CIVILIAN NUCLEAR POWER

... a Report to the President — 1962

U.S. ATOMIC ENERGY COMMISSION

UNITED STATES
ATOMIC ENERGY COMMISSION
WASHINGTON 25, D. C.

OFFICE OF THE CHAIRMAN

November 20, 1962

Dear Mr. President:

I am pleased to submit herewith the report resulting from our "new and hard look at the role of nuclear power in our economy," as requested by you on March 17, 1962. In preparing this report, we have had the benefit of comments and advice from interested offices and individuals within and without the Government. However, the Commission takes full responsibility for the conclusions and recommendations of the report.

The Commission, of course, has concentrated on issues related to the development and use of nuclear power; it has not attempted to appraise the possible effect of major research efforts on the economics of non-nuclear energy sources or on improved transmission methods for either source of energy. However, the study has been greatly aided by the information furnished by the Department of Interior, the Federal Power Commission, and the National Academy of Sciences Committee on Natural Resources.

Those who have participated in the study you requested are agreed that it has proved to be very timely. While the Commission has been proceeding on a considered course in general accord with its 10-year civilian power program adopted in 1958, that program is now on the threshold of attaining its primary objective of competitive nuclear power in high-fuel-cost areas by 1968. However, it became evident with the passage of time that our attention had probably for too long remained focused narrowly on short-term objectives. This restudy made it apparent that, for the long-term benefit of the country, and indeed of the whole world, it was time we placed relatively more emphasis on the longer-range and more difficult problem of breeder reactors, which can make use of nearly all of our uranium and thorium reserves, instead of the less than one per cent of the uranium and very little of the thorium utilized in the present types of reactors. Only by the use of breeders would we really solve the problem of adequate energy supply for future generations.

We believe that it still is necessary for the Government as a interim measure to maintain a substantial program of research and development on advanced types of reactors other than breeder reactors, which are some years away. It appears from the projections made that efficient converter reactors will be required in conjunction with breeder reactors to meet the rapidly growing national demands for electrical power. This Government program over the next several years is also important since it provides the national means for "bridging the gap" between the infancy and maturity of nuclear power. This interim aid will allow the consolidation of the gains made to date and will permit the national nuclear program to proceed in an efficient and sensible manner toward the development of more efficient and economical converter reactors and eventually breeder reactors.

Furthermore, a vigorous national nuclear power program can be pursued without interfering with a growing coal industry; in fact, all our projections indicate that, even assuming an optimistic forecast of nuclear power development, the use of coal by the rapidly expanding electric generating industry will increase severalfold over the next 40 years.

It should be recognized that, largely as a result of early optimism, we have, in a short space of time, developed a competitive nuclear equipment industry which is over-capitalized and under-used at the present time. This optimism has had some good results in terms of bringing many able technical men, manufacturers, and utility executives into the field, and assuring Congressional and industrial support during the development years.

The optimism has also brought about some difficuties in that unless there are new starts on atomic power plants, the atomic equipment industry will probably dwindle down to fewer manufacturers than would be desirable for a healthy and competitive nuclear industry. Fortunately, it now appears that only relatively moderate additional governmental help will be necessary to insure the building of a substantial number of large, water-type power reactors that will be economically competitive in the high-fuel-cost areas of this country and the world. This would increase public acceptance, keep the nuclear industry healthy, and help to furnish the plutonium necessary for a breeder reactor economy as soon as it can be adequately developed.

In summary, nuclear power promises to supply the vast amounts of energy that this Nation will require for many generations to come, and it probably will provide a significant reduction in the national costs for electrical power.

The Commission unanimously concurs in this report.

Respectfully yours,

Glenn T. Seaborg

Glenn T. Seaborg
Chairman

The President
The White House

Enclosure

THE WHITE HOUSE
Washington

March 17, 1962

Dear Mr. Chairman:

The development of civilian nuclear power involves both national and international interests of the United States. At this time it is particularly important that our domestic needs and prospects for atomic power be thoroughly understood by both the Government and the growing atomic industry of this country which is participating significantly in the development of nuclear technology. Specifically we must extend our national energy resources base in order to promote our Nation's economic growth.

Accordingly, the Atomic Energy Commission should take a new and hard look at the role of nuclear power in our economy in cooperation with the Department of the Interior, the Federal Power Commission, other appropriate agencies, and private industry.

Your study should identify the objectives, scope, and content of a nuclear power development program in the light of the Nation's prospective energy needs and resources and advances in alternate means for power generation. It should recommend appropriate steps to assure the proper timing of development and construction of nuclear power projects, including the construction of necessary prototypes. There should, of course, be a continuation of the present fruitful cooperation between Government and industry—public utilities, private utilities, and equipment manufacturers.

Upon completion of this study of domestic needs and resources, there should also be an evaluation of the extent to which our nuclear power program will further our international objectives in the peaceful uses of atomic energy.

The nuclear powerplants scheduled to come into operation this year, together with those already in operation, should provide a wealth of engineering experience permitting realistic forecasts of the future of economically competitive nuclear power in this country.

As you are aware, two major related studies are now or will soon be underway. The study being conducted at my request by the National Academy of Sciences on the development and preservation of all our national resources will focus on the Nation's longer term energy needs and utilization of fuel resources. The other study to be launched soon by the Federal Power Commission will determine the long-range power requirements of the Nation and will suggest the broad outline of possible programs of growth for all electric power companies—both private and public—to meet the great increase in power needs. Your study should be appropriately related to these investigations.

The extensive and vigorous atomic power development programs currently being undertaken by the Commission should, of course, be continued and, where appropriate, strengthened during the period of your study. I urge that your review be undertaken without delay and would hope that you could submit a report by September 1, 1962.

Sincerely,

/s/John F. Kennedy

Dr. Glenn T. Seaborg
Chairman
Atomic Energy Commission
Washington 25, D. C.

Civilian Nuclear Power

a Report to the President

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Introduction

As a result of successes achieved during World War II, it was widely recognized thereafter that nuclear energy could, if properly developed, have important civilian applications. In addition to unique applications in scientific research, in medicine, in agriculture and in industrial operations, it was believed by many that nuclear energy could yield large economic advantages in such massive applications as the generation of electric power. It was also recognized, though not emphasized, that over the long term it would be an important resource, whose timely introduction would help conserve for special uses our finite supply of fossil fuels.

The long-term availability of abundant and economic sources of energy and the development of new techniques and technologies of general applicability are matters of concern to all the people and therefore to the government. Federal responsibility for the peaceful development of civilian uses of nuclear energy—for both short- and long-term ends—within our normal economic and industrial framework was clearly recognized by Congress in the Atomic Energy Act of 1946, and clarified and broadened in the Act of 1954. The latter states in Section 1 (Declaration):

> "It is . . . declared to be the policy of the United States that—
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> "b. the development, use and control of atomic energy shall be directed so as to promote world peace, improve the general welfare, increase the standard of living, and strengthen free competition in private enterprise."

And in Section 3—(Purpose):

> "It is the purpose of this Act to effectuate the policies set forth above by providing for—
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> "a. a program of conducting, assisting, and fostering research and development in order to encourage maximum scientific and industrial progress;
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> * * *
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> "d. a program to encourage widespread participation in the development and utilization of atomic energy for peaceful purposes to the maximum extent consistent with the common defense and security and with the health and safety of the public;" and
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> "e. a program of international cooperation to promote the common defense and security and to make available to cooperating nations the benefits of peaceful applications of atomic energy as widely as expanding technology and considerations of the common defense and security will permit;"

Many sections of the Act and many other acts of Congress expand on the above provisions and provide means and mechanisms for implementing them.

In keeping with the responsibilities assigned it by the legislation, the Atomic Energy Commission has conducted vigorous programs of research, development, and exploitation, directed at realizing the many peaceful benefits potentially to be derived from nuclear energy. Included in the applications are many, such as those of radioisotopes, where nuclear phenomena have special characteristics that are uniquely useful. The major effort has, however, been directed at extraction of energy in large amounts, primarily to accomplish conventional tasks or extensions of them. The most promising, and hence the most vigorously pursued among the various applications, is that of generating electric power. It is with the power program that this report primarily concerns itself.

The Commission has conducted and encouraged a national program, aimed, first, at obtaining the basic scientific and engineering data needed for proof of technical feasibility and safety of the more promising approaches to nuclear power generation and, second, at demonstrating the actual or potential economic feasibility of such approaches. This program has been strongly backed in both the executive and the legislative branches of the Government.

In its early phases the program was largely one of developing the technology. It leaned heavily upon, indeed it started from, knowledge gained from other reactor programs, notably "production" reactors for making plutonium, naval propulsion reactors and "research" and "test" reactors used for scientific purposes. In 1953 the Commission, with the encouragement of the Joint Committee on Atomic Energy, embarked upon a five-year "experimental" program to develop reactors giving promise for civilian power applications. Construction was started on several experimental power-producing reactors on Commission sites, and one "prototype" reactor on a utility grid.*

The revision of the Atomic Energy Act in 1954, which encouraged industrial cooperation, and associated policy decisions by the Government resulted in continued expansion of the program by both government and industry. An important step was the addition, in 1955, of a "Power Demonstration" program under which the Commission and industry have cooperated in building and operating a number of nuclear power plants on utility grids. In one segment of this program, Commission-built and -owned "prototype" reactors are operated by utilities that buy the steam; in another segment utilities are given research and development assistance in designing and constructing their own reactors and, for a few years no charge is made for the lease of Government-owned nuclear fuel.

In 1958, as the five-year experimental program ended, the Joint Committee on Atomic Energy of the Congress published a report, prepared by its staff with the advice of consultants, recommending objectives for an expanded program and various steps that might be taken in furtherance of the program. During that and the following year, the Commission conducted, at the national laboratories and through contracts with the nuclear equipment industry, a series of detailed studies and evaluations of all the reactor concepts believed to hold promise for the development of economic nuclear power. The results were carefully analyzed by the Commission staff and, on two separate occasions, by advisory committees. On the basis of these studies, analyses and recommendations, the Commission published a series of reports, known to the trade as the "Ten-Year Program", which established short-range economic targets as well as long-range goals in economics, resource

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* This Commission-built and -owned reactor, at Shippingport, Pa., provides steam at a plant of an investor-owned utility, which built the power generating equipment and operates the reactor under contract with the Commission.

conservation and international leadership, and outlined a program for achieving these objectives. This has served as a general guide to the Commission during the intervening period.

Meanwhile, beginning with initiation of the "Atoms for Peace" program in 1954, and more intensively since the large International Conference on that subject in 1955, the Commission, in cooperation with the Department of State, has been very active internationally. The United States was the leader in the establishment of the International Atomic Energy Agency which conducts and sponsors cooperative programs throughout the world. The Agency will increasingly be responsible for administering safeguards against diversion of nuclear materials to military use and for developing and recommending international regulations on safety and waste disposal. Cooperation and assistance have been rendered by the United States through formal agreements with such international organizations as EURATOM, and with a large number of individual nations. Western Europe and, more recently, Japan have significant nuclear power programs in being as has the Soviet Union. Considerable interest in nuclear power has also been shown by many of the developing countries.

As a result of the various domestic programs, six sizeable reactors of the more highly developed types are in successful operation on utility grids (two of the largest and one other had no AEC assistance); seven more of small and medium size will be completed by the end of 1963; a few others are under construction or nearly so.

Sufficient developmental and operational experience has been accumulated to permit a reasonably accurate assessment of future possibilities. Nuclear electric power has been shown to be technically feasible, indeed, readily achieved. Power reactors can be reliably and safely operated. However, contrary to earlier optimism, the economic requirements have led to many problems—combining low capital cost with long life and assured reliability; lowering costs by improved efficiency; developing long-lived and, therefore, economic fuels. Attempts to optimize the economics by working on the outer fringes of technical experience, together with the difficulties always experienced in a new and rapidly advancing technology, have led to many disappointments and frustrations. Experiments have not always worked as planned. Many construction projects have experienced delays and financial overruns. Such difficulties led to considerable diminution of the earlier optimism regarding the early utilization of nuclear power, which in turn contributed to the withdrawal of some equipment and component manufacturers from the field.

Happily, more recently much progress has been made toward solutions of these problems. Expectations are being more nearly, and in some cases completely realized. Nuclear power is believed to be on or near the threshold of competitiveness with conventional power for large plants, in areas of the country where fossil fuel costs are high. Further cost reductions are definitely in sight, provided an aggressive program is continued.

The developments to now have verified that, if extensively used, nuclear power could have important implications—as a means of exploiting a large, new energy resource; as an economic advantage, especially to areas where fossil fuel costs are high; as an important contributor to new industrial technology and to our technological world leadership; as a significant positive element in our foreign trade; and, potentially, as a contributor to the nation's defenses. Its potential benefits will actually be realized, however, only if it can be made economically attractive.

To surmount the economic hurdle is the most immediate program goal. Unfortunately the reactors that will do so can extract only about one percent of the energy potentially available in our reserves of nuclear materials. To utilize the rest, which must be done if nuclear energy is to be of lasting usefulness, requires the development to an economic status of more advanced and difficult reactors. This will be a rigorous and expensive task.

How best to pace the short- and long-term efforts, what relative emphasis to give to each, how diversified and intensive the total effort should be—these are the principal program questions.

