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CIVILIAN NUCLEAR POWER

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THE 1967 SUPPLEMENT TO THE 1962 REPORT TO THE PRESIDENT

February 1967

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

U.S. ATOMIC ENERGY COMMISSION

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Introduction

In November 1962, the Atomic Energy Commission submitted to the President of the United States a report on the state of the civilian nuclear power program.¹ That review and assessment of the development program was prepared in response to a request by the President, in March 1962, that the Atomic Energy Commission undertake "a new and hard look at the role of nuclear power in our economy."

The review concentrated on basic policies. It included examinations of the need for nuclear power, the direction in which the central station nuclear power program should be headed, the rate at which the program should proceed and the nature and amount of Government participation necessary.

Emphasis was placed on the role of the Commission in exercising positive and vigorous leadership, both to achieve the technical goals and to assure growing participation by the equipment manufacturing and utility industries as nuclear power becomes economic in increasing areas of this country and the world at large. As stated in the 1962 Report:

"The overall objective of the Commission's nuclear power program should be to foster and support the growing use of nuclear energy and, importantly, to guide the program in such directions as to make possible the exploitation of the vast energy resources latent in the fertile materials, uranium-238 and thorium."

¹ Civilian Nuclear Power—A Report to the President—1962, U.S. Atomic Energy Commission, Superintendent of Documents, U.S. Government Printing Office, Washington, D.C.

More specific objectives may be summarized as follows:

1. The demonstration of economic nuclear power by assuring the construction of plants incorporating the presently most competitive reactor types;
2. The early establishment of a self-sufficient and growing nuclear power industry that will assume an increasing share of the development costs;
3. The development of improved converter and, later, breeder reactors to convert the fertile isotopes to fissionable ones, thus making available the full potential of the nuclear fuels.
4. The maintenance of U.S. technological leadership in the world by means of a vigorous domestic nuclear power program and appropriate cooperation with, and assistance to, our friends abroad."

At the time the 1962 Report was prepared it was felt that light water¹ reactors were near the threshold of economic competitiveness with conventional power, at least in large installations in high fossil fuel cost areas of the country, and had prospects for later expansion on a more widespread geographic basis. In the context of that assessment, prospects for industry development were examined in relation to projections of electrical power need, to improving nuclear power economics and to the developing state of nuclear technology.

The interactions of these factors clearly suggested three phases of application for nuclear power. Light water reactors were in an advanced development stage, but such reactors, as developed for central station use, have limitations on their efficient use of resources. The need for growing amounts of power over the long term indicated a strong requirement for the development of breeder reactors, which produce more fissile material than they consume and thus can make effective use of the vast resources of fertile uranium-238 or thorium-232.

As an intermediate stage between these two phases, it was projected that there would be a period where converter reactors of an advanced design would be useful. Research and development efforts on such reactors showed promise of early improvement in the unit cost of power, as well as markedly higher conversion ratios. Some concepts could have important technical bearing on breeder systems, or offered potential for other applications such as process heat. The 1962 report accordingly recommended a continuation of work on technology and an augmentation of programs for development and demonstration of concepts in the areas of both breeders and converters of advanced design.

The 1962 Report also considered related problems of a general technical nature and of a legal and administrative nature, and suggested courses of action which would be consistent with the developing technology.

In the four years since the 1962 Report was issued, remarkable advances have taken place in the promise of nuclear power and in its acceptance by the U.S. utility industry as a new source of electrical energy. Continued operating experience with initial demonstration and experimental nuclear power plants and commitments to larger size demonstration plants have provided the necessary impetus for commitments by industry to large scale utility units. The Commis-

¹ Reference may be made to "Nuclear Terms—A Brief Glossary," U.S. Atomic Energy Commission/Division of Technical Information, revised October 1966, for definition of terms used in nuclear science and its applications.

sion's power demonstration program, which had been modified in 1962 to encourage support of power reactors above 400 MWe, was expanded in 1963 and at present includes three new light water projects, the Connecticut Yankee, Malibu and San Onofre plants. In 1963 commitments for the Oyster Creek and Niagara Mohawk plants provided a clear indication that economic power was considered by the utility industry to be near. Numerous additional utility decisions have been made in 1965 and 1966 for installation of nuclear power.

As of January 1, 1967, there were 13 central station nuclear power plants in the U.S. and 36 committed or under construction. The industry, rather than being overcapitalized and under-used, as mentioned in the transmittal letter of the earlier study, appears to be approaching a state where presently available resources will be fully committed. These developments have come about through engineering advances, through experience with the earlier plants, through the manufacturing advantages of repeated orders, and, very importantly, through an even larger increase in the unit size of power plants than was anticipated in the earlier report.

The development work for power reactors subsequent to the 1962 Report has been programmed generally as proposed there. Over the years, the number of potential advanced converter candidates has thus far been narrowed to three general programs: the high temperature gas cooled reactor; the heavy water moderated reactor with emphasis on the organic cooled version; and the seed-blanket reactor, a system which is expected to be able to achieve breeding in the light water medium. Emphasis is being placed on high gain breeders as recommended in the 1962 Report. In particular, the program for development of the liquid metal-cooled fast breeder has been substantially augmented. Work is also being carried out on the molten salt thermal breeder concept, which uses the thorium fuel cycle.

During the intervening years, there has been a growing recognition of a matter crucial to the successful development of nuclear power plants, yet not specifically emphasized in the 1962 Report—the achievement of demonstrated reliability through strong engineering and through growing experience. Delays, increased costs, and in some cases cancellation of experimental and demonstration reactor projects have been at least partly due to inadequate depth in reactor design and engineering efforts. Such inadequacies can result in an inability to demonstrate the worth of the concept under study. Careful and high standards of design, construction, inspection, and operation of nuclear power plants are necessary to provide the reliability and safety needed for utility operation.

In a different engineering sense, it has become clear that the magnitude of the cumulative effort invested in a relatively well developed concept can seriously affect the ability of competing concepts to catch up with it, regardless of moderate variations in intrinsic merit. The most important case in point derives from the great resources that have gone into the light water reactors—starting with the naval propulsion program and the early civilian power experiments, going on through intensive civilian development effort, through demonstration projects, and culminating in the large engineering efforts directed to the design of numerous central station plants. The high state of development and production of the light water reactors clearly will make

the development of competing systems difficult. As fossil fuel was a moving target for the light water reactors, so now light water reactors, as well as fossil fuel, will be a moving target for the advanced reactors. Rising uranium prices will eventually give an advantage to reactors making better use of resources, but for utility acceptance they must compete on their total economics.

Although the program has proceeded essentially as projected in the 1962 Report, with marked success in some areas and with promise in others, it is prudent to look back after the passage of a number of years and to assess the course on which the Commission is proceeding in the light of developments and changes in circumstances. Suggestions have been received for a new examination of the program. In particular the Joint Committee on Atomic Energy in its report of May 1966 on the Fiscal Year 1967 Authorization Legislation, suggested :

"The civilian nuclear power program is presently proceeding in accordance with guidelines expressed in the Atomic Energy Commission's November 1962 Report to the President. This report has provided the program with sound objectives for attainment of a virtually limitless supply of energy for this country. However, the committee believes that developments, particularly those in the past year, warrant a general updating of the program presented in this report. The committee urges this review because of the sharply increased rate of addition of nuclear generating capacity, changes in estimates of future growth of nuclear power, the more recent technical developments which have taken place in certain of the advanced reactor fields, and the latest information which has been developed concerning our uranium resources."

The present report has been prepared as an initial response to this suggestion and as a result of similar views within the Executive Department. It is intended to represent a view of the program and prospects as they appear at the start of 1967. It takes note in some detail of the changes that have taken place since 1962 in the technical, economic and resources picture and is intended to provide an updated background for further extensive studies.

The further specific studies, already under way, are intended to provide a new thorough analysis and assessment of civilian power program prospects and of the optimum course of action for the future. In setting up the studies, groups have been established to examine such topics as specific reactor concepts, systems analysis, fuel recycle, and utility outlook. The studies will consider in depth the technical prospects for the reactor concepts under consideration, will relate these to resource projections and to economic considerations, and will identify the decisions that must be made in the light of changing circumstances. It is expected that the individual studies will be completed at various times during 1967 and that they will provide the basis for a reduction in the number of concepts currently being pursued.

The present report is organized in three main sections: an updating of the factors affecting energy resources, requirements, and economics that lead to continuing understanding of the potential for growth in the nuclear power economy; a review of the development program as of the start of 1967; and, as in the earlier report, an updated section on legal and administrative matters.

Summary

The 1967 Supplement to the 1962 Report on the Civilian Nuclear Power Program sets forth the changes that have taken place in the intervening four years and considers the present AEC program in relation to the recommendations of the earlier report.

The substantial acceptance by the utility industry of light water reactors for electrical power generation provides the prospect of a large and fully committed nuclear industry and also has an impact on the basis for development of improved reactor concepts.

The earlier review suggested three phases of application for nuclear power, with related development effort. It was expected in 1962 that light water reactors would soon become economical in high power cost areas and in accordance with industry response to that prospect, the Commission's research and development programs on light water reactors have been limited in scope and size. Several advanced converters are being developed, in accordance with the 1962 Report recommendations, to provide better use of nuclear resources pending full development of breeders. Intensive development of the high gain breeder over the long term has been undertaken as recommended by the 1962 Report.

The objectives expressed in the 1962 Report are still regarded as valid. The Commission intends to continue to exercise positive and vigorous leadership in achieving the technical goals and in assuring growing participation by the nuclear industry as nuclear power becomes economic.

The Commission is conducting a series of comprehensive reviews and assessments of reactor concepts. They will lead to identification of decisions on future program balance and direction and to a reduction in the number of concepts under development. The present supplement to the 1962 Report is intended to provide an updated description of circumstances and programs as of January 1967 to serve as background for the more detailed studies.

Nuclear Power Growth

During the four years since the 1962 Report, the promise shown for nuclear power in the U.S. has developed beyond expectations. This development has warranted a review of the energy resources and requirements, nuclear power projections, and the associated economics.

Energy Resources and Requirements

No significant changes have been made in fossil fuel and nuclear fuel resource estimates since publication of the 1962 Report. Delivered prices of fossil fuels to steam-electric plants have decreased from an

average of 26.4 cents per million British Thermal Units (BTU) in 1962 to 25.2 cents in 1965. Local situations will, in the future, dictate delivered prices of fossil fuels, with location of plants, transportation economics, and use of strip mining as the dominant determining factors.

Known and estimated domestic resources of uranium are adequate to meet predicted light water reactor requirements for about the next 25 years pending the development of advanced converter and breeder reactors. When available commercially, the breeder reactors will provide a virtually unlimited source of energy with uranium costs constituting a very small fraction of the energy cost.

Total energy consumption is expected to increase by 50 percent between 1965 and 1980 and by 150 percent between 1965 and 2000. The current estimates are essentially unchanged from the 1962 Report estimates. The proportion of energy consumed in the form of electricity is currently about 20 percent; it is expected to increase to 30 percent in 1980 and to over 50 percent by the year 2000. Expectation of such large increases is predicated on the use of low cost electricity as a substitute for many of the present industrial and transportation uses of fuel and on large increases in the per capita electricity consumption for residential and commercial use.

Nuclear Power Projections and Economics

Whereas less than 1 percent of the electrical generating capacity in 1965 was nuclear, it is estimated that 23 to 30 percent will be nuclear in 1980 and about 50 percent in 2000. The extent to which nuclear power will capture the utility market in the post-1980 period appears to depend largely on the technology and economics of advanced converters and breeder reactors, on developments in mining and transportation of fossil fuel, and on the extent and rate of discovery of low-cost uranium resources.

The decreasing cost of producing electricity has been due primarily to improved fossil fueled power plant thermal efficiency and to lower capital costs per kilowatt of installed generating capacity for fossil and nuclear fueled plants. The decreasing capital costs are attributable in part to the construction of larger sized generating units. Acceptance of nuclear power by the public utilities has mainly been due to improved economics. In 1962 the estimated cost of producing electricity from a 500 MWe base load nuclear plant was 6.2 mills/KWh, whereas the current estimate for large size investor financed base load nuclear plants is 3.5 to 4.2 mills/KWh, and for publicly financed plants 2.6 to 3.0 mills/KWh. These values correspond to a range of 17 to 25 cents per million BTU for delivered coal.

The current substantial backlog of nuclear plants on order, resulting in a stretchout of plant completion times, may have an effect on plant pricing. Warranted fuel costs, have been decreasing significantly, however, and have led to an over-all reduction in the anticipated cost of nuclear energy.

Development Program

The 1962 Report recommended emphasis on the development of advanced converters and breeder reactors. The need for improved raw material utilization to minimize increases in costs for uranium has become more important because of the success of the light water reactors. However, in view of the utility acceptance of the light water reactor, the advanced reactors, which can improve the raw material utilization, face a severe test in competing economically with the light water reactor.

In exercising the responsibility of developing the advanced converters and breeders, the Commission intends, in cooperation with industry, to emphasize the improvement of nuclear power plant engineering standards. This will help to ensure meaningful results from research and development programs and will promote nuclear power plant safety, economics, and the reliability and availability necessary for utility practice.

Light Water Reactors

The design, construction, and operation of U.S. demonstration plants, joint U.S.-Euratom plants, and other utility operated plants led to forerunners, Oyster Creek and Nine Mile Point, of the present large scale light water reactor commitments.

Extrapolation of the operating experience of the larger cooperative demonstration plants (San Onofre, Connecticut Yankee) will contribute significantly to design and operation of the new large utility plants. Current utility commitments will lead to experience in the operation of large size units, to statistical experience with large amounts of fuel at contemplated burnups and to experience with further improvements in safety. Technical progress has been encouraging and further Government assistance to the development of light water converter reactors under the demonstration program is not planned.

Current support will be continued for the U.S.-Euratom light water research and development and for plutonium recycle for thermal reactors to about 1970. Work will continue under current cooperative demonstration plant arrangements.

Advanced Converters and Light Water Breeder

The Commission effort to develop advanced converters now has been narrowed to three approaches: the heavy water moderated reactor with emphasis on the organic-cooled version, the high temperature gas-cooled concept and the seed-blanket light water breeder concept. Each of these concepts has promise of higher conversion ratios than current light water reactors. Studies underway are expected to lead to a further narrowing of focus.

Heavy Water Moderated

The heavy water moderated systems using either the uranium or thorium cycle, particularly the uranium cycle, have a potential for lower cost power and a lower specific inventory than the current light water reactors. The research and development program has been directed toward providing a technological and engineering base and identifying specific technical limitations, particularly as these relate to the organic coolant concept.

High Temperature Gas Cooled

The initial development efforts on demonstration components and systems for large High Temperature Gas-cooled Reactor (HTGR) power plants will be provided by the Public Service of Colorado (PSC) cooperative demonstration project located at Fort St. Vrain, near Denver, Colorado. The developmental support to be afforded the PSC project will be dependent upon a technical and economic assessment to be made following full power operation of the Peach Bottom reactor.

Light Water Breeder

The seed-blanket Light Water Breeder Reactor (LWBR) fueled with thorium-uranium-233 has promise of a conversion ratio high enough to make available about 50 percent of the potential energy in the thorium fuel reserves. The LWBR would not require a significant departure from pressurized light water reactor technology. Major long-term problems may center on the economics of core fabrication and fuel cycle costs. The Commission plans to determine during Fiscal Year 1968 whether a breeding demonstration core should be built in the existing Shippingport PWR.

