of:

1. Methods to obtain higher heat transfer rates in reactor coolants so that full advantage may be taken of the improved heat flux and temperatures available from high power density cores.

2. Improved instruments, both in-core and out-of-core, to measure reactor performance; in particular, fuel burnup, fuel element failure, coolant flow rate, temperature, pressure and steam void fraction.

3. Fuel handling equipment to permit the interchange and remote removal and replacement of reactor fuel element assemblies while the reactor is in operation.

4. Equipment for remote fabrication of fuel elements incorporating highly radioactive recycled nuclear fuels.

5. Pumps, compressors, valves, seals and similar items for use in high temperature gas reactor systems.

6. Improved pressure vessel and heat exchanger design and fabricating techniques to reduce the cost and increase the reliability of this equipment, and to determine the effects of neutron radiation on these structures.

7. Techniques to remotely inspect and test pressure equipment after long periods of service in radiation environments.

F. REACTOR SAFETY

Problems in reactor safety will intensify by virtue of the increasing number of new reactors and the growing diversity of types. The reactor safety program will continue the experimental and analytical work required to provide a sound technical basis for safe and economical reactor design. The principal categories of work will deal with reactor kinetics and transient tests, hazardous chemical reactions including fission product release, and reactor containment. A major objective of the work is to develop information which may be used not only for developing sound theoretical models for predicting reactor behavior, but which also may be useful in establishing criteria and standards for the safe design and operation of reactors.

1. Reactor Kinetics

The reactor kinetics program will continue with the operation of the SPERT (Special Power Excursion Reactor Test) series of reactors and the KEWB (Kinetic Experiments on Water Boilers) reactor.

The SPERT reactors are designed to obtain transient test data for the full range of heterogeneous water reactors including swimming

pool, boiling water, heavy water, and pressurized water reactors. An additional feature of the SPERT II reactor is the ease with which it can be modified to conduct transient testing of organic systems. Major effort under the SPERT program will be made to obtain data and mathematical models which will be useful not only in design and for hazards analysis of reactors, but also in establishing standard test procedures for providing the dynamic characteristics of new reactors before they are licensed for operation.

The KEWB program should be completed in calendar year 1961 with the test of a cylindrical core. KEWB data will have wide application not only to an understanding of homogeneous reactor kinetics, but also to safety analysis of chemical processing plants.

In an effort to more completely understand the data developed in the SPERT Program, additional analytical work will be done in the fields of kinetics analysis, transient heat transfer, and bubble dynamics.

2. Metal-Water Reactions

The effort to determine the true hazard of metal-water reactions will try to correlate laboratory tests and theory with capsule type in-pile experiments and, finally, with full scale core melt-down measurements. Fission product release studies will be made in-pile for the first time and generalized theories developed to allow accurate prediction of both fission product release and metal-water reaction in any credible accident.

3. Containment

The high cost of containment design will be attacked by investigations of alternate methods of protection, such as confinement in ordinary buildings and the use of energy sinks and vapor suppression schemes. In addition, data and theories of the response of containment structures to dynamic loading will continue to be investigated in order to eliminate any excessively conservative design criteria and their concomitant excessive costs.

V. CIVILIAN REACTOR PROGRAM COSTS

A forecast of the level of costs for research and development, including operating costs and waivers of fuel use charges, design and construction of experiments and prototypes and general engineering support of the civilian power program, have been prepared for planning purposes. The forecast omits commercial plant costs. Gross total costs for the program including prototypes, but not commercial size plants, are expected to range between \$180 million and \$200 million a year. The bulk of the expenditures probably will be made by the Government, but industry is expected to make a substantial contribution. Industry also is expected to spend additional sums on its own plants—prototypes or commercial installations. The following tabulation presents the forecast for the costs indicated:

ESTIMATED COST OF CIVILIAN POWER REACTOR PROGRAM FOR PERIOD 1961-69 AS OUTLINED IN PART IV WITH TENTATIVE ALLOCATION TO R&D AND PROTOTYPES AND PRELIMINARY DISTRIBUTION BY CONCEPTS

(In millions of dollars)

	R&D	Prototypes		Total
		No.	Amount	
Nuclear technology:				
General R&D-----	450			
Support. facilities-----	195			
Total nuclear technology-----	645			645

	R&D	Prototypes		Total
		No.	Amount	
Reactor development-- by concepts:				
Pressurized water-----	70	3	70	140
Boiling water-----	50	2	45	95
Nuclear superheat-----	50	1	30	80
Organic cooled-----	70	1	30	100
Subtotal light water and organic-----	240	7	175	415
Sodium cooled--fast-----	140	1	30	170
Sodium cooled--thermal-----	25	1	30	55
Gas cooled--enriched-----	100	1	30	130
Heavy water-----	55			55
Aqueous homogeneous--R&D-----	65	1	20	100
1. Reactor experiment-----	15			
New concepts--R&D-----	45	3	80	140
5 experimental reactors-----	15			
Subtotal--other concepts-----	460	7	190	650
Total--reactor development by concepts---	700	14	365	1,065
Grand total-----	1,345	14	365	*1,710

*Minimum cost to meet objectives of program. Does not attempt to forecast distribution of this cost between Government and industry.

Does not include cost of projects currently authorized or cost of research and development, additional prototypes or full scale plants which may be initiated by private industry.

Distribution by concepts is a planning estimated and actual cost may be more or less for any particular concept.

Annual cost may be higher or lower than the average of \$200 million per year.

APPENDIX A

1. TID-8518(1) Status Report on Fast Reactors as of 1959.
2. TID-8518(2) Status Report on Pressurized Water Reactors as of 1959.
3. TID-8518(3) Status Report on Aqueous Homogeneous Reactors as of 1959.
4. TID-8518(4) Status Report on Heavy Water Moderated Reactors as of 1959.
5. TID-8518(5) Status Report on Boiling Water Reactors as of 1959.
6. TID-8518(6) Status Report on Sodium Graphite Reactors as of 1959.
7. TID-8518(7) Status Report on Organic-Cooled Reactors as of 1959.
8. TID-8518(8) Status Report on Gas-Cooled Reactors as of 1959.
9. SL-1674 Power Cost Normalization Studies.