The stage of development has also brought forward a number of important policy questions. Many of them relate to nuclear fuels. With extensive applications potentially in the offing, the question naturally arises as to the desirability of changing, at a reasonably early date, to private ownership of special nuclear materials. Its adoption would give rise to the corollary question of policy relating to the "toll" enrichment of privately-owned uranium in the government's diffusion plants, a service which private industry cannot economically provide for itself; this question arises internationally in any case. Action must be taken on the Commission's raw uranium procurement program, contracts for which expire in 1966, and on extension and adjustment of its schedule of guaranteed prices for plutonium produced in non-government reactors, which expires in 1963.

Clearly the time has come for a major review and reassessment—a review more of basic policies than of detailed technical activities; a review of where the nuclear electric power program should be headed, at what rate and with what amount of government participation. It is to these ends that this study has been made.

* * *

A study of this nature requires special knowledge in many fields outside the detailed cognizance of the Atomic Energy Commission. Among these are current and projected rates of use of energy, including electric power requirements, our reserves of fossil fuels, and economic trends in these and related fields. We have, therefore, worked closely with, and relied heavily upon, other agencies and groups that are expert in these fields. We have also taken advantage of studies and evaluations that have been, or are being made by others in such fields as the international impact of nuclear energy, the civilian defense and national security aspects of the problem, and the air pollution problems of fossil fuel plants. Of especial value have been recent reports, some in draft form, prepared by the Department of the Interior, the Federal Power Commission, the National Academy of Sciences, the Committee on Interior and Insular Affairs of the United States Senate, the General Advisory Committee to the Atomic Energy Commission, and the Advisory Committee on United States Policy Toward the International Atomic Energy Agency.

We have had helpful discussions on the content of the report with the Bureau of the Budget, the Office of Science and Technology, the President's Science Advisory Committee, the Council of Economic Advisors, the Department of the Interior, the Federal Power Commission, the General Advisory Committee, and the Joint Committee on Atomic Energy of the Congress. However, the contents of the report are the responsibility solely of the Atomic Energy Commission.

During the early weeks of the study a series of seminars was held at which representatives of AEC contractor organizations, various industries and others made presentations of their own civilian power programs.

A list of reports and discussions is given in an Appendix together with acknowledgments of more informal assistance.

Summary

The Need for Nuclear Power

Our technological society requires ample sources of energy. Although large, the supplies of fossil fuels are not unlimited and, furthermore, these materials are especially valuable for many specific purposes such as transportation, small isolated heat and power installations, and as sources of industrial chemicals. Reasonable amounts should be preserved for future generations.

Comparison of estimates of fossil fuel resources with projections of the rapidly increasing rate of energy consumption predicts that, if no additional forms of energy were utilized, we would exhaust our readily available, low-cost fossil fuels in a century or less and our presently visualized total supplies in about another century. In actual fact, long before they become exhausted we will be obliged to taper off their rate of use by supplementing them increasingly from other sources.

In contrast, our supplies of uranium and thorium contain almost unlimited amounts of latent energy that can be tapped provided "breeder" reactors are developed to convert the fertile materials, uranium-238 and thorium-232, to fissionable plutonium-239 and uranium-233, respectively.* 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 use of nuclear energy for electric power and, less immediately, for industrial process heat and other purposes is technically feasible and economically reasonable. In addition to its ultimate importance as a means of exploiting a large new energy resource, nuclear electric power holds important near-term possibilities: as a means of significantly reducing power generation costs, especially in areas where fossil fuel costs are high; as an important contributor to new industrial technology and to our technological world leadership; as a significant positive element in our foreign trade; and, potentially, as a means of strengthening our national defense.

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*The readily fissionable material found in nature is confined to uranium-235 which constitutes only 0.7% of normal uranium. The energy contained in this isotope in uranium mineable at near present costs is only a small fraction of that contained in our fossil fuel reserves. Fortunately, the so-called "fertile" isotopes, uranium-238, constituting the remainder of normal uranium, and thorium-232 constituting practically all normal thorium can be converted to fissionable plutonium-239 and uranium-233 by absorption of neutrons in a nuclear reactor.

In view of the above we have concluded that: Nuclear energy can and should make an important and, ultimately, a vital contribution toward meeting our long-term energy requirements, and, in particular, that: The development and exploitation of nuclear electric power is clearly in the near- and long-term national interest and should be vigorously pursued.

The Role of the Federal Government

The technological development of nuclear power is expensive. The reactors are complex, and operating units, even of a scaled-down test variety, must of necessity be large and costly. Furthermore, nuclear power does not meet a hitherto unfilled need but must depend for marketability on purely economic advantages that will return the development investment slowly. Hence, the equipment industry could not have afforded to undertake the program by itself. The Government must clearly play a role.

An early objective should be to reach the point where, with appropriate encouragement and support, industry can provide nuclear power installations of economic attractiveness sufficient to induce utilities to install them at their own expense. Once this is achieved the Government should devote itself to advanced developments designed to meet long-range objectives, leaving to industry responsibility for nearer-term improvements. Gradually, as technological maturity is reached, the transition to industry should become complete.

Thus, the proper role of Government is to take the lead in developing and demonstrating the technology in such ways that economic factors will promote industrial applications in the public interest and lead to a self-sustaining and growing nuclear power industry.

The Present Situation

Accordingly, in keeping with national policy, and with the responsibilities assigned to it by the Atomic Energy Act, the Atomic Energy Commission has conducted and encouraged a vigorous program directed toward the development and extensive exploitation of nuclear energy for civilian purposes, with emphasis on nuclear electric power. About $1.275 billion has been expended by the AEC to date* on the civilian power program. This program has included both research and development and a "power demonstration" program, involving aid in the construction and operation of practical reactors on utility

*We estimate that industry has expended approximately $0.5 billion of its own funds, mostly for plant and equipment.

grids. Several reactor types are under development. Most highly developed are "converter" reactors that produce less fissionable material than they consume; much less far along are "breeder" reactors that produce more than they consume.

In one segment of the power demonstration program, Commission-built and -owned "prototype" reactors are operated by utilities that buy the steam; in another segment, utilities are given research and development assistance in designing and constructing their own reactors and, for a few years no charge is made for the lease of Government-owned nuclear fuel. Six sizeable reactors of the more highly developed types are in successful operation on utility grids (the two largest without AEC assistance); seven more will be completed by the end of 1963; a few others are under construction or nearly so.

Experience has shown that nuclear electric power is readily achieved technically but difficulties have been met in developing a technology that is economically competitive with conventional power generation methods. Happily, in recent years these difficulties have been progressively overcome.

Certain classes of power reactors, notably water-cooled converters producing saturated steam are now on the threshold of economic competitiveness with conventional power in large installations in high fossil fuel cost areas of the country. Foreseeable improvements will substantially increase the areas of competitiveness.

Technical Considerations

Saturated steam reactors, however, have certain inherent limitations. They produce relatively low temperature saturated steam which limits their efficiencies and requires the use of large, expensive turbines; they are only moderately effective converters.* Consequently, converter concepts utilizing other moderators and coolants and promising improved economics and fuel utilization are being actively pursued with encouraging results; early competitiveness seems assured for some of them. All of these are "thermal"† reactors. They include the "spectral shift" reactor, the high temperature gas-cooled re-

*They convert 0.5 to 0.7 as much material as they consume. Compounded, this results in doubling to tripling the energy finally made available.

†In a "thermal" reactor most of the fission neutrons are slowed-down (moderated) before interacting with the nuclear materials; this is accomplished through many collisions with light nuclei such as hydrogen (in water or organic compounds), carbon (in graphite) or beryllium. In a "fast" reactor, little or no moderation is used, so that most of the neutrons retain the high energies and velocities with which they were emitted in the fission process. "Intermediate" reactors lie between.

actor, and the sodium-graphite reactor. All have relatively high efficiencies and excellent economic promise. The first two will have excellent conversion ratios; indeed they may eventually be made to breed in the thorium-uranium cycle.* The sodium-graphite reactor can achieve quite high temperatures, has good safety features and helps develop the liquid sodium technology necessary for fast breeders. The heavy water moderated reactor also shows promise of high conversion ratios but present designs are not so attractive economically as other types in the United States. The organic-cooled and -moderated reactor may have application for process heat. Some of these should be carried to the stage of operating prototypes during the next several years, and some will reach the full-scale operational phase by the early 1970's. Operating reactors of these types will help accelerate the industry, will increase operating experience and will help provide plutonium needed for the breeder program.

Although much technical progress has been made, breeder reactors have not yet reached an economically useful stage of development. Even when they do, they will not, initially at least, make new material fast enough to provide the fuel for new plants at the rate required if nuclear power is to increase its proportional share of the national electric power load. Hence, even after breeders become available, it will be necessary to fuel some portion of the installations with uranium-235 until such time as improved breeding gains and reductions in the relative rate of growth in power consumption enable the breeders to be self-sufficient. For the thermal reactors used to make U-233 from thorium, this need can be met by substituting U-235 for U-233 in some of them, at a sacrifice in fuel produced. A similar procedure would, however, be uneconomic in the "fast" reactors required to breed plutonium. Hence, in the transition stage, which will last for many decades, fast breeders that burn as well as make plutonium will probably be augmented by thermal converters burning U-235 and producing plutonium at a slower rate. This need will enhance the desirability of the more advanced converters both for economic reasons and because it is important that the combination of breeders and converters reaches an overall net breeding capability, or very nearly so, while relatively cheap fuel supplies are still available.

In our opinion, economic nuclear power is so near at hand that only a modest additional incentive is required to initiate its appreciable early use by the utilities. Should this occur the normal economic processes would, we feel, result in expansion at a rapid rate. The Government's investment would be augmented manyfold by industry. Equipment manufacturers could finance major technical developments, thus reducing the future need for Government participation.

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*See footnote, page 7.

Continuation of the Commission's present effort, with some augmentation in support for the power demonstration program, and with program adjustments to give added emphasis to breeders, would, we believe, provide industry with the needed stimulus to build a significant number of large reactors in the near future, would bring nuclear power to a competitive status with conventional power throughout most of the country during the 1970's, and would make breeder reactors economically attractive by the 1980's.

Under these conditions, we estimate that by the end of the century nuclear power would be assuming the total increase in national electric energy requirements and would be providing half the energy generated.* This rate of progress, projected into the next century, would be an important step in conservation of the fossil fuels and, unless breeders lagged the converters much more than we predict, would raise no problems in nuclear fuel supplies.

Under conservative cost assumptions, it is estimated that by the end of the century the above projected use of nuclear power would result in cumulative savings in generation costs of about $30 billion.† The annual saving would be between $4 and $5 billion. High cost power areas would no longer exist, since, in the absence of significant fuel transportation expenses, the cost of nuclear power is essentially the same everywhere. This would be an economic boon to areas of high cost fossil fuels and, by enabling them to compete better, should increase the industrial potential of the entire country.

More generally, the introduction of nuclear power technology on a significant scale would add to the health and vigor of our industry and general economy. Technical progress would assist the space and military programs and have other ancillary benefits. Our international leadership in the field would be maintained, with benefit to our prestige and our foreign trade. Nuclear power could also improve our defense posture; it would not burden the transportation system during national emergencies; furthermore, the "containment" required for safety reasons could, if desired, be achieved at little, if any, extra cost by underground installations, thus "hardening" the plants against nuclear attack.

A substantially lesser program would sharply reduce these benefits. Too great a slowdown could result in losing significant portions of industry's present nuclear capability thereby seri-

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*Since, by Federal Power Commission estimates, the total use of electric energy will grow tenfold in the same period, fossil fuel consumption for this purpose would still increase by a factor of from four to five.

†At 5% interest these cumulative savings would have a discounted value of about $10 billion in 1970.

ously delaying the time at which it would assume a major share of the development costs.

On the other hand we do not believe that a major step-up in the whole Commission program is appropriate. Taken as a whole, support of the scientists and engineers engaged in developmental work is about adequate and, in view of the country's other needs, it would seem unwarranted to increase appreciably such manpower in this field.

To summarize we have concluded that the nuclear power program should continue on an expeditious basis. Commission support should continue with added emphasis on stimulating industrial participation. The program should include: (1) early construction of plants of the presently most competitive reactor types; (2) development, construction and demonstration of advanced converters to improve the economics and the use of nuclear fuels; (3) intensive development and, later, demonstration of breeder reactors to fill the long-range needs of utilizing fertile as well as fissile fuels.

An important corollary area is the development of economical chemical reprocessing methods whereby useful fissile and fertile materials are recaptured from used fuel assemblies and the fission products are removed. Another important line of work concerns the ultimate storage or disposal of the large amounts of radioactive fission products that will be generated when a major power industry comes into being.

An overriding consideration is that of safety. Not only must inherent safety be assured in fact but its existence must be conclusively demonstrated to the public. With adequate technical improvements and the accumulation of satisfactory experience, it should be possible gradually to remove many of the siting restrictions in force today, thus permitting plant locations closer to the large load centers.

Possible Construction Program

A composite construction program for the next dozen years might entail the following: (1) the construction and placing into operation of seven or eight power-producing prototype reactors, approximately half of which would be advanced converters and the rest breeders; most of their cost would probably be borne by the AEC; (2) assistance, as necessary, to industry in the construction of 10–12 full-scale power plants of improving design as time goes on; hopefully, industry will concurrently bear full costs of many more of well proven design.

This construction would, of course, be backed by specific development programs directed at the more advanced reactor types, especially breeders, and by research and development related to the underlying technology.

Legal, Financial and Administrative Matters

Careful attention must be paid to several legal, financial and administrative questions, among them (1) private ownership of nuclear materials and related policies on fuel pricing and "toll enrichment"; (2) policies relating to the raw material and other supporting industries; (3) licensing and regulation, including reactor siting criteria.