High Gain Breeders

When developed commercially, high gain breeders will increase fuel use to over 50 percent of the uranium or thorium reserves. Their application will be relatively insensitive to ore prices, and will thus make large fractions of high cost ores economically usable. They will also produce excess fissile material in a timely manner to fuel new reactors.

Fast Breeder

Interest in fast breeders is focused on the Liquid Metal-cooled Fast Breeder Reactor (LMFBR), which uses sodium as the coolant. Effort on the steam cooled and gas cooled alternates has been maintained at a low priority. The sodium cooled fast breeder choice is based on potential economics, industrial and world wide interest, technological experience, and its capability to conserve uranium resources.

Liquid Metal Cooled Fast Breeder

The past four years have been productive of information which enhances the promise of the LMFBR. The U.S. program has been

highlighted by the operation of the Experimental Breeder Reactor II (EBR-II), which now is being used as a test reactor to irradiate fuels and materials for the LMFBR program.

The fuels and materials program is now concentrated on developing plutonium bearing fuels for the Fast Flux Test Facility (FFTF) and the first demonstration plants. The development of fuels and cladding for advanced cores in these and later plants will use the capabilities of the FFTF. The construction of the FFTF, about 400 MWt, and its subsequent operation are necessary to provide adequate and flexible testing space for the many LMFBR fuels and materials which will be developed for the demonstration and commercial fast breeders. The successful achievement of high fuel burnup required for economic operation of the fast breeders will in a large measure be dependent on the FFTF. Full statistical confirmation of this development will be achieved in the demonstration plants. It is expected that test programs in the Southwest Experimental Fast Oxide Reactor (SEFOR), in the FFTF and in the first demonstration plants will provide confirmation of predicted characteristics of the various core configurations selected, and of core physics and associated safety aspects, plant components and systems, plant instrumentation, and the associated sodium technology.

Though the LMFBR program is placing immediate emphasis on the design and construction of the FFTF, plans are being developed for the introduction of a number of sodium cooled fast breeder demonstration plants to be built during the 1970s. Utility acceptance of the demonstration plants probably will be motivated by the incentive of cheaper electricity and will be contingent on developed technology, on the existence of a competitive and self-sustaining industry, and on a minimum investment of risk capital. It does not appear that a prudent commitment to build the first U.S. demonstration plant can be made prior to 1969, nor can the number of demonstration plants be predetermined.

Alternate Coolant Fast Breeders

Because sodium has disadvantages associated with its prolonged radioactivity after reactor shutdown, its chemical reaction with air and water, and its non-transparency, consideration is being given to steam and gas as coolants alternate to sodium. Though it is unlikely that comparisons will show significant advantages in the alternate coolant concepts to change the high priority assigned to the sodium-cooled fast breeder reactor, there is need to establish definitely the emphasis to be placed on alternate coolant fast breeders, and efforts to do so are underway. Advanced fast reactor systems with coolants other than sodium are attractive only if they offer significant advantages with respect to economics and efficient use of resources. Pending results of assessments currently in progress these programs will remain at about present levels.

Molten Salt Breeder

Preliminary studies show that the Molten Salt Breeder Reactor (MSBR) shows promise of efficiently using thorium resources. The

on-site reprocessing concept, by continuous removal of fission products and protactinium, contributes to a good neutron economy and to a low total inventory of fuel. Uncertainties include problems with materials, components, systems, plant maintenance, and effluent and waste management. Sustained operation of the Molten Salt Reactor Experiment, and out-of-pile analysis and experimentation are being performed as prerequisites for demonstrating the potential of the MSBR.

Desalting Program

Based on a favorable assessment of large scale desalting plants, the President in 1964 instructed the Department of the Interior, which is responsible for desalting technology and processes, to initiate, in cooperation with the Commission, an aggressive plan to develop large scale desalting of sea water. Planning studies are assessing the magnitude and details of the effort required to develop the technology needed for very large scale plant construction and operation, and for the coupling of nuclear power and desalting plants.

The Commission will continue to emphasize the development of reactor technology required for economic large-scale desalting. Based upon experience gained from study efforts and the Metropolitan Water District desalting project, the Commission will continue present development programs and will participate, as authorized, in other cooperative demonstration plant projects, probably involving larger and more advanced reactors and improved desalting systems.

Supporting Technical Programs

The Commission's general reactor technology programs, conducted in industrial, university and Commission laboratories, comprise those applied research and development activities needed to generate the technological base underlying the initiation and accomplishment of specific reactor programs, to resolve critical problems and to continually assess programs and projects.

The primary objective of the reactor safety program as stated in the 1962 Report is "to maximize the inherent safety reactor installations." The achievement of this objective requires the continued development of safety related technology, criteria, standards and codes and associated safety research and development facilities, and an integrated procedure by which the programmatic and regulatory interest can be coordinated. Engineered safety features specifically designed to prevent accidents or to minimize their consequences are being developed on a priority basis. Resolution of siting problems requires emphasis on providing reliable experience with advanced types of containment structures and other engineered safety features, experience in coping with all operating conditions, and provisions for designs with a high margin of safety.

Safe and economic management of radioactive waste, essential for an expanding nuclear power industry, has generally been successful at costs constituting a minor fraction of the fuel cycle. Radioactive concentrations in existing nuclear power plant effluents have ranged from one to three per cent of prescribed limits. The capacity and availability of suitable land burial facilities for solid low radioactivity

level wastes are more than sufficient for even the most optimistic growth projections. The long effective life of highly radioactive wastes and the comparatively short life of storage tanks require that the Commission pursue a program aimed at developing and demonstrating, on an engineering scale, systems for the conversion of high level liquid wastes to stable solids and their subsequent storage in dry geologic formations.

Waste management in the future will be more oriented to development of systems and equipment for advanced reactors and their associated chemical processing plants.

Discontinued Programs and Projects

Evaluations since the 1962 Report have shown that some of the concepts described in the report were only marginally superior to others whose success was nearer at hand and their development has been terminated. Other concepts have been discontinued because of especially difficult research or developmental engineering problems and the accompanying increased costs, delays, and difficulties associated with introducing the concept into the utility environment.

Legal and Administrative Matters

Policies Relating to Nuclear Materials

In 1964 the Private Ownership Act was passed to permit private ownership of special nuclear materials and to provide for toll enrichment. This act constituted an important element in the surge of orders for nuclear power plants in 1965 and 1966; it has significantly clarified the near-term outlook for the uranium mining and milling industry, and is expected to encourage use of nuclear power abroad. The Commission is also now studying the feasibility and desirability of transferring gaseous diffusion plants to private operation.

Price-Anderson Indemnity

The Price-Anderson provisions of the Atomic Energy Act of 1954 were amended in 1965 extending the provisions until August 1, 1977, and reducing the Government indemnity by the amount that the private insurance required exceeds \$60 million. The Price-Anderson provisions were further amended in 1966 to provide for emergency assistance payments to claimants, and to authorize the Commission to require the waiver of certain defenses in its indemnity agreements and financial protection policies.

Finding of Practical Value

The Commission determined, in December 1965, that although light water reactor systems show economic promise as evidenced by utility orders, the degree of actual experience needed to confirm the status of these concepts has not yet been obtained; thus, a statutory finding of practical value as defined by the Atomic Energy Act of 1954 has not

been made. This determination was reaffirmed in December 1966. The Commission has also been studying the 1954 Act to determine if there is any continued need for the requirement of a formal finding of "practical value" and is giving consideration to recommending changes on this subject.

Regulatory

Steps have been taken, since the 1962 Report, to improve and expedite licensing procedures. These steps include improvements in the operations of the three-man atomic safety and licensing boards resulting from experience gained since 1962. The issuance of interim general design criteria for nuclear power plants and the development of specific design performance criteria for nuclear power plants will provide guidance and clarification to industry in the licensing process. Improved technical specifications being developed will focus on those reactor features vital to safety. Increasing numbers of preliminary informal reviews are also reducing subsequent licensing time.

Nuclear Power Growth

The 1962 Report examined the need for nuclear power in our civilization taking into account nuclear and fossil fuel resources and prospective energy needs. It was concluded that there is a clear need for supplementary sources of energy and that:

"The development and exploitation of nuclear-electric power is clearly in the near- and long-term national interest and should be vigorously pursued."

During the four years since the 1962 Report, the promise shown then of a near-term place for nuclear power has developed beyond expectations. The trend in size of installed plants and industry confidence in its ability to construct plants expected to be economically competitive have led to a remarkable growth in orders for nuclear plants in 1965 and throughout 1966. The changing near-term circumstances provide an impetus for an updated review of the resources and demand for nuclear power as they interact with the economic factors.

Energy Resources

Fossil Fuels

No significant changes have been made in fossil fuel resource estimates since publication of the 1962 Report. The fossil fuel resource situation has been considered in two major studies¹ since 1962 which throw additional light on the problems but do not call for any major revision of the resource estimates in the 1962 Report. Another Government study, "Energy R&D and National Progress,"² considers the resource situation but it does not reconcile differences between various estimates.

The 1962 Report recognized the probability of decreases in the delivered price of fossil fuels resulting from reductions in transportation costs and from the possibilities inherent in the trend to very large central station power plants which can in many instances be placed close to coal supplies. Delivered prices of fossil fuels for steam-electric plants in the U.S. decreased from an average of 26.4 cents per million British Thermal Units (BTU) in 1962 to 25.2 cents in 1965.³ Price decreases have taken place in all three fuel types—coal, oil and natural gas. Fossil fuel costs can be minimized by increased strip mining, location of the power plant at the mine and by the use

¹ Geological Survey Circular 522, "Resources of Oil, Gas, and Natural Gas Liquids in the United States and the World" by T. A. Hendricks, (1965). "Resources in America's Future" by Landsberg, Fischman, and Fisher. Johns Hopkins Press for Resources for the Future, (1963).

² Prepared for the Interdepartmental Energy Study by the Energy Study Group, Published September 1966.

³ Steam Electric Plant Factors/1965, Sixteenth Edition, October 1966, National Coal Association.

of unit trains. Fossil fuel prices may be increased by restrictions on sulfur content imposed as an air pollution control measure. Local situations will differ significantly from the average. In some areas, price increases have recently taken place.

Nuclear Fuels

DOMESTIC RESOURCES

With reactors of current technology, the known and estimated domestic resources of uranium at prices less than \$10 per pound of uranium oxide (U_3O_8) are adequate to meet the requirements of the projected growth of nuclear electric plant capacity in the U.S. for about the next 25 years. Before the end of this period, new low cost domestic resources, low cost foreign uranium, or uranium priced at \$10 to \$15 per pound of uranium oxide would be used in order to maintain production rates to meet continued requirements.

The extent to which uranium prices may rise above the \$10 per pound level and the timing of the potential rise are now difficult to predict since they will depend on the success of exploration, on the actual growth of nuclear power, and on the success of advanced reactors.

The degree of success that is attained with the advanced reactors under development has an important bearing on use of the resources. The advanced reactors should be able to make better use of low cost uranium, and they will be able to use more costly uranium, if necessary, while still producing low cost energy. The power economy should thus eventually approach a condition where the nuclear fuel resources provide a virtually unlimited source of energy. The breeder reactors are especially important in this regard since they will eventually be capable of providing most or all of the fissile material required to sustain the nuclear power system, at which time the cost of uranium becomes a very small fraction of the energy cost.

As a result of the decisions in 1964 and 1965 to reduce production of nuclear weapons material, it is now expected that by the end of 1970 the Government will have accumulated a substantial uranium inventory in excess of projected AEC needs. On the other hand, because of the recent spectacular growth in civilian nuclear power, which is already providing a substantial private uranium market, the AEC will probably be able to begin the sale of its surplus stocks during the 1970s without adversely affecting the domestic mining and milling industry. Commercial orders for several hundred tons of uranium were placed during 1965 and early 1966 at prices ranging from \$4.00 to \$5.00 per pound of U_3O_8 . Prices of \$6.00 to \$7.00 per pound have been stipulated in recent contracts. Under the expanding market indicated by current projections of nuclear power growth, the price of uranium is expected to increase gradually.

The Commission attaches great importance to renewed uranium exploration activity. It is important that the tempo be increased to a level which will maintain reserves in balance with the indicated growth in requirements. Private exploration can be assisted by increased effort in support activities of the Government. For example, topographic and geologic mapping of the type carried out by the U.S. Geological Survey, if completed in favorable areas on a timely basis, will provide

a firm base for private exploration. This supporting activity, plus research on exploration methods sponsored by the AEC at universities and private institutions, can provide the uranium industry with improved exploration guides and tools and can help to increase the low-cost uranium resources available for nuclear power.

There has been little prospecting activity specifically for thorium because of the low demand, but estimated resources are large. The number of reactors based on the thorium fuel cycle will be limited for the near-term period, and only as the advanced converter and thermal breeder technology develops will estimates have clear meaning. A thorium-based reactor fuel cycle also of course requires natural uranium to furnish the uranium-235 needed to fuel the reactors initially.

FOREIGN RESOURCES

It is desirable to examine the world supply and demand situation since uranium, easily transportable at a very small cost per unit of energy, is rapidly becoming an international article of commerce in established world markets.

Table I summarizes AEC estimated availability of uranium resources, for the United States and the rest of the Free world.

TABLE 1.—NATURAL URANIUM RESOURCES¹

(In Thousands of Tons U₃O₈)

	U.S.	Free World Ex- cluding U.S.	Total Free World
Less than \$10/lb U ₃ O ₈ :			
Reasonably assured ²	200	485	685
Estimated additional ³	325	355	680
Total	525	840	1,365
Less than \$15/lb U ₃ O ₈ : ⁴			
Reasonably assured	350	1,050	1,400
Estimated additional	525	655	1,180
Total	875	1,705	2,580

¹ AEC 1966 Projections.

² Demonstrated reserves.

³ Based on geologic and exploration data.

⁴ Includes less than \$10/lb U₃O₈.

Through 1980, U.S. uranium requirements for civilian power are estimated at about 170,000 tons U₃O₈, based on an estimated U.S. nuclear capacity of 95,000 MWe in 1980.^a The requirements for the Free World, excluding the U.S. are about 240,000 tons (about 135,000 MWe capacity).

Table 2 compares, on a percentage basis, the requirements through 1980 with the availability data in Table 1. The U.S. requirements listed assume U.S. requirements are met from U.S. supplies. A similar assumption is made for the requirements of the Free World excluding U.S. and for the combined total.

^a Uranium requirements are defined as those necessary to sustain the capacity through the stated date and not necessarily over the lifetime of the plant.

TABLE 2.—CUMULATIVE NATURAL URANIUM REQUIREMENTS
THROUGH 1980

	U.S.	Free World Excluding U.S.	Free World Including U.S.
Nuclear capacity in 1980 (1000 MWe) -	¹ 95	135	230
Requirements (1000 tons of U ₃ O ₈)----	170	240	410
	Requirements as Percent of Indicated Resource Category		
Resources:			
Less than \$10/lb:			
Reasonably assured-----	85	50	60
Reasonably assured, plus estimated additional-----	32	29	30
Less than \$15/lb: ²			
Reasonably assured-----	49	23	29
Reasonably assured, plus estimated additional-----	19	14	16

¹ AEC 1966 mean estimate.

² Including less than \$10/lb.