The commission has recommended that private ownership of special nuclear materials be authorized at an early date, thus permitting the free play of normal economic forces and minimizing economic distortions of the technology. To prevent sudden dislocations such ownership should not be made mandatory for a decade or so.

The Commission further believes that a policy of "toll enrichment" or equivalent should be adopted. Industry could then buy its raw materials on the open market, use privately owned plants to prepare them for enrichment, and depend upon the Government only for the actual enrichment in the diffusion plants. This service should also be extended to our friends abroad, subject to proper safeguards against diversion for military use.

Before and during the period of transition to private ownership the value set by the Commission on enriched uranium for lease or sale should, as at present, be determined by the actual cost, with appropriate allowances for depreciation and other indirect expenses. The Commission has recommended that prices for the purchase of plutonium be in accordance with its "near-term" value as a reactor fuel. We believe that consideration should be given to scaling the price in accordance with the content of fissionable isotopes. The same pricing policies should apply to purchases abroad of plutonium made from uranium enriched in the U. S.

The Commission's contracts with uranium miners and processors expire at the end of 1966. Since it seems probable that the requirements for new uranium for weapons, the dominating use to date, will decrease in the next decade, careful planning is necessary to so guide further procurement that the uranium industry will be kept viable during any slack period before civilian power creates another large demand. With this in mind the Commission is planning to offer the industry a "stretch-out" program under which an AEC commitment to purchase additional material after January 1, 1967 would be used as an incentive to induce industry to delay until after that date delivery of part of the uranium presently under contract. If successful, this program would result in a leveling-off process that should carry through the period of slack use without injuring the industry substantially or resulting in an unreasonably large surplus.

The Commission intends to continue and extend encouragement to the industrial activities ancillary to the major equipment industry. Many that could start on a small scale are already well underway. There are, however, a few activities, such as the chemical separation of used fuels, that are attractive to industry only on a fairly substantial scale and for which there will be little private business until civilian reactors have operated for an appreciable period. Strong encouragement is being given to private industry to embark in these fields with some prospect of success. As rapidly as a private capability comes into being the Commission should withdraw from all such work deriving from industry and should utilize private plants to fill its own requirements except, perhaps, for those related to materials for weapons.

Recognizing that simplifying and streamlining licensing and regulatory procedures can be a major help in encouraging the utility industry to adopt nuclear power, the Congress and the AEC have been taking steps in this direction. A major step is the recent enactment of laws that will reduce greatly the number of mandatory public hearings for reactor licensing. The Commission is studying means of simplifying its own licensing procedures by reducing the volume and complexity of administrative processes. Further operating experience should reduce the time and effort required for technical analysis and review.

Objectives for the Future

Clearly: 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.

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 isotppes 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.

The role of the Commission in achieving these objectives must be one of positive and vigorous leadership, both to achieve the technical goals and to assure growing participation by the equipment and utility industry as nuclear power becomes economic in increasing areas of this country and the world at large.

The Need for Nuclear Power

Nuclear Energy as a Resource

Next to the land, the water, and the air, without which we could not exist at all, energy is by far the most important of our terrestrial resources. Without it our industrial society would be impossible. In common with the other three it has no substitute.

Today's society depends almost entirely upon energy originating in the sun. The vast bulk of this has been stored during hundreds of millions of years in the form of fossil hydrocarbons such as coal and oil. The storage process proceeds so slowly that, in terms of foreseeable human history, replenishment must be considered negligible. Although the supply is vast, we are consuming these materials at such a rapidly increasing rate that if not supplemented they will begin to approach exhaustion within the span of a few generations.

The domestic fuel situation can be understood by reference to Figures 1 and 2, showing on an annual rate and on a cumulative basis respectively, various estimates* of future use of fossil fuels in the U. S., and, in Figure 2, authoritative estimates of our total reserves.

The total energy contained in our recoverable fossil fuels of all grades is variously estimated to be between 30 Q† (Energy Study by the Committee on Natural Resources of the National Academy of Sciences; National Fuels and Energy Study of the Committee on Interior and Insular Affairs of the United States Senate) and 130 Q (Energy Policy Staff; Department of the Interior).‡ The primary causes of the spread are apparently differences in estimates as to the quantity of "marginal resources" (e.g., coal in thin veins and/or at great depths), differences in assessments of the feasibility and cost of recovering such mar-

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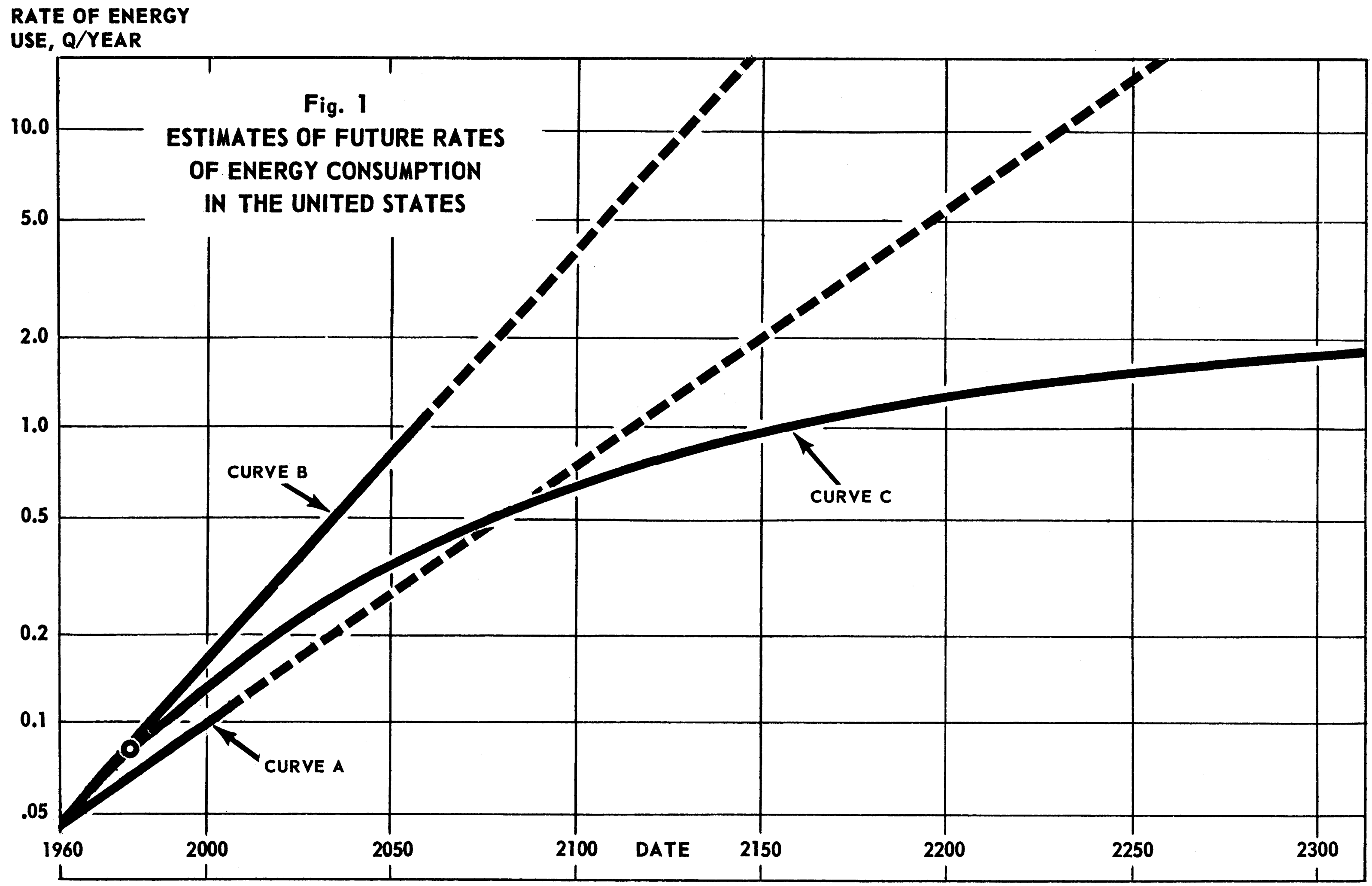
*As indicated by dashed lines on the figures we have extrapolated somewhat farther than did the authors of the estimates. In doing so, we have used the same mathematical formulae as did they, although, of course, they did not assert them to have validity for such longer term extrapolations.

†In discussing total energy reserves or cumulative energy consumption, unwieldy numbers are avoided by using a very large unit, the Q (for quintillion) equal to one billion-billion British thermal units (BTU) or 25 billion-billion kilocalories of energy. This is equivalent to the energy available in approximately 40 billion tons of average high-grade coal. The U. S. currently consumes about $1/_{20}$ Q per year.

‡Geological Survey Bulletin 1136, "Coal Reserves of the United States" estimated remaining recoverable reserves of fossil fuels in the U. S. at 25.7 Q. (Page 98).

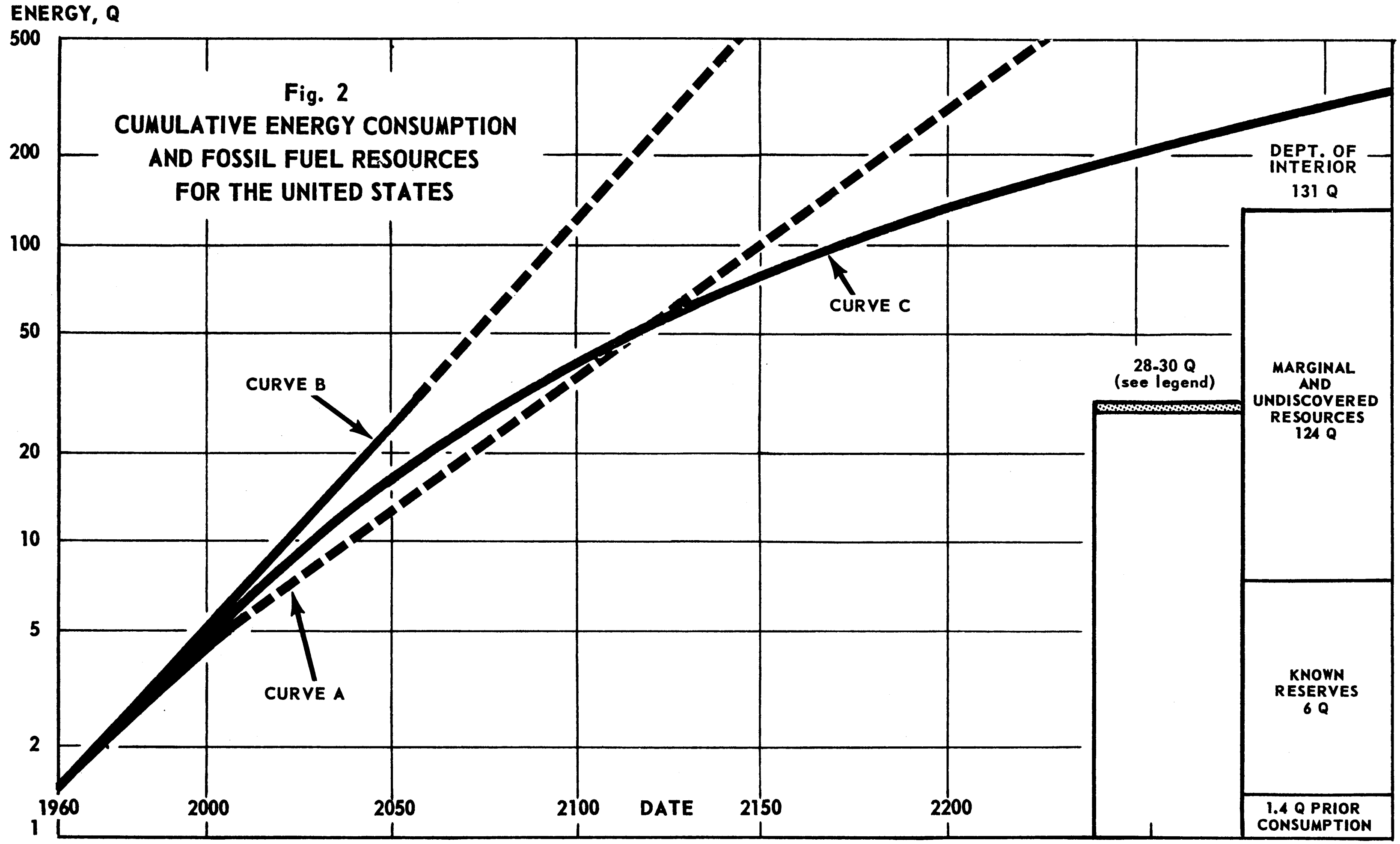
Fig. 1
ESTIMATES OF FUTURE RATES OF ENERGY CONSUMPTION IN THE UNITED STATES



CURVE A is an extrapolation of the experience of the last 50 years. It is based on Fig. 15 in the 1962 report "Energy Resources," prepared for the National Academy of Sciences Committee on Natural Resources.

CURVE B is an exponential curve, by the Department of the Interior, passing through the value O estimated for 1980 in the September 21, 1962 "Report of the National Fuels and Energy Study Group, on an Assessment of Available Information on Energy in the United States, to the Senate Committee on Interior and Insular Affairs."

CURVE C has the same initial rate as Curve B but incorporates downward trends in relative rates of growth in population and per capita use as explained in the text.



CURVES A. B. and C represent cumulative energy use at the corresponding rates from Fig. 1

Fossil fuel resource estimates are indicated by the bars on the right. The estimates of 28-30 Q are given or implied by: the September 21, 1962 "Report of the National Fuels and Energy Study Group, on an Assessment of Available Information on Energy in the United States, to the Senate Committee on Interior and Insular Affairs;" the 1962 report "Energy Resources," prepared for the National Academy of Sciences Committee on Natural Resources; and the estimate of recoverable reserves in the 1961 Geological Survey Bulletin 1136, Page 98.

The Department of the Interior has indicated an informal opinion that, of its estimate of 124 Q in undiscovered and marginal resources, perhaps 24 Q can be recovered with improved technology at costs up to 10-15% above present levels. The remainder would probably be increasingly expensive, to a degree depending upon the effectiveness of new technology.

ginal resources, and different assumptions as to the fraction actually recovered in a given operation; there is little disagreement on the amount of readily recoverable reserves. The Interior Department believes that of its total estimate about 6 Q can be mined at present cost with known technology and, say, an additional 25 Q at 10% to 15% higher costs, provided the technology of mining exploration and extraction is much improved by further research. The remainder would presumably be increasingly expensive with inaccessibility, to a degree depending upon the effectiveness of new technological methods.

Although our current consumption of slightly less than .05 Q per year is small compared to the above figures, the rate is increasing so rapidly as soon to be far from negligible. Estimates of future consumption use past experience to derive estimates of future growth in population and in per capita use of energy. For example, curve A in each figure represents an extrapolation of experience during the past 60 years, when the average increase in annual fuel consumption was 2.04%, or a doubling every 30 years. It is probably conservative, at least for the next few decades, since the past increases would have been much greater had it not been for improved efficiency of use which is now beginning to approach theoretical limits in certain important fields.

The estimate represented by curve B is based on more recent experience. It is an extrapolation of an estimate for the year 1980, made by the National Fuels and Energy Study of the Committee on Interior and Insular Affairs of the United States Senate and is the mean, in terms of relative increase in consumption, among several estimates furnished us by the Department of the Interior. It can be thought of as a composite of the 1.75% annual rate of population growth during the past decade and a 1.5% annual rate of increase in per capita use.* This seems to us a reasonable estimate for the next few decades, but population pressures and a tendency to saturation in per capita use seem likely to result in a leveling-off process in the more distant future. For illustrative purposes we have constructed curves C, in which the average decrement in the relative rate of population growth since 1850 has been applied to the extrapolated population figures† and an arbitrary decrement has been applied to the relative rate of increase in per capita consumption such as to halve it each 100 years. (The latter would still result in tripling the per capita use during the next century.)

* The average annual increase in per capita use during the past decade was about 1%.

† The annual rate of population increase declined from approximately 3.5% per year in the 1850's to 1.75% during the 1950's. The formula used predicts a population of about 320 million in 2000 A.D. and, if extended indefinitely, would saturate at about one billion.

As can be seen, different combinations of the estimates of fuel reserves and of cumulative uses would predict that, if no supplementary forms of energy were utilized, we would exhaust our readily available, low-cost supplies of fossil fuels in from 75 to 100 years and our presently visualized total supplies in from 150 to 200 years. Even if ultimate exhaustion of these materials were made tenable by the introduction of acceptable substitutes for every purpose, the transition would not be made suddenly. Long before the point of exhaustion of the fossil fuels, we would be obliged to taper off their use, passing through a maximum, perhaps within the life-span of persons now alive.

The fossil fuel resources of the world at large are relatively more limited. With but 6% of the world's population, it is estimated that the United States has approximately 30% of the world's reserves of fossil fuels.* The remainder of the world is consuming its reserves at approximately the same fractional rate as we but has been increasing its consumption two to three times as rapidly.† The rapid growth of technology in the less advanced areas—which we are endeavoring to foster—will tend to accelerate this relative increase. Hence, unless we export fuel, the non-U. S. supply will be exhausted considerably before our own. In any case, it seems certain that dependence on foreign sources cannot assist materially the long-range conservation of our total domestic resources of fossil fuels.‡

The long-range prospect should concern us even when considered only in the gross. It is more impressive in detail. In many important applications the fossil fuels have special advantages that are not matched, at least directly, by their foreseeable large-scale substitutes such as fission, fusion, or solar energy. Such substitutes are not directly applicable, for example, to small mobile power units such as the internal combustion engines that drive our autos and our aircraft, although in time effective energy conversion schemes may be developed to make them indirectly so. Fossil hydrocarbons are essential in the iron and steel industry and other metallurgical applications. Furthermore, these hydrocarbons represent a priceless heritage of complex molecular substances, the possible uses for which are only beginning to be realized.

The conclusion seems inescapable: <u>We should, with reasonable expedition, supplement the use of fossil fuels in those applications for which technically satisfactory and reasonably</u>

*Estimate of the Energy Study of the Committee on Natural Resources of the National Academy of Sciences.

†Consumption rates from the United Nations Statistical Papers "World Energy Supplies," Series J, No. 1 to 5. The estimates have taken account of present import rates.

‡This statement does not necessarily apply in detail, for example, to petroleum; however, oil represents only a small fraction of the total resources.

economic substitutes can be utilized on a significant scale.*

As implied in the above conclusion, the ability of any potential source appreciably to supplement our total energy supply rests on positive answers to two questions: (1) Are there technically feasible and economically reasonable ways to utilize the source, and (2) are the potential uses and the available supply of sufficient size to be quantitatively significant? Such positive answers are indeed applicable to important uses of nuclear energy.

Of the two forms of nuclear interactions from which energy can presently be derived, fission and fusion, only the former can now be made to occur in a controlled manner. Whether or not methods of producing controlled and useful fusion reactions can also be developed is not yet predictable. It seems likely that, at best, useful controlled fusion devices are far in the future and that, if they do eventuate, they will be economically feasible only in extremely large installations. Accordingly, our discussions will be confined to the fission reaction.

A major portion of our consumption of fossil fuels is for the simple purpose of providing heat—heat to make steam for driving turbines, heat for use in industrial processes, heat to warm buildings. Now the nature of a nuclear fission reactor is such that most of the fission energy ultimately appears in the form of heat, applicable to the same purposes as that derived from fossil fuels.

There are, to be sure, certain limitations. It is characteristic of nuclear reactors that they must, at best, be relatively large and must usually be surrounded by massive radiation shields. Furthermore, the unit costs for energy become attractive only on a large-scale basis. Hence, their feasible uses are confined to fixed installations—or to large, mobile units such as ships—where there is a large local need or where some energy distribution method can be utilized efficiently.† Another restriction, hopefully diminishing with knowledge and experience, results from the fact that, for safety reasons, prudence now dictates placing large reactors fairly far away from population centers.

Two large-scale industrial applications of nuclear energy are technically feasible—electric power generation and process heat. These uses of fuel now account respectively for approximately 20% and 30% of the fossil fuel consumption in the country and electric power is rapidly increasing its fraction. Nuclear

*Though recognizing the possibilities, the Commission has not given detailed attention to the corollary matter of conserving fossil fuels through more judicious use, e.g., by encouraging the use of less powerful, and hence less wasteful, automobile engines.

†This analysis does not consider such applications as in space, where shielding is unnecessary, or that and certain military applications where economics are a secondary consideration.

energy is economically reasonable for both. Indeed, in high-cost fuel areas of the country, nuclear electric power is on or near the threshold of being competitive in large units now. Undoubtedly, it could, in the relatively near future, also become competitive for many large-scale process heat applications if aggressively developed. In the more distant future nuclear reactors may well also provide an important direct source for space heating in areas of concentrated use, provided attention is given to appropriate distribution methods and safety can be assured. Furthermore, at any time the economics permit, nuclear energy can provide heat through an electric link.

Thus nuclear energy is directly applicable to a significant fraction of our total energy needs. There remains the question as to whether or not our supplies of nuclear fuel are sufficient to meet all, or a substantial fraction, of this need over a long period of time. The answer is complicated. The fissionable material found in nature is confined to uranium-235, constituting only $^7/_{10}$ of 1 percent of natural uranium. The fission energy derivable from this isotope in the known and estimated United States reserves of uranium that could be mined at costs not much in excess of those of the high-grade ores being mined today is estimated to be less than 1 Q. (See columns 1 and 2 of Table I.) Thus, if this were our only potential source, the contribution to our total energy reserves would scarcely be worth the developmental cost. Fortunately, however, this is but a fraction of the story. A reactor containing uranium-238 or thorium in addition to its fissionable material, can be made to create additional fissionable material, part of which is "burned" in situ; the remainder can be reclaimed to serve as fuel in the same or other reactors. The new fissionable materials made by this "conversion" process are plutonium, made from uranium-238, and uranium-233, made from thorium.* Furthermore, some classes of reactors can be made to produce more fissionable material than they consume. This process is known as "breeding."

Breeding will make available as potential fuel all the uranium and all the thorium instead of only the uranium-235. Thus, the potential of a given amount of uranium is multiplied by, say, 100, there being some inevitable losses in the cycling process. Furthermore, and importantly, this factor renders relatively unimportant the original cost of mining the uranium or thorium, thus opening up for potential use vast quantities of low-grade ore (Table I). Indeed, uranium and thorium in only trace amounts, as in the granite rocks, can be considered part of the economical reserves which, on this basis, are almost limitless.†

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*Because of this potentiality, uranium-238 and thorium are referred to as "fertile" materials.

†Even at only 50 grams of uranium or thorium per ton of rock, the energy required for processing is small compared to that latent in the nuclear fuel.

TABLE I— FISSION ENERGY CONTENT OF DOMESTIC NUCLEAR RESOURCES[1]

Cost Range, $ per Pound of Oxide[2]	Energy in U-235, Q: Reasonably Assured Resources	Energy in U-235, Q: Estimated Total Resources[3]	Total Energy Content, Q: Reasonably Assured Resources	Total Energy Content, Q: Estimated Total Resources[3]
I Uranium				
0–10	0.16[4]	0.4[4]	22[4]	50[4]
10–30	0.17	0.3	24	40
30–100[5]	5	10	700	1,400
100–500[5]	220	900	30,000	120,000
II Thorium				
0–10	does not apply		6[6]	25[6]
10–30	does not apply		6[6]	13[6]
30–100[5]	does not apply		700	2,200
100–500[5]	does not apply		63,000	190,000

[1]The magnitude of the resources has been estimated by the USAEC. The energy unit, the Q, equals one billion billion BTU, or 0.252 billion billion kilocalories. The fission energy content is presented on the basis that all the resource material will ultimately fission after being recycled through reactor cores in refabricated fuel. The figures do not take account of losses during fuel recycling and other relatively minor losses.

[2]Present Commission contracts call for a price of $8.00 per pound of uranium oxide. Its present open market price would be somewhat less. Market prices have not been established for thorium oxide on a significant scale.

[3]Includes geologic estimates of future discoveries.

[4]Includes uranium already mined, most of which still exists as uranium.

[5]Cost based on recovery of both uranium and thorium from granite, and only uranium from shale and phosphate rock.

[6]Incomplete estimate because of lack of data.

The enormous size of the nuclear fuel reserves, dwarfing as they do the fossil fuels, makes their development and exploitation of increasing and long-lasting importance; they can meet our energy needs for the indefinite future. Nuclear energy will account for a larger and larger share of our energy consumption and ultimately will predominate. As need arises and technology and economics permit, its use can be expanded by energy conversion methods, for example, by increased dependence on electric power as an intermediate link and by the use of chemical fuel cells for small mobile units. Properly utilized nuclear energy will make it possible to reserve substantial quantities of fossil hydrocarbons to meet long-range needs for which they are especially suited.

Thus, the utilization of nuclear energy fulfills our three conditions. It is technically feasible, it is economically reasonable, and it can be done on a massive scale. We conclude, therefore, that nuclear energy can and should make an important and, eventually a vital contribution toward meeting our long-term energy requirements.

Benefits of Nuclear Electric Power

Granted the long-term need for exploiting nuclear energy as a necessary resource, let us examine the nearer-term advantages to be derived from nuclear-electric power. As with any new technology, its development and widespread use would add to the health and vigor of our general industrial economy. The technical developments would continue to interact with those directed toward space and military applications of atomic energy, to the mutual benefit of all. The availability of an alternative economic energy source would allow flexibility in methods of approach to different situations and lend the possibility of opening up new fields. For example, the developments to date have brought to light the promising possibility of utilizing reactor heat for the economic large-scale desalinization of water by the distillation process. An additional, competitive source of energy would give a healthy stimulus to our conventional power and fuel supplying industries. It would provide incentive, as indeed the prospect has already, for greater efforts to improve technology and minimize the costs of conventional power.

A feeling for the magnitude of the potential impact of our technology and economy can be gained from the fact that the annual rate of spending for new plants by the utility industries, currently about 10% of that for all industrial construction, is expected to reach approximately $6.5 billion by 1980 and $20 billion by 2000 A.D. Approximately 60% of this would be for the steam generating equipment. At projected conventional rates the annual cost of generating electric power is expected to exceed $15 billion by 1980 and to approach $50 billion by the year 2000.

There can be substantial savings to consumers from the use of nuclear power. The first to be forthcoming results from a unique economic feature. The generating cost of nuclear power is almost entirely independent of the area in which it is installed, since transportation costs for fuel are relatively minor. In contrast, for conventional power fuel transportation costs cause a range of nearly three to two in unit generating costs between the most expensive and the cheapest areas. As a result the average cost for power generation in the country is approximately 20% higher than in the areas of lowest cost. With the present power distribution and at the present differential rates, this 20% would, if continued, amount to almost $3 billion annually in 1980 and $10 billion in the year 2000.