Requirements as a percent of the "reasonably assured" category of resources are higher in the U.S. than on a Free World basis. Up to both the \$10 and \$15 per pound levels, requirements as a percent of reasonably assured resources in the U.S. are roughly twice as large as for the Free World excluding the U.S. Based on the "reasonably assured plus estimated additional" categories of resources, the supply to demand situation is generally similar for the U.S. and for the Free World excluding the U.S.

Most of the known less than \$10 per pound resources outside the U.S. are divided nearly equally between Canada and South Africa, both of which are expected to remain exporters of uranium. South African production capacity, because it is tied to gold production, has limited potential for expansion; it may well be fully committed by early long-term contracts. The largest single source of uranium at \$10 to \$15 per pound is in Sweden. On the basis of present information, the shales of Sweden contain an estimated total of 400,000 tons of U₃O₈ that could be recovered in this price range.

Many areas of the world have geological environments similar to those in which uranium and thorium occur in Canada and the United States, and some should have undiscovered low-cost resources of comparable magnitude. Resources of low-cost thorium and of uranium in the price ranges above \$15 per pound are widely distributed throughout the world and should be more than adequate to supply the world's requirements for advanced reactor types for the foreseeable future.

Because of greater existing production capacity, U.S. mining and milling producers may supply a portion of foreign requirements in the near term but in the longer term the U.S. could well be a net importer.

Total Energy Requirements

Since the Commission's analysis of energy growth for the 1962 Report, several changes have taken place which have caused revisions in the forecast of future total energy requirements. Specifically, the pattern of population growth is expected to be different and lower in the next two decades and the growth of per capita energy consumption is estimated to be slightly lower through the year 2000 than estimated in 1962. This is reflected in the over-all estimated energy growth shown in Table 3, which presents the current AEC estimates and the 1962 estimates.

TABLE 3.—U.S. ENERGY CONSUMPTION ¹

(In 10¹⁵ BTU per year)

Year	1962 Report	Current estimates		
		Low	Median	High
1965.....	54	-----	54 (actual)	-----
1980.....	82	76	80	84
2000.....	135	120	130	140
2020.....	207	190	210	230

¹ AEC 1966 projections based on Bureau of Census population figures through 2015 and AEC extrapolation thereafter and on AEC projections of per capita consumption. The Bureau of Census population series B and C were used for the low and high population projections.

Electrical Energy Requirements

Estimates of the proportion of energy which the nation actually will use in the form of electricity are subject to progressive uncertainty as they are projected substantially into the future. Currently, electricity comprises about 20 percent of the U.S. total energy consumption and the percentage is increasing. There are substantial opportunities for growth since, technically, electricity can substitute for many of the present direct uses of fuel. The increasing standard of living, developments in transportation, the need to reduce pollution, and the potential for use of low-cost electricity in industry are considerations which will determine the extent to which the use of electricity will grow.

The Federal Power Commission (FPC) supplied the basic data for the electricity generation figures used in the 1962 Report. The FPC has provided new preliminary estimates, which are shown with previous estimates in Table 4. The FPC is presently engaged in updating its National Power Survey and has indicated that the preliminary estimates may be revised upward.

TABLE 4.—ANNUAL U.S. ELECTRIC UTILITY GENERATION

(Billions of Kilowatt-hours (KWh))

	1960	1965	1980	2000
Actual ¹	753	1, 052	-----	-----
Projected:				
Sporn (1959)			2, 800	6, 000
EEI (1959) ²			2, 800	6-10, 000
AEC Report (1962) ¹		1, 108	2, 900	9, 000
RFF (1963) ³			2, 100	4, 500
AEC-Geneva (1964)				8, 000
FPC (1966)			2, 700	7, 100

¹ FPC data.² Edison Electric Institute.³ "Resources in America's Future," Landsberg, Fischman, and Fisher, Johns Hopkins Press, 1963.

For the purposes of further discussion of the possible market for nuclear power, low, median, and high estimates for electricity generation consistent with Table 4 are used in this report (Table 5).

TABLE 5.—PROJECTION OF ELECTRICITY GENERATION IN THE U.S.¹

(Billions of KWh)

	Low	Median	High
1980	2, 400	2, 700	3, 000
2000	6, 000	8, 000	10, 000

¹ AEC 1966 Projections.

Electrical energy consumption in 1965 was slightly below values projected in the 1962 Report. Actual generation by utilities in 1965 is reported by FPC at 1,052 billion KWh. This compares with the projected value for 1965 of 1,108 billion KWh in the 1962 Report.

In selecting a figure of 2,700 billion KWh for the year 1980, this study has relied on the judgments of the FPC and of electric utilities, as expressed in the National Power Survey. This figure is essentially the same as independent estimates of the Edison Electric Institute (EEI).

The use of the 6,000-10,000 billion KWh range in this study for the year 2000, with a most likely value of 8,000 billion KWh as published in the 1964 AEC-Geneva paper, is based on the belief that: (1) the cost of electricity for applications that other fuels can serve will continue to decline relative to that of direct use of the other fuels; (2) there will be a widespread adoption of electric space heating and air conditioning both in residences and in commercial and industrial establishments, even in cases where the economics may not be favorable; (3) there is a trend toward better lighting in cities; (4) there are trends toward further electrification in industry; and (5) by the year 2000 there will be some significant penetration of the transportation sector by electricity both in mass transit uses and by means of electric automobiles. The low end of the range, 6,000 billion KWh, represents little more than a doubling in the 20-year period from 1980, much lower than the historical growth rates if the 1980 figure of 2,700 billion

KWh is correct, and does not appear to give adequate weight to the many areas that electricity is now beginning to penetrate.

The high side of the range, 10,000 billion KWh, would constitute a 64 percent penetration of the total energy market if an average heat rate of 8,500 BTU per KWh of electricity is assumed; almost complete electrification of the residential, commercial and industrial sectors would be required, along with substantial penetration into the transportation sector of the economy.

Nuclear Power Projections

Nuclear power projections have been made on the basis of installed generating capacity. Total electric generating capacity estimates supplied by FPC are shown in Table 6. The table also shows distribution by type of generation based on AEC estimates of nuclear capacity.

The 1962 Report foresaw a nuclear generating capacity in the United States of 5,000 MWe by 1970 and 40,000 MWe by 1980. In 1964, with improved prospects for nuclear power, it was predicted that by 1970 there would be 6,000 to 7,000 MWe of nuclear generating capacity in the United States. It also was considered likely that there would be between 60,000 and 90,000 MWe by 1980.

In view of the unexpected surge in 1965 of orders for nuclear power plants, the Commission further revised its projections of nuclear power and, in the spring of 1966, made a substantially higher new projection of over 10,000 MWe generating capacity by 1970-1971 and of 80,000 to 110,000 (mean 95,000) MWe by 1980. Subsequently, utility commitments for nuclear power plants have been made at an even faster rate than in 1965.*

Updated Commission forecasts of nuclear capacity up to 1980 and beyond are being developed.

TABLE 6.—U.S. ELECTRIC GENERATING CAPACITY PROJECTIONS ¹
(1000 MWe)

	1965 (Actual)	1980	2000
Steam:			
Fossil.....	185	311	572
Nuclear.....	2	² 95	³ 734
Subtotal.....	187	406	1,306
Other ⁴	48	117	250
Total Capacity, 1000 MWe.....	235	523	1,556
Energy Projection, billion KWh.....	1,052	2,700	8,000

¹ Steam and other projections based on FPC data furnished in 1966.

² AEC 1966 mean estimate.

³ AEC 1962 estimate.

⁴ Hydro, pumped storage, internal combustion.

* A recent projection developed by the Edison Electric Institute for investor-financed utilities indicates that by 1980 there will be about 109,000 to 117,000 MWe of installed nuclear power generating capacity in the U.S. for that type of utility alone. The General Electric Company has recently estimated 125,000 MWe for total installed nuclear capacity for 1980, and the Westinghouse Electric Corporation has estimated 150,000 MWe for total installed nuclear capacity.

The extent to which nuclear power captures the utility market in the post-1980 period appears to depend largely upon the technology and economics of advanced reactors, as well as upon developments in the mining and transportation of fossil fuel, and upon the extent and rate of discovery of low-cost uranium resources. The growth of nuclear power in the post-1980 period also will depend upon the growth of total electricity requirements. If the low forecast of electricity consumption should be correct, the 1962 forecast of 734,000 MWe of nuclear capacity in the year 2000 would not be reached since essentially all steam capacity beyond that now existing or committed would have to be nuclear. If the high estimate of electricity consumption should be correct, the opportunities for nuclear power would be greater, and, on the basis of the assumptions of the 1962 Report, installed nuclear capacity would be well above 734,000 MWe. The validity of these estimates is being considered in the continuing assessments.

Nuclear Economics

The electric power industry is large enough that opportunity exists for considerable savings to the U.S. economy through reductions in the cost of producing electricity. About half of the delivered cost of electrical energy is attributable to the cost of production, the remainder being transmission and distribution.

Unlike almost all other elements of the cost of living, the cost of producing electricity has been declining steadily over the years. This decrease has been due primarily to improving thermal efficiency for the fossil fueled plants and to lower capital costs per kilowatt electrical generating capacity for fossil fuel and nuclear plants. The latter cost improvement is attributable in large part to the distinct trend towards the construction of larger sized generating units.

At the end of 1966, there were 21 steam-electric generating units of 780 to 1130 MWe under construction or committed (Table 7). Twelve, or about 60 percent of these are nuclear fueled. Prior to 1966, nuclear electric plants in service ranged up to 270 MWe (Figure 1), whereas the nuclear plants presently scheduled to enter service beyond 1966 range up to 1065 MWe. It is expected that the trend towards large sized units of generating capacity will continue.

The scheduling of nuclear capacity has proceeded at an unexpectedly high rate in the U.S. At the time that the Commission's 1962 Report on Civilian Nuclear Power was issued, the total amount of domestic nuclear electric power operational or contracted for was 1150 MWe with an average unit size of 72 MWe. As of the end of 1966, the nuclear electric power operational or contracted for had increased to 25,800 MWe. During 1965, 4900 MWe were contracted for, and in 1966 the total was 16,580 MWe. The average size of the nuclear generating units ordered in 1966 was 790 MWe. As of January 1, 1967 about 1800 MWe of nuclear electric plant capacity are operable and 24,000 MWe are under construction or contracted for. Table 8 lists those nuclear power plants which have been operated, are under construction or have been committed.

Until nuclear power comprises more than about one-third of an integrated utility systems capacity, there is an opportunity for the nuclear plants to operate as base-load units. Since nuclear power is not

TABLE 7.—ELECTRICAL GENERATING UNITS UNDER CONSTRUCTION OR COMMITTED

(780MWe (net) or larger)

Unit	Size (MWe)	Scheduled for Operation	Type
Bull Run No. 1.....	900	1967	Coal
Keystone No. 1.....	900	1967	Coal
Keystone No. 2.....	900	1968	Coal
Big Sandy No. 2.....	800	1969	Coal
Indian Point No. 2.....	873	1969	Nuclear
Paradise No. 3.....	1, 130	1969	Coal
Mitchell No. 1.....	800	1970	Coal
Conemaugh No. 1.....	839	1970	Coal
Browns Ferry No. 1.....	1, 065	1970	Nuclear
Surry No. 1.....	783	1971	Nuclear
Mitchell No. 2.....	800	1971	Coal
Oconee No. 1.....	839	1971	Nuclear
Browns Ferry No. 2.....	1, 065	1971	Nuclear
Peach Bottom No. 2.....	1, 065	1971	Nuclear
Burlington.....	993	1971	Nuclear
Conemaugh No. 2.....	900	1971	Coal
Surry No. 2.....	783	1972	Nuclear
Oconee No. 2.....	839	1972	Nuclear
Diablo Canyon.....	1, 060	1972	Nuclear
Metropolitan Edison.....	840	1972	Nuclear
Peach Bottom No. 3.....	1, 065	1973	Nuclear

expected to reach that level before the post-1980 period, nuclear plants now being ordered probably will operate at high capacity factors during most of their life. Gradually, as nuclear power becomes a larger fraction of the total installed generating capacity of utility systems, the nuclear units may be considered on the basis of predicted lower capacity factor operation. Hence, the fixed costs associated with new capacity additions may become more important than they are at the present stage of nuclear growth and may set an economic limit on the proportion of the capacity that is nuclear.

In 1962 the estimated cost of producing electricity from a base load 500 MWe nuclear plant was 6.2 mills/KWh. The current estimate for a 500 MWe unit is about 4.4 mills/KWh. Current estimates (1970–1971 start-up) of the expected economic performance of light water nuclear electric plants in larger sizes and with investor financing are in the range of 3.5 to 4.2 mills/KWh for base-load operation. For those which are publicly financed, the range is 2.6 to 3.0 mills/KWh. Generally speaking, these current estimates compare with the cost of electricity from a similar large coal burning plant with delivered fuel priced at 17 to 25 cents per million BTU. The 1965 U.S. delivered price of coal ranged from 18.9 to 33.4 cents per million BTU for the seven FPC regions in which coal supplies over 10 percent of the energy used to produce electricity, with an average delivered price of 24.4 cents per million BTU. The average delivered price of all fossil fuels was 25.2 cents per million BTU.¹

¹ Steam Electric Plant Factors/1965, Sixteenth Edition, October 1966, National Coal Association.

CENTRAL STATION NUCLEAR POWER REACTORS CONTRACTED FOR

Showing Size & Actual or Scheduled Year of Operation

As of Dec. 31, 1966

TABLE 8.—CENTRAL STATION NUCLEAR POWER REACTORS

NAME	REACTOR OWNER	OPERATOR	CAPACITY, KWE NET	TYPE OF REACTOR
<u>Part I Reactors Operated by end of 1962</u>				
Shippingport Atomic Power Station	AEC	Duquesne Light Company	90,000	Pressurized Water
Yankee Nuclear Power Station	Yankee Atomic Electric Company		175,000	Pressurized Water
Dresden Nuclear Power Station, Unit #1	Commonwealth Edison Company		200,000	Boiling Water
Indian Point Nuclear Power Station, Unit #1	Consolidated Edison Company of New York		270,000	Pressurized Water
Big Rock Point Nuclear Plant	Consumers Power Company of Michigan		70,400	Boiling Water
Hallam Nuclear Power Facility*	AEC	Consumers Public Power Dist. of Neb.	75,000	Sodium Cooled, Graphite Moderated
<u>Part II Additional Reactors Operated by end of 1966</u>				
Piqua Nuclear Power Facility	AEC	City of Piqua, Ohio	11,400	Organic Moderated and Cooled
Elk River Nuclear Plant	AEC	Rural Cooperative Power Association	22,000	Boiling Water
Carolinas-Virginia Tube Reactor (CVTR)	Carolinas-Virginia Nuclear Power Associates		17,000	Heavy Water Moderated and Cooled
Humboldt Bay Power Plant, Unit #3	Pacific Gas and Electric Company		68,500	Boiling Water
Boiling Nuclear Superheat Pwr. Station (BONUS)	AEC	Puerto Rico Water Resources Authority	16,500	Boiling Water with Nuclear Superheat
Enrico Fermi Atomic Power Plant	Power Reactor Development Company		60,900	Sodium Cooled, Fast
Pathfinder Atomic Power Plant	Northern States Power Company		58,500	Boiling Water with Nuclear Superheat
N-Reactors/WPPSS	AEC	Washington Public Power Supply System (WPPSS)	786,000	Graphite Moderated, Pressurized Water Cooled
<u>Part III Reactors Scheduled for Completion by end of 1967</u>				
Peach Bottom Atomic Power Station, Unit #1	Philadelphia Electric Company		40,000	Helium Cooled, Graphite Moderated
San Onofre Nuclear Generating Station	Southern California Edison Co. & San Diego Gas & Electric Company		430,000	Pressurized Water
LaCrosse Boiling Water Reactor (LACBWR)	AEC	Dairyland Power Cooperative	50,000	Boiling Water
Connecticut Yankee Atomic Power Plant	Connecticut Yankee Atomic Power Company		462,000	Pressurized Water
<u>Part IV Reactors Contracted for Completion after 1967</u>				
Oyster Creek Nuclear Power Plant	Jersey Central Power & Light Company		515,000	Boiling Water
Nine Mile Point Nuclear Station	Niagara Mohawk Power Corporation		500,000	Boiling Water
Dresden Nuclear Power Station, Unit #2	Commonwealth Edison Company		715,000	Boiling Water
Millstone Nuclear Power Station	The Millstone Point Company		549,200	Boiling Water
Robert Emmett Ginna Nuclear Pwr. Plant Unit #1	Rochester Gas & Electric Company		420,000	Pressurized Water
Indian Point Nuclear Power Station, Unit #2	Consolidated Edison Company of New York		873,000	Pressurized Water
H. B. Robinson	Carolina Power and Light Company		663,000	Pressurized Water
Faliscades Nuclear Power Station	Consumers Power Company of Michigan		700,000	Pressurized Water
Dresden Nuclear Power Station, Unit #3	Commonwealth Edison Company		715,000	Boiling Water
Point Beach Nuclear Plant	Wisconsin-Michigan Power Company		454,600	Pressurized Water
Monticello Nuclear Generating Plant	Northern States Power Company		471,700	Boiling Water
Quad Cities Station, Unit #1	Commonwealth Edison Co. and Iowa-Illinois Gas & Electric Company		715,000	Boiling Water
Browns Ferry Nuclear Power Plant, Unit #1	Tennessee Valley Authority		1,064,500	Boiling Water
Malibu Nuclear Plant	Los Angeles Department of Water & Power		462,000	Pressurized Water
Pilgrim Station	Boston Edison Company		549,000	Boiling Water
Turkey Point Station, Unit #3	Florida Power & Light Company		721,500	Pressurized Water
Vermont Yankee Generating Station	Vermont Yankee Nuclear Power Corporation		513,900	Boiling Water
Burlington Nuclear Generating Station	Public Service Electric & Gas Co. and others		993,000	Pressurized Water
Peach Bottom Atomic Power Station, Unit #2	Philadelphia Electric Co. and others		1,065,000	Boiling Water
Fort Calhoun Plant	Omaha Public Power District		450,000	Pressurized Water
Surry Power Station, Unit #1	Virginia Electric & Power Company		783,000	Pressurized Water
Browns Ferry Nuclear Power Plant, Unit #2	Tennessee Valley Authority		1,064,500	Boiling Water
Quad Cities Station, Unit #2	Commonwealth Edison Co. and Iowa-Illinois Gas & Electric Company		715,000	Boiling Water
Oconee Nuclear Station, Unit #1	Duke Power Company		839,000	Pressurized Water
Fort St. Vrain Power Station	Public Service Company of Colorado		330,000	Helium Cooled, Graphite Moderated
Turkey Point Station, Unit #4	Florida Power and Light Company		721,500	Pressurized Water
Oconee Nuclear Station, Unit #2	Duke Power Company		839,000	Pressurized Water
Diablo Canyon Plant	Pacific Gas & Electric Company		1,060,000	Pressurized Water
Niagara Mohawk Power Corporation - Unnamed	Niagara Mohawk Power Corporation		755,000	Boiling Water
Surry Power Station, Unit #2	Virginia Electric & Power Company		783,000	Pressurized Water
Metropolitan Edison Company - Unnamed	Metropolitan Edison Company		840,000	Pressurized Water
Peach Bottom Atomic Power Station, Unit #3	Philadelphia Electric Company and others		1,065,000	Boiling Water

* Hallam achieved criticality in August 1962 and operated until September 1964 when it was shut down.

December 31, 1966

The recent commitments have included a considerable number of repeat orders by utilities for nuclear power units, and the size of the power-producing units has been increasing. Capital costs per kilowatt of electrical generating capacity have recently remained fairly constant for a given size of power producing unit or have increased slightly. Design innovations of a product improvement nature continue to be incorporated in succeeding plants, and it probably will be a few years before plant pricing stabilizes, though there has already been a move to standard sizes. Currently, there is a substantial backlog of plants on order. This is stretching out delivery times and presumably has an effect on plant pricing. However, warranted fuel cycle costs have decreased significantly, leading to an over-all reduction in the anticipated cost of nuclear energy.

Several large light water nuclear power units soon will begin operation. The operational experience to be demonstrated in these plants, particularly on fuel performance, plant maintenance and plant reliability, will be of great assistance in better defining the economic expectations of nuclear power plants.

Development Program

In making recommendations for the development program, the 1962 Report took note of the fact that light water reactors were relatively well developed and appeared to be on the verge of being competitive with conventional systems in high fuel cost areas of the country, with possible later extension to other areas as nuclear economics improved. The report recommended a shift in emphasis toward development of converter reactors of improved design and toward development of breeders for application in the long term to make available the full potential of the nuclear fuel resources.

The Commission has strengthened its program on breeders and they now represent the largest civilian power development area. The chief emphasis is being placed on fast breeders, in particular on the Liquid Metal Cooled Fast Breeder (LMFBR).

The continuing program on advanced converters is based on the rationale set forth in the 1962 Report. This class of reactors shows promise of economic improvement, and the effective use of resources could be substantially improved over the current light water reactors in both fuel inventory and in the requirements for burnup. Success of one or more of these concepts can provide an alleviation of resource requirements during a period before high gain breeders are fully developed. This may be particularly important if technical problems or economic limitations of the high gain breeders develop in such a way as to delay their progress into widespread utility application.

To some extent, the utility acceptance of the light water reactors has provided a new context for the advanced reactor projects. One of the promising features of the more advanced concepts has been the prospect that they can compete economically with the light water reactors; but in present circumstances they will face a more severe test in this regard than could have been predicted. On the other hand, the need for improved raw material utilization in order to forestall increases in cost for uranium has become more important because of the success of the light water reactors. Uncertainties in resource availability over the next few decades arise from the lack of intensive uranium prospecting in the U.S. in recent years. To the extent that renewed exploration may make available additional low cost resources, the need for higher conversion ratios than can be provided by the light water reactors will be reduced; if additional low cost resources should be more limited than expected, there will be greater need for improved converters, pending the development and commercial acceptance of breeders.

Although this report is essentially an updating to January 1967 of the circumstances and status of the Civilian Nuclear Power Program within the general context of the plan laid out in the 1962 Report, and does not reflect new conclusions or fundamental changes in direction,

brief descriptions are included under the individual concepts on the prospects for the future as seen in relation to the planned development of each particular concept viewed at this time. The series of analyses and assessments of current development programs now being made may lead to changes in the apparent promise of the concepts and to resultant changes in emphasis or direction of the program as a whole. Some of the development programs are approaching a very critical stage, and meaningful and important information will be available within the year 1967. It is anticipated that this information will provide a basis for reducing the number of concepts now being pursued.

Such changes as may result from the studies will be carried out consistent with the conclusion in the 1962 Report that:

"Thus, the proper role of Government is to take the lead in developing and demonstrating the technology in such ways that natural economic forces will promote industrial applications and lead to a self-sustaining and growing nuclear power industry; the program should be guided in such directions that those economic forces will work toward ends in the public interest, including the long-range conservation of both our fossil and our nuclear fuel resources."

In going forward in further fulfillment of this responsibility, the Commission intends to proceed under arrangements similar to those made in the past. The Commission will, generally speaking, participate in the development of technology directly, working through its own laboratories and with industrial contractors. Cooperative programs will be used, if possible, for demonstration reactors, bringing to bear both the developing industrial capability and the utility interest through direct participation and sharing of the required investment and associated risks.

In exercising the role of positive and vigorous leadership recommended in the earlier report, the Commission intends to place particular emphasis, in cooperation with industry, on the development and application of a continually improving standard of design, construction and operating practice. Such upgrading—applied to the Commission's own programs and experimental facilities, to cooperative programs, and throughout the industry—should become an important factor in insuring meaningful results from experimental and demonstration programs, in improving the economics, in providing the high degree of reliability and availability necessary for utility application and in continuing with increasing assurance the nuclear industry's excellent record of safety.

Light Water Reactors (LWR)

The Commission's Power Demonstration Reactor Program has provided assistance for a number of light water nuclear power plants: Shippingport, Yankee, Elk River, Pathfinder, BONUS, Big Rock Point, San Onofre, LaCrosse Boiling Water Reactor (LACBWR), Connecticut Yankee, and the proposed Malibu plant. These plants have exhibited various levels of technical and economic success, and are expected to continue to make contributions to water reactor development and demonstration.

Manufacturers now are able to shop-fabricate pressure vessels and other components for nuclear power plants up to at least a 1500 MWe

rating, an important factor in the trend to the larger, more economic plants. Improvements in plant components and reactor control have resulted in increased reactor power density, leading to reductions in pressure vessel dimensions and in plant cost for a given power level. Safety features, including engineered safeguards systems, have been improved. Though fuel burnup averaged over entire cores has been in the range of 12,000-15,000 megawatt days per ton (MWD/T) of fuel, limited quantities of Zircaloy clad uranium oxide fuel have reached a burnup in excess of 30,000 MWD/T in light water reactors.

Despite the status and projected advances in light water reactors, there remain some reservations about the state of the technology. No plants have operated in the sizes which are being committed. There is no statistical experience with large amounts of fuel at exposures which are being contemplated for the new commercial plants. There is continuing concern for safety. The impact of regulatory requirements on the economics of committed projects cannot be fully known until after they have gone through the regulatory process and been put into operation. While it is not felt that these reservations reflect on the basic promise of the water reactor systems, the Commission has held that it is not now in a position to make a statutory finding of practical value within the meaning of the Atomic Energy Act of 1954.

Continued improvement of the pressurized and boiling light water reactors is being undertaken by industrial suppliers and by the electric utilities. Commission support of development will be limited to activities in the main related to plant safety, including participation in the development of engineering standards, practices and procedures, and to the support of improvement of fuel resource utilization in light water reactors. Further Government assistance to the development of light water converter reactors under the demonstration program is not planned.

Current commitments to support the U.S.-Euratom light water research and development program will be continued until mid-1969.

It is intended that support of Shippingport reactor operations will be continued. Much of the research and development support involving the Shippingport operation will be reoriented to the seed-blanket light water breeder concept which is directed toward demonstrating the potential for breeding in pressurized light water plants.

The AEC support for plutonium recycle work for thermal reactors is being decreased with the expectation that the industry will increase its research and development programs to make plutonium recycle an effective part of the nuclear power system. Phase-out of the Commission recycle program is planned about 1970.

Current cooperative arrangements will be continued relating to the participation in examination of fuel from the Yankee reactor and operational analysis and support for the cooperative demonstration plants such as Elk River, LaCrosse, Pathfinder, and Big Rock Point. Support for the thermal reactor superheat program is being limited to the BONUS and Pathfinder plant cooperative demonstration program commitments.

Advanced Converters and Light Water Breeder

In 1962 a number of converters of advanced design were under development because of their promise of better economics and higher conversion ratios than the pressurized or boiling light water reactors. Included were the organic-cooled and moderated reactor, heavy water moderated reactors, the "spectral-shift" reactor combining light and heavy water in the moderator, the sodium-cooled graphite-moderated reactor, high temperature gas-cooled reactors moderated by graphite or beryllium, and the seed-blanket light water concept.

The Commission effort to develop advanced converters now has been narrowed to three approaches: the heavy water moderated reactor with emphasis on the organic-cooled version, the high temperature gas-cooled concept and the seed-blanket light water breeder concept. Current studies are expected to lead to a further narrowing of focus.

Heavy Water Moderated Reactor Program

Heavy water moderated reactor systems in the 1000 MWe range and above, in addition to the potential for lower cost power and higher conversion ratios, require less natural uranium to provide the slightly enriched inventory than do present light water reactors. Very large unit size reactors can be accommodated by the modular pressure tube design of the heavy water moderated reactor. These sizes may be advantageous for dual purpose electrical and desalting plants. The pressure tube concept also permits refueling while at power to achieve high plant availability.

The heavy water moderated reactors have the flexibility to accept different fuels and coolants. Although the thorium fuel cycle results in a higher conversion ratio and consequently better utilization of fertile fuel resources, the cost of electricity using that cycle in a heavy water moderated reactor designed for power production is estimated to be somewhat higher than that of a uranium fuel cycle. The uranium cycle has therefore been assigned a higher priority. The reference cycle uses slightly enriched uranium, which has been shown to have economic advantages in the U.S., but detailed evaluations of cycles using natural uranium fuels are under way.

Coolants considered for the heavy water moderated systems have included organics, boiling light water, and heavy water. In proceeding with the present program it has been concluded that the most desirable avenue to follow from the point of view of potential power generation costs and fuel utilization is one which avoids pressurized heavy water coolant and the attendant possibility for costly losses. From a power cost and fuel utilization standpoint, the organics and boiling light water coolants as alternates can match heavy water and they have the potential for providing lower power costs. There have not been sufficient resources available to pursue both programs; industrial interest and experience and a lesser need for new or modified experimental facilities were important factors in the decision to emphasize the organic route for the present research and development program.

The heavy water organic cooled reactor (HWOOCR) 1000 MWe reference design incorporates a low pressure organic coolant and is moderated by heavy water at low pressure and temperature. Organic coolant flows through pressure tubes made of sintered aluminum powder (SAP) or zirconium alloy. The slightly enriched uranium carbide fuel elements contained in the tubes are clad with SAP. Design features may include refueling while at power, carbon steel primary systems and provisions for coolant purification.

The research and development program is directed toward providing the technological and engineering base for an HWOOCR demonstration plant and toward identifying specific technical limitations, particularly as these relate to the organic coolant concept. In-pile tests at HWOOCR conditions indicate that organic coolant decomposition rates are predictable; however, operation of the rebuilt organic cooled and moderated Piqua reactor is necessary to demonstrate that organic film formation on the fuel elements can be adequately predicted and that the buildup of coke¹ will not occur. Additional experimental verification that organic film formation on fuel elements can be controlled within acceptable limits needs to be established; it is intended that allowance will be made in the fuel element design to accommodate the predicted organic film formation. Effort is being directed to identify the limits of this problem and the economic incentives or penalties for variation from reference conditions. The program also includes the determination of uranium carbide fuel growth characteristics under HWOOCR conditions and application of results to fuel element and core design. It is intended that coolant purification systems will be operated to demonstrate control of organic purity within specified limits. A series of in-pile experiments is being performed to verify the predicted performance of SAP and zirconium alloy pressure tubes, including their ease of replacement. Experiments and analyses will also be conducted on physics and reactor control, and on interrelated safety considerations associated with a positive temperature coefficient of reactivity.

The technology for many of the heavy water subsystems and components is embodied in reactor experiments and nuclear power plants in this country and elsewhere that have used pressure tubes, and heavy water or organic cooling; additionally, the large light water reactor plants being constructed contribute significantly to the development and manufacture of such components and instrumentation.