In our opinion, nuclear power is on the threshold of being competitive with conventional power in the highest fuel cost areas. With further cost reductions it can, if used, increasingly reduce the inter-area differential in power generation costs and eventually place the entire country on an equal basis.* Such a change would be an economic boon to the regions where costs of fossil fuels are high. In addition to saving substantial sums for the consumers, it would encourage additional industrial development in such regions and hence increase the industrial and economic potential of the nation. An interesting technological effect would be that the reduction in electric rates relative to fuel rates would tend to encourage increased use of electric power for industrial and space heating purposes.

There are important international implications. As stated earlier, the United States has more than its proportionate amount of the world's resources of the fossil fuels; many parts of the world have none at all. Consequently, nuclear power has even greater application in many other countries than in this; indeed, in some there is an immediate need. There are vigorous nuclear power programs in Western Europe and in Japan, which must import most of their fuel. India and other less technologically developed nations are embarking on important programs. With a few exceptions the various countries look to us and to a very few others for technological assistance and as a source of nuclear power equipment. So far the United States has led in the sale of such equipment.

The maintenance of a position of technological leadership in nuclear power will enable us to maintain an important position in the affairs of the International Atomic Energy Agency. In our opinion, the role of this Agency should be a vital one when nuclear power comes into widespread use. In particular, through its safeguards systems, it will be the best mechanism to assure that nuclear materials are not diverted to military purposes in nations not otherwise possessing resources for a nuclear weapons program.

Thus it is clearly to the advantage of the U. S. to maintain world leadership in the nuclear power field. A vigorous domestic power program will help enable us to do so.

Nuclear power could also have a bearing on the defense posture of the country. The nature of the fuel makes transportation requirements very small. Hence, in periods of national emergency, nuclear installations would not put a burden on our transportation systems; in case of actual attack upon the country, installations that survived need not be paralyzed for lack of fuel, even though the transportation system actually broke down. Furthermore, it would be quite feasible and relatively cheap to locate our power installations underground so that many of them could continue operation even after a large-scale attack. Even though the distribution systems were

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*The introduction of nuclear power will, of course, be gradual. The power generated by conventional plants will continue to increase for at least several decades, and consumption of fossil fuels, especially coal, will increase accordingly. See page 61.

temporarily disrupted, the existence of operable plants would greatly hasten post-hostility recovery.

A further advantage of nuclear power relates to the increasing smoke pollution of the atmosphere as the use of coal increases. Nuclear power does not contribute to this problem. Its waste disposal problem is of a different nature; it will be discussed in a later section.

In summary we see that nuclear-electric power holds enormous possibilities—as an important means of exploiting a large new energy resource; as an economic advantage, especially to areas where fossil fuel costs are high; as an important contributor to new industrial technology and to our technological world leadership; as a significant element in our international posture; and potentially as a means of strengthening our defense posture. From all these and other factors we conclude that the development and exploitation of nuclear-electric power is clearly in the short- and long-term national interest and should be vigorously pursued.

The Role of Government

The continuing availability of abundant and economic sources of energy is a matter of concern to all the people. To assure that availability is, therefore, clearly a responsibility of Government. The Atomic Energy Act recognizes this responsibility in the case of nuclear energy.

Unlike such revolutions as those introducing the railroad, the automobile, the airplane, the telephone, the radio, and, indeed, electric power itself, the large-scale use of nuclear energy for electric power generation will not result in qualitatively new capabilities. Its public marketability will be based almost completely on economic factors. Hence, working within our free economy, the Government can best assure widespread use of nuclear energy by fostering developments that make such use economically attractive.

The economics has two aspects: (1) The costs of initially developing the technology; and (2) the costs of manufacturing and using nuclear power plants vis-a-vis the costs of more conventional methods.

The development of even a fairly simple nuclear reactor concept is an expensive process, both because of the complexities involved in the development of individual components and processes, especially those involving radiation, and because operating units, even of a scaled-down test variety, must of necessity be large and costly. Hence, a large investment was required of someone before safe and efficient operating units could be designed and built. Since the product does not meet some hitherto unfilled need but rather must depend for its marketability upon purely economic advantages which, for some time, will be small compared to the investment, industry could not have afforded to undertake the development by itself. The Government must clearly play a role.

Even a well-developed nuclear technology would not be utilized unless its manufacturing and operating costs were at least competitive with those of more conventional methods. Hence the task of government includes assuring that technological developments are carried to the point where, with appropriate encouragement and support, industry can provide nuclear power installations of overall economic attractiveness sufficient to induce public- and investor-owned utilities to install them at their own expense. Once this is achieved, and nuclear power becomes a profitable endeavor, normal economic incentives will bring about a growing business. The Government's investment will be augmented manyfold by industry. The equipment manufacturers can finance major technical development programs, reducing, and finally removing, the burden on the Government.

Hence, the creation of a self-sustaining and growing nuclear power industry should be a prime objective of the program.

The developmental and promotional programs to attain these ends must, of course, be carried out in such a way that both short- and long-term goals are reached—that the economic, technological and other immediate benefits are expeditiously realized, that the total energy latent in our nuclear reserves is made available and that a significant contribution is made toward conservation of our fossil fuels. Hence, it is essential that, within a reasonably short time, the goal should be attained of making breeder reactors technologically and economically attractive. The Government must take the lead in this regard.

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.

The Present Situation

In bringing the civilian nuclear power program to its present stage, the Atomic Energy Commission has carried out and encouraged a national program, aimed first at obtaining the basic scientific and engineering data needed for proof of technical feasibility of the more promising approaches to nuclear power generation, and second at demonstrating the actual or potential economic feasibility of such approaches. The program has leaned heavily upon, indeed it started from, technical knowledge gained in other reactor programs—notably "production" reactors for making plutonium, naval propulsion reactors, and "research" reactors used for scientific purposes. It has also been vitally assisted by the existence of several AEC production facilities, notably the large and efficient gaseous diffusion plants for enriched uranium-235, the production reactors for plutonium, and the chemical separation plants.

The scope of the program to date has been purposely kept very broad. Not only has it included a whole spectrum of reactor classes from almost pure burners to fast breeders, but, in each general class, technical and economic uncertainties have prompted many avenues of approach. The program has included two distinguishable but interlocking phases:

1. A research and development program on a laboratory scale to investigate and understand the basic science and to develop and prove out the general technology. This program, predominantly at AEC expense, has included work in the National Laboratories and other Government-owned facilities and in laboratories of the nuclear industry. It includes basic and applied research in physics, chemistry and metallurgy; development work on reactor components such as fuel elements, structural materials, moderators, coolants, and such external system components as heat exchangers, pumps, etc.—and the development of processes such as chemical reprocessing, fuel fabrication and waste disposal. Knowledge of reactor behavior is acquired through "exponential" and "critical" experiments to investigate the physics of the chain reaction and through reactor "experiments" to study the behavior of complete reactor systems.

2. A "power demonstration" program of utility installations to verify technology in actual practice, to yield economic information and to provide experience on which to base improvements. This includes Commission-owned, public utility-operated "prototypes", usually reduced in scale from current utility practice, and utility-owned installations which the Commission has assisted to various degrees.

The arrangement for the Commission-owned prototypes, usually on publicly-owned utility grids, has been that steam produced in a Commission-built and -owned reactor is fed to electric generating facilities owned by the utility. The utility operates the entire installation with appropriate financial arrangements covering operating costs and the market value of the steam. Most such operating contracts are of 5-year duration, with the utility holding an option to purchase the reactor at a price commensurate with its utilitarian value at the end of that period. An exception is the Commission-owned reactor at Shippingport, Pennsylvania, operated by the investor-owned Duquesne Electric Company which, during the first 4 years of operation, absorbed a significant portion of the operating loss.

Various forms of assistance have been given to investor-owned utilities to encourage them to construct their own nuclear plants. These include research and development assistance to the fabricator; the use of government-owned fuel at government interest rates, plus a charge for fuel consumed and, in some instances, a waiver of interest ("use") charges during the first five years of operation. Offers of assistance have been made in such a way as to encourage various utilities, especially those requiring small plants, to adopt a variety of reactor plants and thus help demonstrate their feasibility.

To date, the Commission has spent approximately $1.275 billion* specifically on the civilian power program, including $275 million for the development, construction and operation of Commission-owned reactors on utility grids, and $37 million for development assistance on utility-owned installations. The present annual rate of expenditure is approximately $200 million.* During the past several years industry has spent approximately $500 million, mostly for plant construction but also for laboratory and other development facilities and for development work.

Significant progress has been made in the 9 years since authorization of the Shippingport reactor, the first built primarily for the generation of central station power. In addition to great technical progress all along the line, costs have been reduced, from the first actual experience of about 50 mills per kwh at the Shippingport prototype reactor in 1958 to less than 10 mills per kwh for full-scale plants now in existence and an estimated 5.5 to 6 mills for a large plant to be built in the near future at Bodega Bay, California.

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*These figures are somewhat indefinite since they include a rather arbitrary assignment of the costs of research and development programs contributing technical results to other programs as well.

In addition to the Government-owned Shippingport pressurized water reactor,* which has generated 1.36 billion kilowatt hours of electric power, and privately-owned "Yankee" pressurized water reactor in Massachusetts, and the "Dresden" boiling water reactor plant, built without Government assistance in Illinois, have generated 1.45 and 2.43 billion kilowatt hours, respectively.† Recently placed in operation are the Consolidated Edison pressurized water reactor plant in New York, also built wholly with private capital, an AEC-owned sodium-graphite reactor in a plant of the Consumers Public Power District of Nebraska and a boiling water reactor owned by the Consumers Power Company in Michigan. They will bring the total nuclear electric generating capacity in the country to approximately 850,000 kilowatts, about 0.5% of our total installed capacity. Seven other central station nuclear power plants are scheduled to start operation in the next few months. Table II lists these and other less complete power installations, together with their capacities and types. The list does not include five small experimental plants, of which two are privately owned.

In addition to the previously mentioned assistance gained from other technical programs and from AEC production facilities, the program has been aided by a number of circumstances, including: (1) The policy of both the Executive Branch and the Congress to bring industry actively into the development; (2) the optimism, indeed the over-optimism, on the part of many people in the early years; (3) the prestige to be derived by private utilities from engaging in this development rather than leaving it entirely to public bodies; and (4) the incentive of international prestige and international trade; this was accentuated by the Suez crisis of 1956-57 which made all Europe more concerned about its fuel supply and spurred them to vigorous efforts, in many of which the U. S. has actively participated. (Continental European countries alone have spent some $200 million in their first five years of operation and the United Kingdom has spent even larger sums and is presently spending nearly $100 million per year.)

Experience has verified the fact that at the present time construction costs and, hence, capital charges assignable to generating costs are higher for nuclear than for conventional plants,‡ though the margin is decreasing. On the other hand, fuel cycle costs are lower for nuclear plants in appreciable

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*The various reactor types named here and in Table II are described in a subsequent technical section.

†These totals are as of October 29, 1962.

‡Estimated near-term costs for large installations are roughly $125 to $150 per kilowatt for conventional plants and $160 to $190 per kilowatt for nuclear plants.

TABLE II—NUCLEAR POWER PLANTS OPERABLE AND BEING BUILT[1]

NAME	REACTOR OWNER	OPERATOR	NUCLEAR CAPACITY, KWE[2]	TYPE OF REACTOR
Part I Operating Reactors				
Shippingport Atomic Power Station	AEC	Duquesne Light Company	67,000[3]	Pressurized Water
Yankee Nuclear Power Station	Yankee Atomic Electric Co.[4]		165,000	Pressurized Water
Consolidated Edison Thorium Reactor	Consolidated Edison Co. of N. Y.		202,000[5] (164,000)	Pressurized Water
Dresden Nuclear Power Station	Commonwealth Edison Company		209,000	Boiling Water
Big Rock Point Plant	Consumers Power Company[4]		50,000	Boiling Water
Hallam Nuclear Power Facility	AEC	Consumers Public Power District of Nebraska	82,000	Sodium Cooled and Graphite Moderated
Part II Reactors to be completed by the end of 1963				
Elk River Reactor	AEC	Rural Cooperative Power Association	18,000[6] (16,000)	Boiling Water
Humboldt Bay Power Plant	Pacific Gas and Electric Company		50,000	Boiling Water
Carolinas-Virginia Tube Reactor	Carolinas-Virginia Nuclear Power Associates[4]		16,000[7] (15,700)	Heavy Water Cooled and Moderated
Enrico Fermi Atomic Power Plant	Power Reactor Development Company[4]		65,900	Fast Breeder
Piqua Organic Moderated Reactor	AEC	City of Piqua, Ohio	12,500	Organic Cooled and Moderated
Pathfinder Atomic Power Plant	Northern States Power Company[4]		66,000	Boiling Water, with Nuclear Superheat
Boiling Nuclear Superheat Reactor	AEC	Puerto Rico Water Resources Authority	17,300	Boiling Water, with Nuclear Superheat
Part III Reactors to be completed after 1963				
Experimental Gas Cooled Reactor	AEC	TVA	29,400	Helium Cooled and Graphite Moderated
La Crosse Boiling Water Reactor	AEC	Dairyland Power Cooperative	53,500	Boiling Water
Peach Bottom Atomic Power Station	Philadelphia Electric Company[4]		42,200	Helium Cooled and Graphite Moderated

[1] This table includes only plants operated by utilities. It does not include a few small plants whose power is used on site or sold in small quantities.