A valuable source of additional technology for the heavy water program is made available through technical exchange arrangements with Atomic Energy of Canada Limited (AECL). Use of organic cooled irradiation facilities in the National Reactor Universal (NRU) at Chalk River and the Whiteshell Reactor (WR-1) contribute to the U.S. HWOOCR program. The Canadian program on the light water cooled heavy water moderated reactor concept is also providing information of use to the U.S. in its assessment of that concept.

Another technical information exchange agreement is being negotiated with Euratom to obtain information on the HWOOCR type ORGANIQUE-Eau Lourde (ORGEL) reactor. The exchange will also include the Euratom sponsored ESSai ORgel (ESSOR), a heavy water moderated and organic cooled reactor rated at about 20 MWt,

¹ Coke—porous solid organic coolant decomposition products.

with a pressure tube arrangement much like the WR-1, which is expected to begin operation in 1967.

High Temperature Gas Cooled Reactor

The High Temperature Gas Cooled Reactor (HTGR) system is a helium cooled graphite moderated concept with a potential for lower power costs and higher conversion ratios than present light water reactors. Large HTGR plant designs use the thorium fuel cycle; the initial fuel loadings will use uranium-235, but after about seven years the core loadings will be primarily recycle uranium-233, with only small additions of uranium-235.

During the period since the 1962 Report, fundamental advances have been made in the technology of the fuel for the High Temperature Gas Cooled Reactor concept. The present fuel consists of coated particles—small thorium-uranium carbide spheres coated with high density (pyrolytic) carbon—mixed homogeneously with a substantial amount of graphite. This fuel has much greater proven capacity for fission product retention than fuels previously under consideration and should favorably affect reactor design, operation and maintenance. During the past four years a greater understanding of the problems involved in using graphite as a high temperature reactor material has been reached. Analytical methods developed for the reactor physics of high temperature graphite cores have been confirmed through the initial criticality operation of the Peach Bottom reactor and additional physics tests are planned after power operation is attained. The advent of the prestressed concrete technology for large reactor vessels provides new possibilities for this concept.

Operation of the 40 MWe Peach Bottom reactor, and to a less direct extent of the 3 MWt Ultra High Temperature Reactor Experiment (UHTREX), located at Los Alamos, and of the 20 MWt Dragon reactor, located in the United Kingdom, will provide information important to the development of the HTGR concept. The Peach Bottom reactor is cooled with helium at 300 pounds per square inch (psi). Graphite is used for the moderator, cladding, core structure and reflector. The vented thorium-uranium carbide fuel in Peach Bottom provides for a three year core life and the plant is designed to produce steam at 1450 psi and 1000° F. Several problems arose during the construction of Peach Bottom, which started in early 1962. They resulted in delays for this first-of-a-kind plant with its unique components, systems and instrumentation. Initial criticality was achieved in March 1966 and full power operation is scheduled in 1967.

Plant components for large HTGRs will differ substantially from those used in Peach Bottom. The important plant and component design changes are dictated by the use of a prestressed concrete reactor vessel, increased component size requirements, different safety and containment concepts, and the required high degree of plant performance, reliability and maintainability. The new components require development and testing. Leakages of helium, lubricating fluids and steam will require careful control, and systems and special instruments to achieve this control will be developed.

The initial development efforts on demonstration components and systems for large HTGR power plants will be provided by the Public

Service of Colorado (PSC) cooperative demonstration project—a 330 MWe HTGR to be located at Fort St. Vrain, near Denver, Colorado. The PSC reactor will use the improved thorium-uranium coated particles. The reactor will be cooled with 700 psia helium and will be designed to produce steam at 2400 psi and 1000° F. with a 40 percent net plant thermal efficiency. A prestressed concrete reactor vessel will house the entire primary system, including the core, and the steam driven axial-flow helium circulators and the steam generators, which are located under the core. Research and development and design were initiated in July 1965. Commercial operation of the plant should be attained by 1972.

The support to be afforded the PSC project will be dependent upon a technical and economic assessment to be made following full power operation of the Peach Bottom reactor. Support of the over-all HTGR program will depend upon successful and timely operation of the Peach Bottom reactor, the rate of progress in the design of the 330 MWe PSC plant and the development of critical HTGR components.

Two designs of a 1000 MWe HTGR reactor are being prepared for assessment. The reference design will incorporate potential improvements in the HTGR concept beyond that of the PSC plant. Refueling while at power, for example, would increase plant availability and lower the cost of power produced. A backup design will embody essentially the features being developed for PSC.

Research and development efforts will continue on nuclear safety analysis, fuel development, prestressed concrete pressure vessels, containment and related safety features, and on component development, including turbine-driven circulators, control rod drives, steam generators and fuel handling machines. Fuel recycle studies will include fuel reprocessing, fabrication, handling and related safety implications.

Light Water Breeder

The thorium-uranium-223 fueled seed-blanket Light Water Breeder Reactor (LWBR) concept has an expected conversion or breeding ratio high enough to increase the fuel utilization significantly beyond that of either present types of light water reactors or advanced converters currently in the AEC program. Successful development of the LWBR would make available for power production about 50 percent of the potential energy in the thorium fuel resources.

The breeding gain expected in the LWBR concept is not as great as that potentially obtainable using plutonium fast breeder systems, and the system would not produce the excess of fissile material over that consumed which would make possible the fueling of additional reactor capacity from bred fissile material. On the other hand, the LWBR is based on proven pressurized light water reactor technology and, except for changes in the reactor core, does not require a significance departure from the technology on which the growth of the U.S. nuclear utility industry is at present dependent. The seed-blanket breeder therefore has few engineering development uncertainties in the plant and can provide a system of proved practicality and comparable reliability along with its substantial improvement in fuel utilization over present types of light water reactors. With the

engineering status in a relatively favorable condition, the major long-term problems on seed-blanket light water breeder acceptance may center on the economics of core fabrication and fuel cycle costs.

As an initial step, it appears feasible to design a reactor core which could actually demonstrate breeding using the thorium seed-blanket concept in an existing pressurized water reactor plant. Successful completion of such a breeding demonstration would show that it is technically feasible to install breeder cores in existing and future pressurized light water reactor plants.

The Commission is presently proceeding with a program of research and development including large scale physics critical experiments using uranium-233 and thorium, reactor component development and engineering tests, and extensive fuel element development, irradiation testing, and analysis. The Commission plans to determine during Fiscal Year 1968 whether a breeding demonstration core should be built for an existing pressurized water reactor plant such as the Commission owned reactor at Shippingport, Pennsylvania. No major changes would be required to the plant except those associated with the changes in the core design.

High Gain Breeders

As stated in the 1962 Report:

"... our supplies of uranium and thorium contain almost unlimited amounts of latent energy that can be tapped, provided 'breeder' reactors are developed ... successfully done, this will render relatively unimportant the cost of nuclear raw materials so that even very low-grade sources will become economically acceptable."

The development of high gain breeders will increase fuel utilization from the few percent potentially usable in present day reactors to over 50 percent. The energy that can be extracted from the low cost ores will thereby be extended by factors of 10 to 30. The relative insensitivity of high gain breeders to ore prices will also make usable the large amounts of uranium available from higher cost ores. High gain breeders will also produce an excess of fissile material over that initially present, which can be used to fuel new reactors in an expanding power system.

Fast Breeder

The fast breeder, with a potential for a doubling time of 8 to 10 years, can most efficiently use the fertile uranium-238 in depleted and natural uranium.

The fast breeders of major interest are divided into three categories—sodium cooled, gas cooled and steam cooled. The sodium cooled fast breeder has been established as the priority program on the basis of potential economy, reactor manufacturer interest, and technological experience gained in the U.S. and abroad. Worldwide interest is concentrated on the sodium cooled breeder. The sodium cooled and gas cooled breeder have a better economic potential and capability for conserving uranium resources than the steam cooled fast breeder. Though sodium possesses certain technical advantages, use of alternate coolants, gas or steam, would reduce the complexity of

coolant servicing, and of component and system maintenance. Though it is not expected that comparisons will show advantages in the alternate coolant concepts sufficient to change the high priority assigned to the sodium-cooled fast breeder reactor, there is a need to establish definitely the emphasis to be placed on alternate coolant fast breeders, and such efforts are underway.

LIQUID METAL FAST BREEDER REACTOR (LMFBR)

The Liquid Metal-Cooled Fast Breeder Reactor (LMFBR), using sodium as the coolant, has an extensive background dating from 1945. Sodium was chosen as the coolant primarily because it has a combination of advantageous characteristics; good nuclear characteristics which help in attaining high breeding ratios, with potential doubling times of 8 to 10 years; a high boiling point which allows for high temperature and low pressure operation, with resultant high plant thermal efficiency and thin primary wall structures; excellent capability for transferring heat; a large heat capacity, which allows for timely action in the event of a power transient or loss of coolant flow; low pumping power; and relative freedom from corrosion in the absence of air and water. Sodium as a coolant has disadvantages—associated with its prolonged radioactivity after reactor shutdown, its chemical reaction with air and water, and its nontransparency—which make maintenance difficult. The chronology of the world's existing sodium cooled fast breeder program is shown in Table 9. All of the fast breeder plants in operation, committed or planned are cooled with sodium except Dounreay, cooled by a sodium-potassium alloy, and one steam cooled plant (250 MWe) under consideration in Germany.

TABLE 9.—CHRONOLOGY OF FAST REACTORS

	Achieved		Design Power	
	Criticality	Electrical power	KWe	KWt
U.S.:				
Clementine ¹	Nov. 1946	(²)		25
EBR-I ¹	Aug. 1951	Dec. 1951	250	1, 200
LAMPRE I ¹	1961	(²)		1, 000
Fermi	Aug. 1963	Aug. 1965	67, 000	200, 000
EBR-II	Nov. 1963	Mar. 1965	20, 000	62, 500
Foreign:				
UKAEA Dounreay	Nov. 1959	Aug. 1962	15, 000	60, 000
USSR BR-1 ¹	1955	(²)		
BR-2 ¹	1965	(²)		100
BR-5	1958	(²)		5, 000
CEA Rapsodie	Early 1967	(²)		20, 000
Total Existing			102, 250	349, 825

¹ Projects now terminated.

² Produced No Electric Power.

Demonstration and prototype fast reactor plants have been committed in the U.K. and U.S.S.R. to a total of 600 MWe and have been planned in France and Germany to a total of 550 to 850 MWe. Dem-

onstrations plants probably larger than 300 MWe are planned for the U.S. development program.

The past four years have been productive of information which enhances the promise of the sodium cooled fast breeder reactor. The U.S. program has been highlighted by the operation of the Experimental Breeder Reactor II (EBR-II) and the Fermi reactor. Successful maintenance of components in a sodium environment has been demonstrated. The EBR-II, designed for 62.5 MWt, achieved criticality in 1963 and now is being operated at 45 MWt as the only available fast neutron flux fuels and materials irradiation facility. The reactor is irradiating on a continuous basis about 235 core length LMFBR experimental capsules containing samples of plutonium bearing fuels and of structural materials.

The Fermi reactor, designed for 200 MWt, first operated in 1963 and achieved 100 MWt in 1965. Plans for further operation were interrupted by a major fuel failure in October 1966. Future plans for Fermi will depend on determining the cause of fuel failure and the extent of damage. It appears that fuel has melted in one or more fuel subassemblies,¹ in total equivalent to about one subassembly. It will take some months of effort to remove the subassemblies in question, analyze the failure and determine an appropriate course of action.

Fast reactor operating and irradiation information has been provided by the United Kingdom as a result of the successful operation of the Dounreay Fast Reactor (DFR). The DFR 60 MWt reactor has been in operation since the summer of 1963 as a fuels and materials irradiation facility. Plutonium-uranium oxide fuel in experimental subassemblies has achieved a burnup in excess of 90,000 MWD/T. The DFR is presently irradiating about 300 fuel element experiments, about half of which are for the U.K. fast breeder program.

Concurrently with the EBR-II and DFR operation, reactor physics experiments have been conducted by the U.S., and U.K. and the Euratom community which have demonstrated that fast reactors fueled with plutonium-uranium oxide using a slightly softened neutron energy spectrum can probably be provided with an inherent Doppler effect that will satisfactorily stabilize power excursions. Further detailed and confirming information on the Doppler effect will be provided by the 20 MWt Southwest Experimental Fast Oxide Reactor (SEFOR) experiment which is scheduled to operate in 1968. The capital cost of this reactor is being financed jointly by the Southwest Atomic Energy Associates, Euratom, and the German Gesellschaft für Kernforschung (GFK). The AEC is providing about half of the total of capital, operating and research funds, with its support devoted to research and development and operation of the reactor.

Further manifestations of the confidence of other nations of the world in the success of fast reactor development include the series of critical and subcritical test facilities initiated by Euratom in 1964; the construction of the French Rapsodie, a 20 MWt experimental fast breeder reactor; the initiation of construction at Dounreay of the 250 MWe Prototype Fast Reactor (PFR) in 1966; the initiation of construction of the 350 MWe equivalent power and desalting BN-350 fast breeder in the Soviet Union; the U.S. initiation in 1965 of the con-

¹ Fuel subassembly—A collection of fuel elements forming a unit structure which can be inserted, or removed, from a reactor core.

ceptual design for the Fast Flux Test Facility (FFTF) of about 400 MWt; and the expression of interest by U.S. industry in participating in research and development and in building demonstration plants.

The Commission is continuing to strengthen its research and development activities in the LMFBR program. The total program effort will identify the key research and development problems; provide conceptual plant designs; determine the role of demonstration plants in the research and development program; select methods for developing engineering capability in an industrial complex; determine the amount and allocation of resources required; and determine the priorities and schedules for each segment of the program necessary to develop commercial plants.

Intensive and comprehensive reviews are being made in each technical area of the LMFBR program to assess its status and to determine the major needs of the program. Initial reviews have been completed on fuels and materials, physics, and associated facilities.

The fuels and materials program is concentrated on the plutonium-uranium oxides, carbides and alloys, with the objective of developing fuel for the FFTF and the first demonstration plants. Sufficient development to select and verify the fuel and cladding for the Fast Flux Test Facility (FFTF) and for the initial loadings of the first demonstration plants can be performed in existing thermal reactor irradiation facilities and in EBR-II.

The development of fuels and cladding for advanced cores in these and later plants will use the capabilities of the Fast Flux Test Facility. The construction of the FFTF and its subsequent operation are necessary to provide adequate and flexible testing space for the many LMFBR fuels and materials which will be developed for the demonstration and commercial fast breeders. Its power level of about 400 MWt will provide a fast neutron flux, temperature and coolant environment similar to that of a commercial breeder. The successful achievement of high fuel burnup required for economic operation of the fast breeders will, in a large measure, be dependent on the FFTF. Full statistical confirmation of high fuel burnup will be achieved in the demonstration plants.

Research and development on physics pertinent to the LMFBR is being concentrated on acquiring accurate measurements for core criticality and safety studies and for economic analyses of reactor cores. Understanding and demonstration of the LMFBR behavior will require accurate prediction of reactivity coefficients. Major additional facilities, such as the Oak Ridge Linear Electron Accelerator and the Fast Neutron Generator at Argonne National Laboratory scheduled for 1968-69 operation, will provide cross section measurements needed to establish reactivity coefficients. It is expected that test programs in the Southwest Experimental Fast Oxide Reactor (SEFOR), in the FFTF and in the first demonstration plants will provide confirmation of predicted characteristics of the various core configurations selected and of the core physics and associated safety aspects of the LMFBR.