[2] The gross electrical generating capacity (KWE) is given for each reactor. For plants equipped with fossil-fired steam superheaters, this gross nuclear electric capacity is determined by prorating the gross electric output of the plant in accord with the respective heat outputs for the nuclear reactor and the fossil-fired superheater; the alternate figure for capacity given in parentheses assumes the reactor could achieve 28% efficiency in converting reactor heat to electricity.

[3] The plant will operate at a thermal output equivalent to 150,000 KWE in 1964.

[4] AEC provided assistance on research and development, and waived use charges.

[5] A fossil-fired superheater brings gross capacity to 275,000 KWE.

[6] A fossil-fired superheater brings gross capacity to 23,000 KWE.

[7] A fossil-fired superheater brings gross capacity to 19,000 KWE.

areas of the country. For new plants that can now be built, these differences plus other minor ones approximately offset each other for large plants in the highest fuel cost areas. The unit cost of power, of course, decreases with increased plant capacity in both cases, but somewhat more rapidly for nuclear than for conventional plants. Hence, nuclear plants become economically more competitive as the size of plant increases. The growing trend to very large installations* thus favors nuclear power.

In order to assess the competitiveness of nuclear plants, it is convenient to express that competitiveness in terms of fuel costs for fossil fuel plants having the same total generating cost. Nearly all of the central station power in the U. S. is generated at fuel costs between 15¢ and 38¢ per million BTU. At efficiencies now achieved in first-rate large plants, each cent per million BTU adds approximately .085 mills per kilowatt hour (m/kwh) to the generating cost. For such plants, other elements in the cost, which are nearly independent of plant location, amount (for an enclosed plant) to approximately 2.8 to 3.0 m/kwh. Hence, total costs range, approximately, from 4.1 to 6.2 m/kwh.

Manufacturers' current estimates indicate that a large water-cooled nuclear plant initiated now could initially generate power at approximately 6 m/kwh or less and, therefore, compete with about 36¢ fuel or even lower. However, over plant lifetime the average generating costs could go down appreciably for two reasons: (1) If research and development are vigorously pursued, "burn-up", i.e., the energy extracted from a given fuel loading, could be improved and thus reduce the frequency of fuel reprocessing and fabrication; this, plus technical advances in fabrication and reprocessing techniques, would reduce the overall cost for fuel; (2) the operating power level, which tends to be set very conservatively initially, could be increased, thus decreasing the fixed charge, operating, and maintenance cost per kilowatt hour.† We estimate that the sum of these effects could decrease the total cost by an average of 0.5 or 0.6 m/kwh, thus making the plant, over its lifetime, competitive with about 30¢ or 31¢ fuel. If so, such a plant would be competitive with conventional plants built at the same time in areas which now account for approximately one-third of the electrical

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*At present about two-thirds of the total electric energy in the U. S. is generated in plants of 300 megawatt (300,000 kilowatt) capacity or greater and 40% in plants of 500 mw capacity or greater. Plants as large as 1 million kilowatts are now being considered by utilities and equipment manufacturers.

†Conventional plants — utilizing as they do, a highly developed technology — cannot reduce unit generating costs over plant lifetime nearly as much as can nuclear plants in the present stage of their development.

energy consumption in the country.* Potential savings would be from zero in 31¢ fuel areas to about 10% of the total generating costs in 38¢ fuel areas.

In our opinion the above facts will, when demonstrated to their satisfaction, give to an appreciable fraction of the utility industry sufficient economic incentive to bring about extensive installation of nuclear electric power. A few full-scale plants will, we believe, provide that demonstration. Indeed, increasing numbers of utilities in high fuel cost areas are considering nuclear plants. For example, the Pacific Gas and Electric Company is moving forward on a plan for an entirely self-financed 325 megawatt installation at Bodega Bay, California, in one of the highest fuel cost areas. Relatively modest expenditures for assistance by the AEC will, we believe, be sufficient to assure the construction of additional plants, in other areas.

Thus we conclude that nuclear power is on the threshold of economic competitiveness and can soon be made competitive in areas consuming a significant fraction of the nation's electrical energy; relatively modest assistance by the AEC will assure the crossing of that threshold and bring about widespread acceptance by the utility industry.

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* Electrical energy consumed in the U.S. is distributed roughly uniformly over the range of fossil fuel costs (38¢ – 15¢ = 23¢ per million BTU). Hence, once nuclear power is competitive in the areas of highest fuel costs, each 0.1 mill/kwh reduction in its cost will add $0.1/(23 \times .085) = 5\%$, to the fraction of the energy consumption for which it is competitive.

Reactor Systems

Several types of reactors are in various stages of development. They include both "converters" that produce less fissionable material than they consume, and "breeders" that produce more than they consume. The following sections will describe briefly several of the more promising of the various types.

Converters

The most highly developed reactors for electric power generation are reactors that are cooled and moderated* with "light" or "normal" water and produce saturated steam. They are of two sub-types: (1) "Pressurized-water" reactors in which the reactor and a closed primary cooling "loop" are entirely filled with water so that no steam is formed therein; steam to drive the turbines is formed in a secondary loop coupled to the primary through a heat exchanger. (2) Boiling water reactors, in which steam is formed in the reactor proper. Sometimes this steam is used directly in the turbines; sometimes a secondary loop is used.

All of the large and many of the medium and small power installations built thus far are of these types. Although there is still room for improvement, such as attainment of higher temperatures, higher power density, and greater fuel "burnup", they have definitely "arrived". They are reliable and safe. It is believed that large reactors of these types could now be built and operated in high cost fuel areas with a lifetime promise of greater economy than conventional plants. Even better economics can undoubtedly be achieved in the future from better fuel performance and other general improvements.

Although at present the most economical and reliable, these reactors have certain inherent limitations. They suffer from the fact that they produce relatively low temperature saturated steam, which limits their ultimate efficiencies and requires the

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*The neutrons emitted from a fissioning nucleus have very high velocities and are spoken of as "fast". They are said to be "moderated" when they have been slowed down through many collisions with light nuclei such as hydrogen (in water or organic compounds), carbon (in graphite), or beryllium. If moderated enough to reach equilibrium at the temperature of the reactor, they are referred to as "thermal". Because their behavior depends markedly on the neutron energy spectrum, reactors are characterized as "thermal", "intermediate", or "fast".

use of large and expensive turbines. Furthermore, they do not have the potential of breeding and, hence, cannot make appreciable use of the fertile materials on which we must depend in the long-range future. Consequently, other converters, promising improvements in these respects, are being actively pursued.

Among the more highly developed of these improved types are water-cooled reactors producing super-heated steam. Variants of this basic idea include systems in which (1) steam is produced in one reactor and superheated in another; and (2) steam is produced and superheated in the same reactor. In some of the latter type the steam-producing portion of the reactor has a thermal neutron spectrum and the superheater has a fast one. The superheat concepts offer fairly extensive economic incentives because of the higher temperatures, and hence higher thermal efficiencies, than in saturated steam reactors and because smaller, less expensive turbines can be used. The major problem seems to be development of materials to withstand the superheated steam. The "Bonus" and "Pathfinder" prototype reactors are of this type.

Also fairly well-developed though not so extensively as the saturated steam reactors are a number of converters utilizing other moderators and coolants. Most promise better economics, many of them markedly so. Others have improved conversion ratios. Still others have special characteristics such as the type of fuel they use or the tasks they can perform. Some reactors combine two or more of these characteristics. Among these potentially better converters are:

1. The organic-cooled and -moderated reactor, utilizing organic liquids for moderation and for cooling, in order to reduce the pressure and increase the temperature in the reactor vessel. Although showing early promise, this development has been plagued by a tendency of the fluids to "foul"; that is, to form gummy substances that coat the metal surfaces and interfere with heat transfer. This fouling increases markedly with temperature. Although this problem will undoubtedly be solved, at least for moderate temperatures, it is not clear that this reactor has better potentialities than the light water ones for power generation, though it may for process heat because the liquids used do not become radioactive. The Piqua "prototype" reactor is of this type.

2. Reactors using "heavy" water; that is, water incorporating deuterium instead of normal hydrogen. Although not so effective a moderator, heavy water has the advantage of absorbing fewer neutrons, making possible the use of natural rather than enriched uranium. If enriched fuel is used, the neutron economy can result in higher conversion ratios and greater fuel economy than in light water reactors. A principal drawback is the high cost of heavy water, requiring large capital investment and extreme measures to prevent leaks and, hence, economic losses. In enriched reactors, this draw-

back can be reduced, at the expense of part of the neutron economy, by using heavy water only as the moderator, and cooling with organic liquid or with normal water. Heavy water reactors are being energetically developed by the Canadians who have a 20 megawatt reactor under utility operation and a 200 Mw one in construction. We are cooperating closely with them.

3. The "Spectral-shift" reactor combining light and heavy water. In this concept a freshly charged reactor is cooled and moderated by a mixture of predominantly heavy water. This results in "under-moderation" and a higher than thermal neutron energy spectrum, leading to high conversion ratios. As the fuel is used, and neutron absorbing fission products accumulate, the ratio of light to heavy water is increased, maintaining the chain reaction at its initial level. This procedure avoids the necessity for expensive control rods or chemical solutions that waste the neutrons and reduce the fuel economy. Thus quite high conversion ratios can presumably be achieved over the fuel cycle. This concept is especially promising for the thorium-uranium cycle. It could, presumably, move to the construction stage quite quickly.

4. The "sodium-graphite" reactor, cooled by liquid sodium and moderated by carbon in the form of graphite. This reactor has potential for achieving quite high temperatures, and hence thermal efficiencies, and could also be a somewhat improved converter. The fact that molten sodium absorbs iodine almost quantitatively will substantially ease the siting problem of this type of reactor by minimizing the dispersion of radioactive material in case of a reactor accident. Importantly, the technology of liquid metals such as sodium will be vital to the ultimate fast breeders, so that this development has strong future implications. The Hallam reactor is of this type.

5. Gas-cooled reactors. Such reactors incorporate cooling with such gases as helium, hydrogen or carbon dioxide and moderation by a solid such as graphite or beryllium. They give substantial promise for high temperatures and fairly high conversion ratios. High temperature gas-cooled reactors are especially promising for the thorium-uranium cycle, where conversion ratios of nearly, if not quite, one seem feasible. The Peach Bottom reactor, near Philadelphia, is of an advanced gas-cooled type.

Breeders

In our discussion of nuclear resources we have seen that the energy contained in fissionable uranium-235 in the supplies of relatively low-cost ores is so limited that the fertile materials must be extensively exploited if nuclear energy is to be of widespread and lasting benefit. Hence, there is a fairly near-term, though not immediate, need for reactors that produce more fissionable material than they consume.

Breeder reactors are of two general kinds, "fast breeders", utilizing the uranium-plutonium cycle and "thermal" breeders utilizing the thorium – U-233 cycle. Unfortunately, none of these are nearly so well developed at this time, either technically or economically, as the converters are.

The nuclear properties of uranium-235 and plutonium are such that more neutrons are released from fissions brought about by fast than by slow neutrons. Indeed, the difference is so great as to make breeding feasible in fast, but not in thermal reactors utilizing these materials.* Unfortunately, there are combined technical and economic difficulties in fast reactors. Good breeding gains obviously require that the fuel material be not overly diluted with other substances that absorb or moderate the neutrons.† Hence, to avoid large and expensive fuel inventories, the power that they generate must be concentrated in small volumes. This gives rise to engineering and safety problems of removing heat at the necessary rate. Furthermore, it is difficult to develop concentrated fuels that will endure until a substantial fraction of the fuel has been consumed and hence minimize expensive refabrication of the fuel elements. So far these factors have combined to make fast breeders quite expensive. Fortunately, there are promising developments for greatly improved fuels. These include "ceramic" fuels such as uranium- and plutonium-oxides and carbides. In the farther future is the possibility of utilizing molten plutonium.

Most effort in fast breeders has involved utilizing molten sodium or sodium-potassium alloys as the coolant. This has required a complex and expensive new technology, including development of pumps, heat exchangers, and the like, of com-

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*In a "thermal" reactor the number of neutrons emitted per neutron absorbed varies from somewhat below to slightly above 2 for both U-235 and plutonium, depending on the degree of moderation. The corresponding figures for unmoderated fission neutrons are 2.45 for U-235 and 2.94 for plutonium. In each case, of course, one neutron is required to keep the chain reaction going. There are inevitably some losses through leakage and absorption in other reactor materials. Hence, whereas thermal reactors fueled with U-235 or with plutonium probably cannot breed at all, fast reactors might technically achieve breeding gains of, say, 1.2 when fueled with U-235 and as much as 1.6 when fueled with plutonium. Economic considerations will, however, reduce these figures appreciably.

†In addition to producing fewer neutrons per neutron absorbed in the fissile material, slow neutrons are more readily absorbed by other materials, including the fission products.

patible materials. Fortunately, development work for the sodium-graphite reactor has also contributed to this technology.

In the thorium–uranium-233 cycle, the situation is quite different. U-233 emits more neutrons in thermal fission than does U-235; on the other hand, it is only slightly better in fast fission than in slow.* Hence, thermal breeders offer greatest promise, minimizing as they do the power density and fuel endurability requirements. However, thermal breeders have a different complication in that fission products act as strong absorbers of slow neutrons, requiring that these products not accumulate too much. Among the most promising solutions of this difficulty is to use the fuel in fluid form, thus permitting continuous extraction and reprocessing to remove the fission products. Various fluid fuels have been studied for this purpose. The currently most promising approach is the use of fused uranium salts which can be circulated, both for reprocessing purposes and for heat transport. This technology is, however, in a fairly early stage.