Several significant factors must be considered in establishing the safety of the LMFBR: the short neutron lifetime; the small delayed neutron fraction associated with plutonium; the hypothetically possible critical reassembly of the fuel in the event of core meltdown; the possibility of increased reactivity from void formation in the sodium; and the possibility of chemical reactions of sodium with air and water.

The Commission's safety program is being oriented to provide the research and to develop the components and systems necessary to resolve the many problems associated with these factors.

The LMFBR program includes operation of fuel, components, systems and instruments in sodium at temperatures up to 1200° F., in the gas over the sodium, which is saturated with sodium vapor, and in the presence of impurities in the sodium and sodium vapor. Sodium components will be developed and tested to perform in the LMFBR environment in a safe and reliable fashion. The role of impurities in the sodium is being investigated in relation to sodium heat transfer; fluid dynamics; chemistry; analysis, monitoring, and purification of sodium; and the effects and control of sodium-air and sodium-water reactions. Analytical procedures, purification methods, and detection systems are being developed based on these investigations.

Although the LMFBR program is placing immediate emphasis on the design and construction of the FFTF, plans are being developed for the introduction of a number of sodium cooled fast breeder demonstration plants to be built during the 1970s. A series of large commercial fast breeder design studies initiated by the Commission is being undertaken by several industrial firms. These will provide a basis for the design of demonstration plants which will be essential in validating the results of the over-all research and development program, in strengthening the industrial base and in obtaining acceptance of the plant types by utilities. The first utility demonstration plants to be included in the over-all LMFBR plan probably will have a capacity greater than 300 MWe, and will demonstrate or prototype as many features as possible of 1000 MWe, or larger, plants.

The commitments to build the demonstration plants will depend upon an assessment of the technological and engineering uncertainties; the economics; the financial risks; and the willingness of reactor manufacturers, utilities and the Commission to participate in and accept the projects and the risks involved. Utility acceptance probably will be motivated by the incentive of cheaper electricity. The acceptance will be contingent on developed technology, on the existence of a competitive and self-sustaining industry, and on a minimum investment of risk capital. It does not appear that a prudent commitment to build the first U.S. demonstration plant can be made prior to 1969, nor can the number of demonstration plants be predetermined. It is foreseeable that over a period of perhaps 10 years, as many as 3 to 5 demonstration plants of different designs and sizes could be built and operated.

ALTERNATE COOLANTS FOR FAST BREEDER REACTORS

Steam and helium are being considered as coolants alternate to sodium for fast breeder reactors. Fast reactor systems with coolants other than sodium are attractive only if they offer significant advantages with respect to economics, efficient use of resources, safety and timing. An assessment currently in progress on reactor systems using the alternate coolants will continue and will include a determination of the economic and technical potential of each concept; the research and development program required to achieve the objectives of each con-

cept; the resources required for development of potential demonstration and commercial plants and the timing of the plants.

Pending the results of these assessments, the alternate coolant fast breeder programs will remain at about present funding levels, concentrating primarily on key development areas, such as fuel, physics and design concepts.

Gas Cooled Fast Breeder Reactor (GCFBR)

The gas (helium) cooled fast breeder has a combination of advantageous characteristics which make it an attractive alternate to the LMFBR. It has good neutron economy, with doubling times approaching those of the LMFBR, and high temperature operation with high plant efficiency. Maintenance is facilitated by low coolant radioactivity and by the fact that the coolant is transparent and chemically inert. Coolant void reactivity and materials compatibility problems are minimal with helium. Its disadvantages include difficulty of emergency cooling, stringent limitations on steam and helium leaks, use of relatively high pressure, and high pumping power.

The GCFBR differs from the High Temperature Gas Cooled Reactor primarily in that no moderator is required and the fuel element consists of metal clad small diameter ceramic fuel pins. Both oxide and carbide fuels are of interest. The requirements and provisions for the emergency cooling system in the event of a loss of coolant accident are significantly more stringent than for the HTGR, because of the lower overall heat capacity of the system.

In a typical GCFBR the reactor and steam generators are contained in a prestressed concrete reactor vessel which also serves as the biological shield. Electricity is generated from a high pressure steam cycle with a net plant thermal efficiency of about 40 percent. The steam generators are supplied with 1000 psi high temperature helium from the reactor.

Conceptual design work was undertaken by the Commission in 1963. More recently, industry has completed conceptual design studies to establish the practicality of a 1000 MWe plant. Assessments of this concept are continuing, and projections based on these assessments will be used to determine the degree of emphasis to be placed on the program.

Steam Cooled Fast Breeder Reactor (SCFBR)

The steam cooled fast breeder has advantages associated with a large industrial capability base of useful technology from light water reactors, the possible use of a direct cycle, and high temperature operation with high plant thermal efficiency. The fact that the coolant is transparent and does not react chemically with air facilitates maintenance. There are uncertainties affecting feasibility and economic attractiveness of the SCFBR. These include the magnitude and effect of steam density and Doppler coefficients; the breeding ratio; control and safety; corrosion and radiation damage of fuel cladding; and fission product carry-over from the reactor to other parts of the system in a direct cycle.

Although study efforts have been carried out in the U. S. and abroad on the steam concept, with consideration given to both supercritical

and lower pressure steam conditions, there is little information presently available upon which to base an economic evaluation. Analysis and assessments are now in progress on lower pressure steam systems to determine the effort to be placed on the SCFBR.

Molten Salt Breeder Reactor (MSBR)

The near-term objectives of the MSBR program are the development and demonstration, to the extent required for an assessment of its potential as a commercial power plant, of an experimental breeder reactor system based on the thorium cycle. Preliminary studies show that the MSBR promises a low fissile inventory, which, when combined with a potential breeding ratio of about 1.05, may result in a relatively short doubling time. The MSBR uses a stable molten fluoride salt fuel which permits the use of nickel base structural materials. The fuel has an ionic structure that resists radiation damage. It has a low vapor pressure and is relatively inert in air, which ameliorates safety problems. Uncertainties with the molten salt breeder concept include problems with materials, components and systems needed to contain the fluid fuel and fission products, and plant maintenance.

The concept of reprocessing continually at the reactor site achieves removal of fission products and protactinium, and thus contributes to a good neutron economy and to the low total inventory of fuel. Such processing requires control of effluent and waste management appropriate to a reprocessing plant at each reactor site.

The Molten Salt Reactor Experiment (MSRE) incorporates a single region, nonbreeding circulating molten fluoride salt fuel, a graphite moderator and an air-cooled radiator for heat dissipation. The reactor attained criticality in June 1965 and since that date has served to provide information pertinent to the development of molten salt breeder reactors. It operated 30 percent of the time during 1966 at power levels up to 7.5 MWt.

The MSBR, a two-region system which has been proposed at the next step in development of the molten salt reactor concept, incorporates two separate molten salt regions, one for the core and one for the blanket. Sustained operation of the MSRE, and out-of-pile analysis and experimentation are being performed as prerequisites for demonstrating the potential of the MSBR.

The operation of MSRE and other research and development will be directed to the development of technology for a large breeder reactor. The near-term research and development efforts will include the development of graphite suitable for use as fuel tubes, the improvement of Hastelloy-N structural material, the investigation of fission product transfer, deposition and decontamination, and the design of components and instrumentation.

Desalting Program and Other Process Applications

The Commission's investigations into the potential of nuclear energy for process applications have identified large scale desalting of sea

water as a most promising process. A study by the President's Office of Science and Technology in 1963-64 concluded that large scale desalting plants using nuclear energy could produce fresh water from the sea at costs which could be economic for industrial and municipal use. Based on this favorable assessment, the President in 1964 instructed the Department of the Interior, which is responsible for desalting technology and processes, to initiate, in cooperation with the Commission, an aggressive plan to develop large scale desalting of sea water.

Intermediate and large scale dual purpose desalting plants which also produce electricity appear to offer the most favorable near-term approach to desalting water economically. A dual purpose plant with a single large size reactor, producing electricity and fresh water, has inherent economic advantages over multiple single purpose plants. The Commission's present effort in support of the desalting program depends on the use of light water reactor systems. Assessments have been made on other reactor concepts, and studies and concept design are continuing to explore the use of large scale reactors including the heavy water moderated types.

Planning studies are assessing the magnitude and nature of the effort required to develop the technology for very large scale plant construction and operation (up to 10,000 MWt), and for the coupling of nuclear power and desalting plants. Other important considerations include the determination of optimum timing, sizing and location of large dual purpose plants to meet growing water and power market demands.

A large scale dual purpose nuclear desalting project is being undertaken by the Metropolitan Water District (MWD) of Southern California, in cooperation with local power utilities and the Federal Government (Department of Interior and the AEC). It is expected that the project will be located on an artificial island off Bolsa Chica State Beach south of Los Angeles, and will consist of two light water reactors and a desalting plant. It will have a capacity of 1,800 gross MWe and ultimately will provide 150 million gallons of water per day. At design conditions, water is estimated to cost approximately 22 cents per 1,000 gallons at the plant for power costs estimated to be equal to or lower than the costs of power now being produced in the Los Angeles area.

Results of a cooperative Israel-U.S. study have indicated that a light water reactor producing in the range of 200 MWe and 100 million gallons of water per day could contribute to a solution to Israel's power and water needs. Other cooperative studies are underway with Greece to assess the potential of nuclear desalting for Athens, and with Mexico under the auspices of the IAEA to study development of the arid regions of northern Mexico and the southwestern portion of the United States.

The Commission will continue to emphasize the development of reactor technology required for economic large scale desalting. Based upon experience gained from study efforts and the MWD desalting project, the Commission will continue present development programs and will participate, as authorized, in other cooperative demonstration plant projects, probably involving larger and more advanced reactors and improved desalting systems.

The production of chemicals and metals is also being studied under the Nuclear Desalting and Other Process Applications Program. These studies will include processes requiring large quantities of low-cost process heat and electricity.

Processes which have been considered include the production of hydrogen by electrolysis of water for use in ammonia synthesis for fertilizers, the production of aluminum from alumina ore by electrolysis, the reduction of iron ore in an electric furnace, and the production of magnesium from sea water by electrolysis. Large-scale desalting, by increasing the concentration of elements and compounds in the effluent brine, may indirectly benefit the production of these products for industrial use.

The Commission will continue to assess the potential of other applications for nuclear power, such as high temperature process heat and fission-chemical processes,¹ and the use of power reactors to provide isotopes for power, radiation sources, and other uses.

Supporting Technical Programs

The 1962 Report described the supporting technical programs in general reactor technology, reactor safety, and waste management as "essential to success and to development of improved systems in the future."

These activities provide the research, exploratory development, and advanced technology necessary for accomplishing specific reactor programs, for assuring the safety of reactor installations and for providing safe and efficient methods of handling the fission products and other radioactive waste products resulting from reactor operations. The success of these supporting technical programs continues to be a vital factor in the growth and acceptance of nuclear power.

General Reactor Technology

The Commission's general reactor technology programs, conducted in industrial, university, and Commission laboratories, comprise those applied research and development activities needed to generate the technological base underlying the initiation and accomplishment of specific reactor programs and projects, to resolve critical problems and to continually assess programs and projects.

General reactor technology programs are needed to open up new areas of technology upon which future advances may be based, such as development of reactor fuels and materials capable of operating at very high temperatures; and invention of new devices and techniques, including fluid control devices and ultrasonic techniques for reactor instrumentation. Development of engineering information is necessary for the design of gas or liquid metal lubricated bearings in rotating machinery, including gas circulators or liquid metal reactor coolant pumps. Proof-of-principle experiments must be conducted to verify the performance of engineering configurations.

Fast breeder reactor fuels now foreseen will operate at higher temperatures and sustain higher burnups than light water reactor fuels.

¹ Fission-chemical processes—Chemical processes in which the reactions are initiated by fission fragments.

Similarly, the cladding and other structural materials used in fast breeder reactors will receive neutron dosages much greater than those sustained in the light water reactors; thus, potentially they will be subject to greater neutron damage. General reactor technology programs have identified problems such as fuel swelling and possible loss of strength and ductility of fast reactor materials, and will provide an understanding of these problems and a basis for their solution.

The satisfactory status of calculational techniques achieved for thermal reactors must now be attained for fast reactors and advanced converters.

Aqueous fuel processing research and development is directed toward providing technology for application to advanced thermal reactor and fast reactor fuels. Volatility processing research and development is being conducted on fluoride processes to demonstrate economic potential for the recovery of power reactor fuels. Partial decontamination pyrochemical methods are under development for longer range application to provide economic fast breeder reactor fuel recycle systems.

Reactor Safety

The primary objective of the reactor safety program as stated in the 1962 Report is "to maximize the inherent safety of reactor installations." The achievement of this objective requires the development of safety related technology, criteria, standards and codes and associated safety research and development facilities, and an integrated procedure by which the programmatic and regulatory interest can be coordinated.

The results of the present light water reactor safety program, involving the studies of reactor behavior under major power excursions without loss of coolant and reactor behavior with loss of coolant, are being applied to the design of light water reactors. The results of containment experiments now underway will make possible more efficient containment vessel designs which will maximize safety and minimize costs.

Engineered safety features specifically designed to prevent accidents or to minimize their consequences, will be developed on a priority basis. Examples of engineered safety features now being developed are: methods of scavenging radioactivity in containment buildings to reduce leakage effects; detection of incipient cracking in reactor piping and vessel materials; emergency core cooling (sprays, flooding) to prevent fuel meltdown; methods of estimating and reducing reactor containment building leakage; surface coatings that absorb radioactive fission product iodine; tests to determine plant component and instrumentation reliability during operation; improved blast shields to contain explosion effects; and methods for safely venting fission products from fuel elements. Development work will include field tests of engineered safety systems. Other engineered safety features will be developed as plant operating experience and continuing safety experiments indicate their needs; these include means for minimizing effects of potential seismic disturbances.

The question of location of large central station nuclear power plants is complex. The advent of reactors in the 1000 MWe range and

the incentive on the part of utilities to locate such plants closer to load centers have introduced additional important siting questions. Resolution of siting problems requires emphasis on providing reliable experience with advanced types of containment structures and other engineered safety features, experience in coping with all operating conditions, and provisions for designs with a high margin of safety.

Work in the safety program is being oriented to the advanced reactors. Emphasis will be placed on research which will provide the knowledge necessary for determining the safety problems associated with these reactors and will provide the base for the developments which may be necessary to resolve the problems. Developments will include, where necessary, the demonstration of the course and consequences of abnormal conditions, and the development of counter-measures for these conditions.

Radioactive Wastes

Safe and economic management of radioactive waste from an expanding nuclear power industry, and the development of methods for this management are essential. The waste management problem for the nuclear industry may be considered in two parts (1) the handling, treatment, and disposal at nuclear power plants of liquid, solid, and gaseous wastes with very low levels of radioactivity, and (2) the processing and disposal of much smaller volumes of highly radioactive wastes from commercial fuel reprocessing plants.

NUCLEAR POWER PLANT WASTES

The management of radioactive wastes at nuclear power plants is not expected to impede the development of the nuclear industry. Waste systems for power reactors have been constructed which provide double containment of pipes and tanks in the event of leakage, and adequate capacity and flexibility for the future.

Waste treatment and storage systems which concentrate and contain or dilute and disperse the radioactive wastes have been developed for the light water reactors. In many cases, liquid waste radioactivity is allowed to decay in storage, and released without further treatment when the activity is reduced below prescribed limits. The waste volumes handled at power reactor facilities (up to 50,000 gallons per day for 300 MWe plants) are quite small in comparison with industrial wastes from many other industries. Radioactivity concentrations in existing nuclear power plant effluents, with no environmental dilution, have ranged from one to three per cent of amounts allowed by AEC radiation protection standards, with are compatible with internationally accepted standards.