Probable Trends

Even when breeder reactors become economic and begin to be installed there will be a complication regarding fuel supplies. At least for some time to come, economic breeders will have breeding gains so low that they will produce not more than 3% or 4% of their fuel inventory each year.† Hence, since the annual growth in energy consumption is about 6%, it will be necessary, if nuclear power increases its fractional share of the total load, to fuel some portion of the installations with fissionable uranium-235.

This leads to no great problem in the thorium-uranium thermal breeders. The fuel demand can be fulfilled simply by charging some of them, initially at least, with U-235, though at

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*At thermal energies, the average number of fission neutrons emitted per neutron absorbed in U-233 is 2.3. This number is 2.58 for unmoderated neutrons and more like 2.35 or 2.4 for the neutrons in any actual fast reactor.

†In thorium-uranium breeders, the inherent nuclear constants confine economic breeding gains to not much more than one so that the excess production is a very small fraction of the fuel consumed, and the relative rate of increase in U-233 is very low. In the "fast" reactors used as plutonium breeders, higher breeding gains are feasible, but the fuel inventory required is much larger compared to the consumption rate, resulting again in low relative rates of increase. It is usually customary to express the relative production rate in terms of the "doubling time", that is, the time required for a reactor to produce enough excess material to fuel a second reactor. This will probably be 15 to 20 years, or even longer for the first economic breeders.

some sacrifice in economics and in the amount of U-233 that they produce.*

On the other hand the "fast" reactors required to breed an excess of plutonium are economically attractive only when plutonium rather than U-235 is used to fuel them. Hence the most promising arrangement for incorporating them in a rapidly expanding nuclear power economy would undoubtedly be to use thermal converters to help provide the plutonium needed for added installations. This combination would continue until increases in the relative "yield" of plutonium from the breeders, together with a lower relative rate of growth of electrical energy consumption enabled the breeders to catch up and produce enough plutonium by themselves.

This requirement enhances the need for the high efficiency converters mentioned in an earlier paragraph. Not only will their continued employment into the breeder era increase the importance of their better economics, but their higher plutonium yield† will increase the rate at which new breeders can be built and, hence, enrich the breeder-converter mixture. This could be especially important if the requirement for converters to complement the breeders extends beyond the duration of our supplies of cheap uranium. Ultimately, of course, there must be a net breeding gain for the nuclear power industry as a whole.

Breeders will, of course, be attractive to the utilities only if they compete economically with the best available converters. This will depend on the relative capital costs, the operating efficiencies and, importantly, on the relative abundance and values of the various nuclear fuels. Considering all the facts, we believe that fast breeders will become competitive with converters in the next decade or two, and will be built on an increasing scale along with additional converters. The economics of the various fuels on a free market basis will, we feel, automatically assure a proper ratio. Scarcity of plutonium and/or abundance of uranium would lead to more converters and vice-versa.‡ As breeders improve in economic breeding ratio and uranium-235 costs mount with exhaustion of cheap

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* When charged with U-235 such reactors will probably have a conversion ratio less than one and hence will not then be breeders.

† The "yield" of plutonium in a converter is the difference between that produced and that burned in situ. Long burn-up times, important economically, increase the fraction of plutonium burned in situ.

‡ At the expected economic breeding gains (less than 1.1) and fuel values the economic advantage given to the breeders by the additional plutonium they produce is more than offset by the added carrying charges resulting from their large fuel inventory. Hence high plutonium values are unfavorable to them. The situation would reverse at sufficiently high breeding gains.

ores, the proportion of fast breeders will increase, at a rate limited only by the plutonium supply.

Meanwhile, thorium—uranium-233 breeders will, if vigorously developed, no doubt also become economic. Neglecting the possible use of plutonium in such breeders, the situation is less complicated than in the plutonium cycle, since only thermal reactors are involved. The scale of use of such breeders will, therefore, depend largely on the economics of the total situation. Initial economic pressures may well, however, tend to favor the uranium-plutonium cycle since plutonium will be an immediate product of the converters that will constitute the bulk of the initial power reactor installations.

Much developmental work and several generations of reactors, involving many decades, will no doubt be required to reach the point where improved economic breeders, together with possible reductions in the relative rate of growth in power needs, will make the breeders sufficient to themselves. When that point is ultimately reached, new uranium will be required only to provide the uranium-238, although use will, of course, be made of the uranium-235 that it contains. By that time, or even sooner, advantage can be taken of our large supplies of "depleted" uranium from which the major fraction of the uranium-235 has been extracted in the diffusion plants.

Thus, the future program should include the vigorous development and timely introduction of improved converters and especially of economic breeders; the latter are essential to long-range major use of nuclear energy.

Assessment of the Degree of Urgency

Granted that there is an ultimate requirement for nuclear power that, extensively used, it could provide important near-term benefits and that Government should play a leading role in its development, we should assess the degree of urgency, taking into account the present stage of advance, the cost of future development and the magnitude of the benefits to be derived.

It is perhaps worthwhile to recapitulate our assessment of the present situation. As a result of comprehensive research and development programs over the past dozen years much of the technology has reached a highly developed stage. Water reactors can now be built that, over their lifetime, will be competitive with conventional power in significant areas of the country; improved converters can be brought to the same stage in a relatively few years; although much remains to be done, definite progress is being made on breeders. Practical experience is being accumulated from a number of reactors in operation on utility grids and much more will become available in the near future. There exists a substantial nuclear equipment industry that is eager and well able to build nuclear power plants on a scale considerably larger than that for which there is a present demand. There is widespread and growing interest abroad in the utilization of nuclear power and an increasing tendency to turn to American industry as a manufacturing source. Nuclear power seems to be on the threshold of coming into being on a significant scale.

It must be realized, however, that the development of a mature nuclear power technology and its utilization on an extensive scale will be a long process. As in any other technology, progress is brought about not only by research and development but also through experience. Operating units must be used and tested throughout their normal lifetimes. Unlike devices normally used intermittently, such as cars, airplanes and radios, the process cannot be shortened by speeding up the tests. Hence successive generations in the development are even decades long.

There is also the factor of psychology. Before committing a substantial fraction of their installations to nuclear technology, utility executives will want to be convinced, themselves, that nuclear power is economical, reliable and safe. With few exceptions this conviction will require observation of results of actual installations operating for periods that are significant in terms of the normal lifetime of power installations.

There is, of course, no absolute yardstick by which to measure goals for nuclear power. The relative advantages of progressing more or less swiftly are matters of degree. Perhaps the most convenient method of assessment would be to use the present Commission program as a frame of reference.

Continuation of that effort, with some augmentation in support for the power demonstration program,* and with program readjustments to give added emphasis to breeders, would, we believe, provide industry with the needed stimulus to build a significant number of large reactors in the near future, would bring nuclear power to a competitive status throughout most of the country during the 1970's, and would make breeder reactors economically attractive by the 1980's.

Assuming this result, we estimate that by 2000 A.D., nuclear power would be assuming the total increase in electrical energy production, and, taking account of the Federal Power Commission's estimates, that about two-thirds of the energy then being produced would be from plants built at a time when nuclear power was more economical than conventional power in their locations. Clearly, not all of these will actually be nuclear. A given area will not always need a large plant when nuclear power first becomes competitive. Furthermore, there will be a natural reluctance to utilize a new technology, rather than a tried and true one, until the economic difference becomes appreciable. Allowing for these effects, we have crudely estimated that by the century's end nuclear installations might actually be generating approximately half the total electric energy in the country.† This fraction could be expected to increase over the following several decades so that by mid-century all the energy would be of nuclear origin except a small fraction generated in special purpose plants, including, perhaps, some built for peak load purposes.

The rate of growth described is illustrated in Figure 3. Curve A plots on a <u>linear</u> scale the rate of use of energy shown logarithmically by the corresponding curve of Figure 1. Curve

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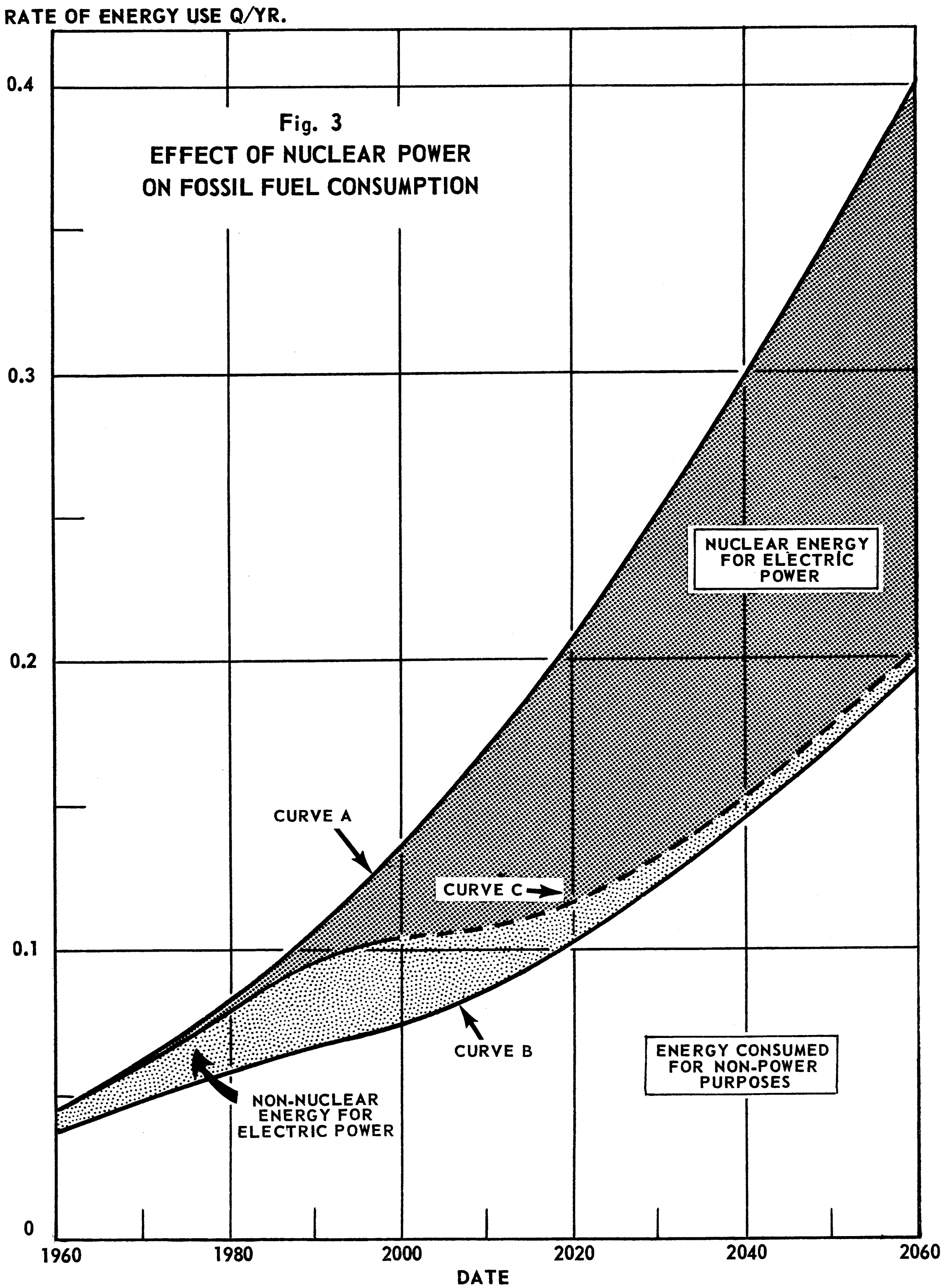
* The "power demonstration" program, as the term is used here includes research and development and operational activities, as well as construction costs, related to utility installations, whether Commission- or utility-owned.

† The nuclear plant capacity would, undoubtedly, be appreciably less than half, since the relationships between capital costs and fuel costs would encourage using nuclear power more for base loading and conventional power more for peak loading purposes.



CURVE A represents total energy on the same basis as Curve C in Fig. 1.
CURVE B represents energy consumption for other purposes than generating electricity.
CURVE C is obtained by deducting from Curve A the total nuclear energy consumed in generation of electricity.

B is obtained by subtracting estimates* of fuel energy to be consumed for electric power from the values represented by curve A. Curve C divides the consumption for electric energy into two parts: That above the curve is due to nuclear power and that below is due to fossil fuels. Thus, if no other use were made of nuclear energy, curve C would be a measure of the rate of use of fossil fuels.

For conservation of our fossil fuels, this rate of progress would appear to be sufficient, if by mid-century nuclear energy were also contributing appreciably to filling other needs, either directly or through the use of electric power for tasks not now performed by it.† Any appreciably slower rate of growth could result, however, in undue short-term consumption of our fossil fuels, especially if the more conservative views of their availability and ultimate recovery costs should turn out to be correct. Fortunately, provided the nuclear technology is developed in a timely manner, the economic pressures of a coming scarcity of fossil fuel would tend to accelerate its use.

Provided our assumptions regarding breeders are reasonably accurate, the estimated growth of nuclear power described above would raise no problem with respect to the supply of nuclear fuels. By the year 2000 approximately the amount of uranium listed in the 0–10 dollars per pound category of Table I would have been mined. Of the .4 Q of energy originally contained in the uranium-235, approximately half would still exist in reactor inventories and in stockpiles of depleted uranium. By that time the ratio of breeders and converters would be such that a major fraction of the energy produced would be coming from what was originally uranium-238 and thorium, so that somewhat higher ore prices would have no appreciable effect on the cost of power. On the other hand, should breeders be seriously delayed, for example by as much as a few decades, the high grade uranium ore might be exhausted while large amounts of uranium-235 were still required. Hence, it is important that the breeder technology be developed expeditiously.