Solid wastes are baled and sealed in containers. Liquid non-combustible wastes are fixed in concrete in standard 55-gallon drums. The waste containers are disposed of in approved commercial burial grounds. Solid waste volumes for a nuclear plant such as Dresden and Yankee amount to several thousand cubic feet per year. Commercial land burial costs at locations in the States of New York, Kentucky, Nevada and Washington range from \$0.65 to \$1.50 per cubic foot.

The capacity and availability of suitable land burial facilities are more than sufficient for even the most optimistic growth projections.

Radioactive gases are normally produced in water-cooled and moderated reactors through irradiation and radiolytic decomposition of reactor water, its impurities, and any traces of air in the water. Defects in fuel element cladding may also permit small amounts of the fission gases present in the fuel to be released into the reactor coolant water. Radioactive particulate matter, present in waste gases after hold-up for decay, is generally passed through high efficiency filters which remove 99.9 percent of the particles 0.3 micron in size or larger, before discharge to the atmosphere. Radioactive gaseous effluents are continuously monitored on site. Off-site monitoring is provided by both State and Federal agencies. Nuclear power plant records indicate gaseous discharges only one-tenth of one percent of permissible limits. On-site waste management processes for light water reactors developed over many years have been proven adequate for adaptation to the large plants now under commitment. The increasing emphasis on breeder reactors and plutonium and uranium-233 fuels requires a continuing development of waste treatment and disposal technology.

Waste management systems at the reactor power plant are estimated to account for about 2 percent of the total reactor facility cost, and operation and maintenance ranges from 5 to 10 percent of the over-all plant operation and maintenance costs.

FUEL REPROCESSING PLANT WASTES

Chemical reprocessing of irradiated reactor fuel produces highly radioactive wastes which must be contained and isolated for hundreds of years. In chemical reprocessing operations on production reactor fuels, over 65 million gallons of such high activity wastes have been satisfactorily handled to date.

The growth of nuclear power now is leading to increasing amounts of reprocessing plant wastes. However, improvements in fuels and in the reprocessing of fuels have served to reduce markedly the volume of wastes generated per unit of nuclear heat produced. Present estimates indicate an accumulated volume of wastes from the reprocessing of nuclear power fuels by 1980 of less than 4 million gallons and 40 million gallons (180 ft. cube) by the year 2000.

While more than 20 years' experience with storage of liquid high activity wastes in tanks has shown it to be a safe and practical means of interim waste handling, the long effective life of the wastes and the comparatively short life of storage tanks require that the Commission pursue a program aimed at developing and demonstrating, on an engineering scale, systems for the conversion of high level liquid wastes to stable solids and their subsequent storage in a dry geologic formation such as salt. The resultant volume, about a 60 foot cube by the year 2000, indicates a possible reduction by a factor of 27 below that for liquid storage.

Solidification and disposal technology for high-activity waste has reached the pilot plant and field demonstration phase. Results of these research and development programs will be made available to industry during 1967-69 for use in the commercial reprocessing of spent reactor fuel.

Further technical progress in waste management has been the engineering development of hydraulic fracturing—a method for injecting certain types of intermediate level liquid wastes into specific geologic formations. Research and development on this method at Oak Ridge has proceeded to the point where it is now being used operationally. The possible use of this technique in other areas will be investigated during 1967–68.

Methods for removal of the fission product krypton-85, from gaseous effluent streams, and from fuel reprocessing operations, are to be studied during 1967–69. These techniques could be used to prevent a long term buildup of this radionuclide in the atmosphere above prescribed limits.

Waste management research, during 1967–72, will emphasize the development of systems and equipment for advanced reactors and their associated chemical processing plants, which will prevent the release of hazardous concentrations of radioactive effluents produced from these operations.

High activity waste treatment and ultimate storage have been estimated to cost between 0.02 to 0.03 mills/KWh. This represents about one to two percent of the total fuel cycle cost and substantially less than two percent of the cost of nuclear power in a 4 mills/KWh economy. Waste management costs will be a minor fraction of nuclear power costs and should not deter the development of safe and economical nuclear power.

Discontinued Programs and Projects

The 1962 Report stated of the advanced converters :

“The Commission must continue to evaluate these systems carefully against the criteria described. Some should be carried to the stage of building operating prototypes during the next several years, but only when significant advantages seem reasonably assured.”

Evaluations since the 1962 Report have shown that some of the concepts described in the report were only marginally superior to others whose success was nearer at hand, and their development has been terminated. Other concepts have been discontinued because of especially difficult research or developmental engineering problems and the accompanying increased costs, delays, and difficulties associated with introducing the concept into the utility environment.

The advanced converter reactor development program described in the 1962 Report was assessed during 1964 in an evaluation of five promising reactors. The concepts considered were the High Temperature Gas Cooled Reactor (HTGR), the Heavy Water Moderated Reactor, which included organic and water cooled versions, the Light Water Seed-Blanket Reactor (LSBR), the Sodium Graphite Reactor (SGR), and the Spectral Shift Reactor (SSR). The HTGR, the Heavy Water Moderated Reactor—organic cooled version (HWOCR), and the LSBR were selected for continued support.

The Sodium Graphite Reactor (SGR) program, initiated in Fiscal Year 1957, was directed toward the development of a sodium cooled and graphite moderated reactor. The concept included the design, construction and operation of the Sodium Reactor Experiment (SRE) and the Hallam Nuclear Power Facility (HNPF). A principal con-

sideration influencing the decision to discontinue the SGR concept in 1964 was uncertainty regarding the economic competitiveness of the concept. This uncertainty, combined with serious technical problems with the Hallam nuclear reactor core requiring costly modifications, resulted in the termination in August 1965 of Commission support for the HNPF. The SRE was terminated in December 1966, because its support for the SGR was no longer needed and its use in the LMFBR program was not of sufficient priority to warrant additional expenditures for conversion and operation of this facility.

The Spectral Shift Reactor (SSR) using a thorium fuel cycle concept and a varying mixture of heavy and light water as moderator and coolant, was given serious consideration as a means for providing good fuel use and economic nuclear power. Congress, in 1963, authorized \$30 million for the development, design, construction and operation of a demonstration plant, and in February 1964 the AEC invited proposals for the construction of a 150 MWe Spectral Shift Reactor. However, the 1964 evaluation resulted in a decision not to support the concept or to construct a demonstration plant, because the reactor did not offer significantly better economic potential than the light water reactors.

The Heavy Water Component Test Reactor (HWCTR), placed in operation in 1962, was used to investigate fuel element designs and to provide other data pertinent to pressurized heavy water reactors. Analysis of heavy water moderated systems indicated lower capital and fuel cycle costs, and a lower heavy water inventory in a system cooled with either an organic fluid or light water than could be obtained in a system cooled by heavy water. This analysis formed the basis for concentrating research and development on the Heavy Water Moderated Organic Cooled Reactor (HWOCR). The HWCTR was shut down in December 1964 and placed in a standby status.

The Experimental Gas-cooled Reactor (EGCR) project, started in 1957, was terminated in January 1966 before construction was completed. Construction of the EGCR was begun in 1959 with completion initially scheduled for 1962. Important factors contributing to the decision to terminate were continuing design and engineering difficulties with corresponding delays and rising costs, the diminishing potential of timely and significant contribution of the EGCR project to commercial development of high temperature gas-cooled reactor technology, and competing demands for limited funds.

Commission support of the general development of the thermal reactor superheat program was terminated in 1966, except for cooperative commitments to Bonus and Pathfinder. This decision was a consequence of the development of the current light water reactors which produce saturated steam, and of the technical status of the superheat program. At the time of the decision to terminate support of the program, commercial vendors were not willing to offer nuclear superheat reactor plants until additional irradiation experience on nuclear superheat fuel was obtained. The thermal reactor superheat concept was designed to produce high temperature steam resulting in a high overall nuclear power plant thermal efficiency. Uncertainties included the design complexity of the reactor, problems associated with the fuel element materials, and the risk of radioactive contamination of the steam circuit in a direct cycle reactor.

The Experimental Beryllium Oxide Reactor (EBOR) project, started in 1958, was terminated in December 1966. Major contributing factors to this decision were continuing serious technical problems with some components, the associated risks of schedule delays and increased costs, and the low priority requirement for beryllium oxide irradiation data in view of the favorable progress in the development of graphite as the reference moderator for high temperature gas reactors.

The Los Alamos Molten Plutonium Program (LAMPP), started in 1957, was discontinued in mid-1966, and construction of the Fast Reactor Core Test Facility (FRCTR) was terminated. The Los Alamos Scientific Laboratory research and development effort in the field of fast reactors is being focused on plutonium bearing ceramic fuels and on sodium technology, which are areas of technology closer to the LMFBR effort.

International Programs

Advances in development of the U.S. nuclear power programs have drawn to a substantial extent on interchanges of information with foreign programs. A brief review of the status and prospects for the major Free World reactor programs, other than the U.S., is thus appropriate.

Belgium

Belgium is substantially involved in many phases of nuclear development. Two small power reactor projects have been undertaken; Vulcain, a 30 to 50 MWt spectral shift reactor at University of Liege, and BR-3 at Mol, a 10.5 MWe PWR. Two 600 MWe nuclear units are planned for the early 1970s.

Canada

The near-term Canadian power reactor development program is based on the heavy water moderated and cooled pressure tube reactor (CANDU) which has the potential for low fuel cycle costs. The heavy water moderated-boiling light water cooled reactor (HWBLW), is being developed on a long-term basis as an evolution of the CANDU concept. Plans have been announced for construction of a 250 MWe HWBLW prototype, to be located in Quebec, and completed in 1971. Interest is continuing in the organic cooled heavy water moderated reactor on a low priority basis. This program is linked to the U.S. HWOCR effort.

The heavy water moderated and cooled commercial nuclear power plants include the 200 MWe Douglas Point nuclear power plant which became operational in 1966, and two 500 MWe units under construction at Pickering, near Toronto, which are expected to be in service in 1970 and 1971. Pickering is being planned to accommodate 4000 MWe in nuclear capacity by the year 1980.

Euratom

The Euratom Community, consisting of Belgium, France, Italy, West Germany, the Netherlands, and Luxembourg, is responsible for a considerable portion of the research and development for the civilian nuclear power programs in the Community.

A light water reactor program, initiated in 1959, has had as its objective an industrial complex capable of developing designs based upon U.S. light water reactor concepts. The Euratom program has included the development of advanced converters such as heavy water moderated organic cooled ORGEL reactors using natural or slightly enriched uranium and high temperature gas reactors using enriched uranium or thorium fuel. Euratom participates in the development of the West Germany Arbeitsgemeinschaft Versuche Reactor (AVR). The AVR, a 15 MWe pebble bed reactor located at Juelich, is helium cooled and graphite moderated and uses enriched uranium or thorium fuel.

The Euratom fast reactor program, predicated on the introduction of large fast breeder reactors about 1980, has its main efforts located in France and Germany. Euratom has arranged for the irradiation of several fast reactor subassemblies in the Dounreay reactor. Irradiations are also planned in the Fermi reactor assuming resolution of the Fermi fuel failure.

A joint civilian nuclear power program was initiated by the European Atomic Energy Community (Euratom) and the United States in 1958. The joint effort has been aimed primarily at improving the performance of light water reactor systems as represented by the three power reactors now operating in the Community under the U.S.-Euratom joint power reactor program.

The three reactors included under the joint power reactor program are the 150 MWe plant of the Garigliano Nuclear Power Station (SENN), operating at Punta Fiume, Italy, the 266 MWe reactor of the Société d'Energie Nucleaire Franco-Belge des Ardennes (SENA) at Chooz, France, and the 237 MWe power plant of the Kernkraftwerk RWE-Bayernwerk (KRB), at Gundremmingen, West Germany.

EUROPEAN NUCLEAR ENERGY AGENCY (ENEA)

The ENEA sponsors Dragon, a 20 MWt high temperature helium cooled graphite moderated advanced converter reactor, built at Winfrith Heath in the U.K. This reactor attained criticality in August 1964, reached full power operation in April 1966, was shut down on schedule at the end of August 1966 for refueling and placed back in power operation in January 1967. ENEA plans to operate Dragon until the end of 1967. A three year extension of the program beyond this date is under consideration. Dragon, built as an international demonstration plant, has concentrated on the development of fuels for large HTGR type reactors.

The ENEA also sponsors Halden, a heavy water moderated boiling heavy water cooled reactor located in Norway. The reactor power level for the third core is 25 MWt. Future work (1967-1969) will concentrate on experiments with high fuel heat ratings, thorium fuel, physics of thorium fueled reactors, in-core instruments, on-line computer control, and fuel irradiations.

France

The French Commissariat à l'Energie Atomique (CEA) development effort has been concentrated on natural uranium fueled, graphite moderated, carbon dioxide cooled reactors similar in design to the UKAEA Magnox reactors. The magnesium alloy clad metal fuel has performed well and will be used in plants under construction. Improvements such as prestressed concrete pressure vessels and an internally and externally cooled annular (INCA) fuel element with inner and outer fins, are being introduced for the later large-sized INCA reactors.

The CEA interest in advanced converters centers on an 80 MWe heavy water moderated, carbon dioxide cooled reactor now being constructed for intended use with a natural uranium fuel cycle. The CEA has placed in operation a 25-ton per year heavy water pilot plant as a first step in its heavy water production program.

The CEA fast breeder program has concentrated on the development of a sodium cooled concept. Consideration is being given to committing construction of a 250 MWe demonstration plant in 1969. Studies related to fast reactors are carried out in the framework of an association between Euratom and the French CEA and include the 20 MWe sodium cooled Rapsodie reactor and the Harmonie and Masurela air-cooled critical assemblies.

Germany

Germany will rely on light water reactors to supply most of its anticipated nuclear power capacity (about 10,000 MWe by 1980) until fast breeder reactors are developed. The 237 MWe BWR based on U.S. designs at Gundremmingen, (KRB), built under the Euratom-U.S. joint program, was completed in 1966.

A 100 MWe heavy water moderated gas-cooled reactor demonstration plant scheduled for 1969 operation will provide experience in the use of natural uranium as a fuel.

The German research and development effort is concentrated on fast breeder reactors, with the effort directed toward achieving the information necessary to commit the construction of demonstration plants for one or both of the two fast breeder types under consideration, sodium or steam cooled. The Netherlands and Belgium will participate in this program.

Greece

An April 1966 joint agreement with the U.S. included provision for studies of water desalting and nuclear power needs. A preliminary study was completed in December 1966.

India

The development of commercial nuclear power in India to date has been based on the purchase of the American BWR and the Canadian heavy water moderated and cooled (HWR) reactor types. The selection of the second Canadian HWR reactor reflects India's interest

in the possible use of its thorium resources in this type of reactor. Two 190 MWe BWR reactors are being built at Tarapur for 1968-69 operation, and two 200 MWe HWR reactors are under construction at the Rajasthan Atomic Power Plant (RAPP) for 1970-71 operation. Two 200 MWe HWR reactors, planned for the Madras Atomic Power Plant (MAPP), are scheduled for operation in 1971-72.

A technical exchange program has been initiated between India and the United States which includes thermal and fast reactor technology.

Israel

A cooperative Israel-U.S. study concluded that a dual purpose light water reactor desalting plant could contribute to a solution of Israel's power and water needs. Israel is determining the feasibility of proceeding with such a project.

Italy

The commercial development of nuclear power in Italy has to date been based on the purchase of U.K. and U.S. reactors. Italy has three operating nuclear power plants: a 210 MWe U.K. Magnox type plant (Latina); a 169 MWe American BWR (Garigliano), built under the Euratom-U.S. joint program and a 300 MWe American PWR (Fermi Trino). Plans include seven 600 MWe nuclear plants to be added in the 1970-75 period.

Italy has under consideration the development of dual purpose desalting-nuclear power plants for its arid regions.

Japan

Japan is relying primarily on technical exchanges with United States and United Kingdom reactor and fuel fabricators for the development of domestic manufacturing capabilities. Efforts are being made to establish a domestic nuclear industry based on light water technology obtained from the United States.

The Japanese are developing a heavy water moderated boiling water cooled advanced converter. Japanese nationals are also being assigned to participate in fast breeder projects in other countries.

Japan has in operation two nuclear power plants, an 11.7 MWe BWR, and a 169 MWe Magnox type plant. A 310 MWe BWR is being built and plans include an additional 12 nuclear power units for operation in the 1971-74 period with a capacity of about 4000 MFe.

Mexico

A joint International Atomic Energy Agency (IAEA)-Mexico-U.S. agreement in 1965 provided for studies of dual purpose desalting-nuclear power plants, now being conducted by a joint team of specialists. Mexico is also determining the feasibility of supplying fresh water to Mexico City by desalting using nuclear energy.

Norway

Plans are underway to operate a nuclear power plant in Norway by 1975. Projections indicate 4,500 MWe of nuclear power by 1980. Norway has a substantial investment in research and development for nuclear power.

Pakistan

A 132 MWe Canadian heavy water nuclear power plant is being built at Karachi. Studies of dual purpose desalting-nuclear power plants are underway.

Portugal

Feasibility studies and discussions are underway between Spain and Portugal to undertake a 500 MWe nuclear power plant (HUELVA).

South America

Argentina and Brazil are the only two countries in South America which are considering the development of nuclear power, probably in the 1970s, but have reached no decisions to date.

Spain

Spain has two U.S. light water nuclear power plants under construction: a 153 MWe PWR (Zorita) and a 460 MWe BWR (Nucenor) scheduled for completion in 1968 and 1970, respectively. Spain is also planning the construction of a 30 MWe HWOCR reactor (DON) and is undertaking a joint venture with France for a 500 MWe natural uranium gas cooled nuclear plant (Cataluna) near Vandellos for operation in 1971.

Two other nuclear plants of comparable capacity, but of undefined type, are being considered for construction, one the Castellon plant near Peniscola and the other a joint project with Portugal in the province of Huelva near Ayamonte.

Sweden

Sweden's primary interest in nuclear power has been the development of heavy water reactors. In 1963, Sweden placed in operation a 10 MWe natural uranium heavy water reactor plant (Agesta), and currently is building a 200 MWe slightly enriched, boiling heavy water plant (Marviken) for operation in 1969. The interests of the Swedish electric utilities in the U.S. light water reactors have also resulted in a decision to build a 400 MWe BWR (Simpevarp) near Oskarshamn which is scheduled for operation in 1970.

Switzerland

Switzerland has selected two heavy water moderated reactors for prototype development, one light water cooled, and the other gas cooled. However, the commercial plants currently planned for operation utilize the U.S. light water reactor designs. A 350 MWe PWR (NOK) located at Beznau, is under construction for operation in 1969. In addition a 250 MWe BWR (BKW), located at Berne, and a 500 MWe PWR or BWR, located in Zurich, are planned for operation in 1971 and 1972-73, respectively.

United Arab Republic (UAR)

The UAR has under consideration a 150 MWe 5 million gallons of water per day dual purpose desalting-nuclear power plant at Borg el-Arab.

United Kingdom (U.K.)

The United Kingdom (U.K.) nuclear power plant capacity consists primarily of 3000 MWe of graphite moderated, carbon dioxide cooled Magnox type plants. These plants use natural uranium metal fuel elements clad with magnesium alloy. The experimental Dounreay Fast Reactor (DFR) also provides a small electrical output (15 MWe). The U.K. has no light water moderated and cooled nuclear power plants and has indicated no programmatic interest in this type of reactor.

The Magnox reactors, using on-line refueling, are designed for high plant availabilities. The 590 MWe Wylfa plant, scheduled for operation in 1968, uses a pre-stressed concrete pressure vessel containing the entire primary system. Once-through steam generators are designed to produce steam at about 750 psia and 750°F. The thermal efficiency is expected to be 31.4 percent, and burnups of 3000-4000 MWD/T are estimated for the magnesium alloy clad uranium metal fuels.

The present U. K. program is based upon a transition from the Magnox to the Advanced Gas Reactor (AGR) plants. Improved performance over the Magnox plants is attained by operating at higher fuel clad temperatures and coolant pressure (maximum 1472° F., 450 psia) than found in the Magnox plants (842° F., 400 psia). Average burnup of 18,000 MWD/T is predicted for the stainless clad UO₂ fuel. High steam pressure and temperature (2315 psia, 1050° F.) for the 600 MWe Dungeness B plant, the first unit in the AGR program, results in a 41.5 percent thermal efficiency as contrasted to 31.4 percent for the Wylfa plant.

Two 600 MWe units, Dungeness B-1 and B-2, are being built for 1970 operation. By 1975 the expected 5,000 MWe capacity from the Magnox plants will be increased by 8,000 MWe from the AGR plants.

In its future development program, the U. K. has placed the highest priority on the liquid metal cooled fast breeder program begun in 1951, and since 1959 it has used the 15 MWe DFR, fueled with a uranium-molybdenum alloy, for irradiating prototype ceramic fuel

for the Prototype Fast Reactor (PFR). Construction of the 250 MWe PFR was begun at Dounreay early in 1966 with operation scheduled for 1971. The PFR is the demonstration plant for the large (about 1000 MWe) fast reactor nuclear power plants which the UKAEA believes will prove economical for the national grid after 1975. The demonstration plant will be fueled with plutonium-uranium oxide and will have its primary components (reactor, pumps, heat exchangers) in a large tank, similar to EBR-II.

The U.K. also is building a 93 MWe steam generating (boiling water cooled) heavy water moderated reactor (SGHWR) scheduled for operation in 1967. The SGHWR utilizes Zircaloy pressure tubes and slightly enriched UO_2 (about 1.42 percent). This concept, with its low capital cost, low fuel enrichment and refueling flexibility, is visualized by the U.K. as a low cost alternative for medium-sized nuclear plants.

Other

Many of the remaining countries of the Free World such as Australia, Denmark, Finland, Korea, and the Philippines, are now planning for the development of nuclear power in the 1970s.

Legal and Administrative Matters

Policies Relating to Nuclear Materials

In the 1962 Report, the Commission indicated that it favored legislation to permit private ownership of special nuclear materials. The Private Ownership Act was passed in 1964 and may be considered an important element in the 1965 and 1966 surge of orders for nuclear power plants.

A key element of the Private Ownership Act was the provision for a transition period to private ownership. AEC may continue to distribute special nuclear materials by lease for power reactor use until January 1, 1971, and lessees may retain materials on lease until July 1, 1973. It is expected that reactor inventories gradually will be transferred to private ownership through toll enriching during the transition period, although a specific provision has been made for installment payments on cash purchases of such inventories sold before July 1, 1973. The transition also is being smoothed by a provision that guarantees a purchase price for plutonium or uranium-233 (if produced through the use of special nuclear material leased or sold by AEC) delivered through December 31, 1970. The guaranteed market for uranium-233, but not plutonium, may be extended by the AEC beyond 1970. These prices have been set at the estimated fuel value of \$10 per gram of fissile plutonium and \$14 per gram of uranium-233. The uranium-233 price is subject to discount for uranium-232 content, which complicates fuel handling because of radioactive daughter products, and for uranium-238 content. Prices for both materials are subject to adjustment in proportion to the AEC's charge for enriched uranium.

The new law also authorized the AEC to provide toll enrichment services whereby raw materials normally will be purchased on the open market, rather than from the Government, and will then be processed to uranium hexafluoride in privately-owned plants, enriched in the Government-owned gaseous diffusion plants, and further processed into fuel elements under private auspices. Private commitments for purchase of uranium concentrate for use as feed under the terms of this enrichment service, which will start after December 31, 1968, have improved the near-term outlook for the uranium mining and milling industry, as evidenced by firming prices and the signing of contracts for the delivery of feed in 1968 and later years. The availability of the enriching service also is expected to encourage the use of nuclear power abroad and the foreign sale of U.S.-designed reactor systems using enriched uranium.

Under Section 161v of the Atomic Energy Act, the AEC on December 23, 1966, established criteria under which the uranium enrichment services will be provided. The criteria provide that the AEC will offer to contract to supply separative work for periods up to 30

years, at a unit charge to be announced, but subject to a ceiling. The ceiling will be \$30 per unit of separative work¹ plus escalation for power and labor costs beyond July 1, 1965.

In addition to the toll enriching criteria, a number of related AEC policies with respect to sale and lease of enriched uranium during the transition period have been announced in order to help the nuclear industry estimate the relative economics of sale, lease and toll enriching. In order to encourage the emergence of a viable domestic uranium market, the AEC will continue to base its enriched uranium sale or lease charge schedule on \$8 per pound of U_3O_8 through June 30, 1973. Ownership of leased inventories of enriched uranium may be acquired after December 31, 1970, by a transaction equivalent to toll enriching (customer delivers uranium feed and dollars to AEC and acquires ownership of a corresponding amount of the leased inventory). This process is referred to as "in situ" toll enriching.

Contracts offered by the AEC to implement the enrichment services criteria may be signed at any time, but the services may not commence before January 1, 1969. The contracts contain a provision permitting termination by the Government if comparable commercial uranium enriching services become available from another domestic source on reasonable terms and at reasonable prices within the AEC ceiling charge. This will permit the Government to be relieved, as may be judged appropriate, of strictly commercial commitments extending over the life of these contracts.

One possible source of a commercial enriching service could be the disposition of one or more of the three AEC gaseous diffusion plants to a privately or publicly financed corporation. The AEC is conducting an internal study on the feasibility and desirability of transfer of gaseous diffusion plants to private operation. The Commission is also discussing with the Atomic Industrial Forum the scope and ground rules for a proposed Forum study of such transfer.

Price-Anderson Indemnity

The Price-Anderson provisions of the Atomic Energy Act of 1954, as amended, afford protection to the public and to AEC licensees and contractors from the risks associated with atomic energy by providing for a program of private insurance and governmental indemnity amounting to a maximum of \$560 million to cover damages that conceivably could arise from a nuclear incident. The statute provides for a limitation of liability of all persons indemnified in the event of a nuclear incident resulting in claims which exceed the total amount of private insurance and governmental indemnity. By amendment in 1965 (Public Law 89-210), this indemnity program was extended until August 1, 1977, and the amount of Government indemnity (\$500 million for licensed reactors) was reduced by the amount that the private insurance required exceeds \$60 million. The present capacity of the nuclear energy liability pools, and the amount of private insurance required for large power reactors, is \$74 million.

In 1966, the Price-Anderson provisions were further amended (Public Law 89-645) to provide authority for the Commission and

¹ Separative work—A measure of energy required to enrich uranium.

insurers to make emergency assistance payments available to claimants immediately following a nuclear incident without requiring claimants to sign a general release. Also, the Commission may require parties to indemnity agreements or financial protection policies to waive certain issues or defenses.

Finding of Practical Value

A distinction between developmental and commercial licenses is contained in the Atomic Energy Act of 1954. Section 102 states that whenever the Commission finds that any type of production or utilization facility has been sufficiently developed to be of practical value for industrial or commercial purposes, the Commission may thereafter issue licenses for such type of facility only pursuant to Section 103 of the Act. Until the time of the finding of practical value, the Commission is to continue its policy of issuing licenses for production and utilization facilities pursuant to Section 104 of the Act, the developmental section. The original intent of this provision of the Act was to provide the Commission with discretionary authority over commercial reactor plant construction, based upon determining that there was sufficient availability of nuclear fuel.

In 1964, the National Coal Policy Conference, the National Coal Association and the United Mine Workers of America petitioned the Commission to make a finding of practical value for pressurized and boiling water reactors.

On December 29, 1965, the Commission said, in denying the petition from the coal groups, that although the economic prospects for nuclear power in the United States are very favorable, a statutory finding of practical value for light water reactors within the meaning of Section 102 of the Atomic Energy Act must await an adequate appraisal of the economics, based on demonstration of the technology and performance of large nuclear plants now under construction.

On August 29, 1966, the Commission advised the Joint Committee of its belief that there is no continued need for the requirement of a formal finding of "practical value" as embodied in Section 102, or for the statutory distinction between licenses issued for production and utilization facilities under Section 103 (commercial licenses) and Section 104b (research and development licenses), and that the Commission is giving consideration to preparing legislation on this subject.

On October 18, 1966, the National Coal Policy Conference, the National Coal Association and the United Mine Workers of America again petitioned the Commission to make a finding of practical value for light water reactors. The petitioners cited the large number of firm commitments made by utilities during 1966 for nuclear electric plants, and noted the order by TVA for a nuclear plant in an area where coal is cheap. On December 23, 1966, the Commission, in denying the petition, stated:

"The Commission believes that the basis for its Determination of December 29, 1965, is equally valid today and that the matters set forth in the new petition filed on October 18, 1966, do not provide sufficient grounds to warrant a change in its position. The developments since December 29, 1965, cited by the petitioners, are further strong indications that economic competitiveness will be achieved. The Commission continues to believe, however, that it should await a reliable estimate of the economics based

upon a demonstration of the technology and plant performance. Pending the completion of scaled-up plants, and the information to be obtained from their operation, the Commission remains of the view that there has not yet been sufficient demonstration of the cost of construction and operation of light water, nuclear electric plants to warrant making a statutory finding that any types of such facilities have been sufficiently developed to be of practical value within the meaning of section 102 of the Act."

Licensing and Regulation

To accommodate the electric power industry's rapidly increasing plans for nuclear power plants, several major steps have been taken since 1962 to improve and simplify the facility licensing process. Three-man atomic safety and licensing boards have been established and mandatory public hearings have been limited to the construction permit stages.

Progress is being made in developing reactor safety standards. General design criteria for nuclear power plant construction permits are being developed. These criteria, which have evolved from AEC licensing experience, will be used as a guide for reactor design and performance. Concurrently, the AEC is working with industry organizations to develop supplementary specific design performance criteria for components and systems of the light water reactors.

An improved technical specifications system for reactors was recently issued for comment and interim guidance. The changes in this system will focus attention of both licensee management and the AEC on those reactor features which are vital to safety. The proposed regulation changes also give guidance to applicants on the types of information needed by the AEC at the construction permit stage and at the operating license stage.

A guide on the preparation of safety analysis reports has been issued, specifying more clearly the information needed by the AEC for its safety evaluation. It is expected that this guide will further assist applicants and help expedite review of licensing cases.

An increasing number of prospective applicants are meeting with the AEC staff in advance of filing applications to obtain informal views on siting questions, safety features of projected reactors, and information on licensing procedures. The regulatory staff also has offered the opportunity to manufacturers to conduct prelicensing reviews of the reactor systems and components to reduce subsequent licensing time.