The financial benefits of such a growth would soon begin to be appreciable. Using the same assumptions as above, the savings in generating costs are estimated to be approximately $2 billion to $2.5 billion per year by 1990, and between $4

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* This projection was made by utilizing the Federal Power Commission estimates of electric power needs to the year 2000. Thereafter the relative use of electric power was further increased (from 47% of the total consumption in 2000 A.D.) until it reached 50% and was held at that fraction thereafter.

† Under the assumptions used, consumption of energy for purposes other than nuclear power would, by mid-century, be about 10 Q and the annual rate would be about 0.35 Q per year. By 2100 total consumption would be between 25 and 30 Q.

billion and $5 billion* per year by 2000. By the latter date the cumulative savings would approximate $30 billion.† The savings would not be in direct proportion to the amount of nuclear energy actually used since if that amount were smaller a greater proportion of it would be in the areas where the greatest unit savings would accrue.

Thus highly worthwhile results could be anticipated from a continuation of the Commission effort with additional early support of the power demonstration program. Industry would be brought into full financial, as it has been in technical, partnership in the enterprise, thus reducing the future need for government participation. The development of the new technology would add additional health and vigor to our industry and would stimulate our whole economy. Our international leadership in the field would be maintained with benefit to our prestige and to our foreign trade. Substantial financial savings would accrue to consumers of electric energy; properly designed and installed nuclear power plants could add to our defense posture. An enormous new source of energy would be tapped in a timely manner.

An appreciably lesser effort would, in our opinion, result in substantially reduced benefits. The reduction in financial savings would be more than proportional to the reduced federal expenditures. If the program slowed too much, our international leadership in this field could be lessened or even lost. Too much delay could dissipate the potential benefits to national defense.

It would be particularly unfortunate to fail to take advantage of the present opportunity to stimulate a rapid industrial development that would permit industry to assume increasing responsibility for future development in this field. Should the program falter too long, the nuclear power equipment industry would suffer severe setbacks; many companies would no doubt withdraw and turn their talents elsewhere, leaving the field with

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* These calculations have conservatively assumed that the unit cost of nuclear power does not fall below that for conventional power in the low-cost areas during this century. Larger savings would, of course, result if it should do so. Allowance has been made for projected decreases in the capital and operating costs of conventional plants and for increased efficiency in the conversion of heat energy to electrical energy. In the latter connection it is assumed that by the year 2000 conventional plants will achieve 50% efficiency and nuclear plants 40% efficiency. No account has been taken of such possible new techniques as the use of magneto hydrodynamics which would be equally applicable to both nuclear and conventional plants. It is assumed that the plant-side costs of fossil fuel remain unchanged, i.e., that on the average, changes in recovery costs and in transportation costs cancel each other.

†At 5% interest these cumulative savings would have a discounted value in 1970 of approximately $10 billion.

too few companies. Technical skills and experience would be dissipated. If this should happen, it would take time to rebuild the capability and the program could be delayed far longer than would be implied by the slow-down in the Commission program proper.

Contrariwise, there would be, in our opinion, no virtue in a greatly enlarged governmental program at this time. Taken as a whole, support of the scientists and engineers engaged in developmental work is about adequate, though there should be program readjustments in the near future. In view of the country's research and development needs it would seem unwarranted to increase appreciably such manpower in this field. Only in the area of support of operating prototypes and full-scale operating units does there seem to be a need for significant increase, and that only for the near-term future. The increased technical manpower needed for the industrial growth would be largely design and production, rather than research and development personnel.

To summarize, we have concluded that the nuclear power program should continue on an expeditious basis with added emphasis on stimulating industrial participation; there should be some augmentation of support for the power demonstration program and program readjustments to give additional emphasis to the development of breeders.

Statement of Objectives

Taking account of the need for nuclear power, the responsibilities of the Atomic Energy Commission, the state of nuclear power technology, its future possibilities, and the existence and potentialities of the nuclear industry, we have arrived at the following statement of objectives:

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.

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.

The role of the Commission in achieving these objectives must be one of positive and vigorous leadership both to achieve the technical goals and to assure growing participation by the equipment and utility industry as nuclear power becomes economic in increasing areas of this country and the world at large.

The Future Program

We have concluded earlier that a logical progression to achieve the objectives of the nuclear power program will involve three overlapping phases: (1) The immediate utilization of reactor types that are, or can readily be made, economically competitive with conventional power installations; (2) a transitional stage, characterized by improving economics through higher temperatures, longer fuel life and other technical improvements and by the introduction of improved converter types with better economics and higher conversion ratios; (3) a long-range phase utilizing breeders that multiply by a large factor the energy extracted from the nuclear fuel, hence freeing the technology of any marked dependence on the cost of raw materials and opening up vast energy reserves; converters burning U-235 will continue to be essential until such a time as breeders produce enough new fissionable material to fuel the necessary additional reactors; in the interval, conversion ratios will become increasingly important as the costs of raw materials rise.

As seen in an earlier section, the technical programs now under way include reactor types appropriate to each of these three phases. Their complete development involves four progressive steps: (1) Conceptual studies of feasibility and methods of approach; (2) reactor experiments to study and to optimize the reactor system concept; (3) construction and useful operation of prototype power-producing systems, usually on a reduced scale; in general these are not economically competitive and hence must be built or strongly supported by the Government; (4) encouragement, and, if necessary, some financial support of full-scale installations built by utilities; information gained from their operation is, of course, fed back to assist future development and design.

The following sections will discuss our concept of the future reactor development program. This program must be backed, of course, by continuing and vigorous research and development of the basic technology, and subjected to periodic re-evaluation.

A Program for the Immediate Future

The principal objectives in encouraging immediate full-scale applications are to gain experience and knowledge from actual operations, to get a growing nuclear equipment industry really under way, and to convince utilities of the future economic benefits that they can gain from increasing use of nuclear power.

Saturated steam reactors have reached a stage where, provided they are built and used, industry can and should increasingly assume the major cost of their improvement; only such things as fuel and component development need be pursued by the government;* benefit will, of course, continue to be derived from advances in space and military programs, and from general technological developments.

The Intermediate Program: Improved Converters

Successful as they are, saturated steam reactors provide an adequate basis to achieve the general objective of bringing nuclear power utilization into being. Hence appreciable Government financial support should be given to other converter types only if they: Promise early marked improvement in unit costs for power; are markedly higher ratio converters; have direct, important technical bearing on breeder systems; or offer potential for other applications such as process heat. The Commission is reviewing the entire spectrum of non-breeder reactors in the light of these criteria to determine which should be continued or redirected and which should be discontinued or phased out. In some instances reliance can be placed on programs in other countries. For example, at least in the immediate future, we expect to depend primarily on the Canadian program for heavy water, natural uranium reactors in which we are cooperating at a modest level.

Several systems give promise of meeting the criteria. For example, the spectral shift, the high temperature gas-cooled, the sodium graphite and the nuclear superheat reactor systems all show excellent economic promise. The first two are excellent converters and may be made to breed in the thorium—uranium-233 cycle. Heavy water reactors are also excellent converters but are less promising economically. The sodium graphite reactor utilizes the liquid sodium technology necessary for fast breeders and its iodine absorbing quality is attractive from the safety standpoint. The organic cooled and moderated reactor can be economically competitive with saturated steam water reactors and may have application for process heat generation.

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*An exception is the so-called "seed and blanket" reactor in which zones of natural uranium are interspersed with zones of fully enriched uranium. Developmental studies and experiments relating to this concept are deemed worthwhile since, although leading to no marked advances in conversion ratio, this reactor type is less dependent on the somewhat uncertain costs of fuel reprocessing and since, in the event of large-scale disarmament, it could take advantage of the large supplies of highly enriched uranium produced for weapon purposes. Furthermore, information gained could be of value in other types with discontinuous zones, such as those using differing degrees of enrichment in different zones or, farther in the future, reactors using breeder blankets.

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. Hopefully a few will ultimately warrant full-scale construction by utilities. In addition to shedding light on the specific systems in question, operating reactors of these types will help accelerate the industry, will add additional operating experience and will help provide plutonium to get the breeder program going.

Program for the Long-Range Future

Although breeding in the thorium—uranium-233 cycle can build upon experience gained with less advanced reactors (indeed one or more of the latter might even breed, though barely), vigorous and specific efforts will be required to attain breeding on a significant scale. Both fuel and blanket systems must be pushed. Attention should be directed at methods of continuous removal of fission products, including the use of fluid fuels (such as fused uranium salts) and blanket materials. Experimental reactors designed to breed must be built and operated. Hopefully, within the next several years the program will achieve the stage where operating prototypes will be appropriate.

In contrast, the fast breeders needed for the uranium-plutonium cycle are quite different from the thermal reactors now in use. Increased effort must be placed on their development. Promising fuels such as the carbides must be pursued with vigor. The plutonium utilization program should be oriented with the fast breeder program well in mind. Economic methods of handling and fabricating this difficult and dangerous metal must be developed. Improvements in heat removal can be of very great importance in fast breeders. Additional experimental reactors must be built in the near future to serve the usual purposes, with emphasis upon control and safety problems. It can be hoped that in the later 1960's or early in the following decade, the stage of operating prototypes will be reached.

With luck and adequate effort, practical and economic full-scale breeder reactors might be achieved by the late 1970's or early 1980's. When they are, adequate steps must be taken to see that they are built and utilized.

A Possible Construction Program

A composite construction program for, say, the next 12 years (FY-1964 through FY-1975) might entail the following: (1) The construction and placing into operation of seven or eight power-producing prototype reactors approximately half of which would be advanced converters and the remainder breeders. Most of their cost would probably be borne by the AEC. (2) Assistance to industry in the construction of ten to twelve full-scale power plants, of improving design as time goes on; hopefully, industry will concurrently bear full costs for many more of well-proven design.

This program of construction would, of course, be backed by specific development programs directed at the more advanced reactor types, especially breeders, by research and development related to the underlying technology, and by general safety programs.

To encourage construction of full-scale power installations by utilities, the support of research and development and the temporary waiver of fuel charges have recently been augmented by the offer of reimbursement of design costs for fuel installations of 400 megawatts or more. Both public-* and investor-owned utilities are eligible. It is hoped that these forms of assistance will suffice to bring about a marked increase in the number of full-scale installations. If it does not, further efforts should be made to search for more attractive forms of incentives or other means to assure that such large-scale installations are actually constructed. Although a few examples should be enough to start the program going, it may well be necessary, in future years, to offer incentives to encourage industry to install newer and improved reactor types that have not yet had opportunity to prove themselves. An attractive incentive program may be needed to encourage timely use of breeder reactors when they reach the stage of full-scale application.

The demonstration prototypes involve a different situation. Here the principal objective is to prove out in actual practice a new and untried system which, in general, will not be economically competitive at the stage of development reached and the capacity involved. To achieve this best they should be under AEC technical direction. Depending on the cost, the degree of confidence, and the level of the competitiveness, a major fraction, or possibly all the cost of the reactor proper will generally be borne by the Commission. We believe that participation in such ventures should be open to publicly-owned utilities, as in the "Second Round," and to investor-owned utilities as in the case of Shippingport. In some instances of very advanced prototypes it may be best for the Commission to build and operate the installation on a government site, using the power for internal purposes.

*It is recognized that there are very few non-federal, publicly-owned utilities that require installations of 400 megawatts or more. However, the City of Los Angeles Water and Power Board has expressed considerable interest in this offer.

Supporting Technical Programs

In an earlier section we have described various reactor systems that give reasonably early promise of producing economic nuclear power. This section will discuss briefly the supporting research and development that is essential to success and to the development of improved systems in the future. It also will describe the very important safety programs and their bearing on reactor siting, and the program of handling the fission products resulting from reactor operations.

General Technology

The general technology is being pushed with vigor. Unusual problems are involved. In the reactor proper, one must find fuel systems, moderators, and coolants that are mutually compatible for long periods at high temperatures and in intense radiation fields, while minimizing neutron losses by absorption and permitting efficient heat transfer. In fast reactors, coolants, structural materials, and fuel diluents must not moderate appreciably.

Great progress has been made toward achieving these objectives all along the line. Perhaps most striking is the development of many kinds of fuels and fuel assemblies, including: metals and metallic compounds encased in almost foil-like containers of stainless steel or more exotic metals; thin sandwiches containing alloyed fuel in the inner layer; thinly-coated pellets to maximize the heat transfer area; simple uncoated fuels such as uranium in oxide or carbide form dispersed in a graphite matrix; and fluid fuels containing fissile material as a solution or a suspension slurry or in a molten compound. Each has its application and its promise. Parallel problems relating to coolants, moderators, and structural materials are by no means minimal.

Difficult problems are also present in the external system, particularly where new coolants are involved. Pumps, heat exchangers, valves, and piping must be compatible with the coolant, and have high reliability. Where radioactivity is involved, especially in the circulating liquid fuels, many safety precautions must be taken.

Most of this development is done in the laboratory and in "test" reactors, where the effects of radiation are studied by long exposure of small material samples, full-scale fuel elements and, where appropriate, "loops" for fluid circulation.

In a corollary but important area lies the development of economical chemical reprocessing methods whereby useful fissionable and fertile materials are recaptured from used fuel assemblies and the fission products are removed for storage or disposal or, in some cases, for useful applications.

Not to be forgotten is the development of reliable instruments and control systems to monitor reactor performance and assure no misbehavior.

Reactor Safety: Siting Problems

Vigorous efforts must be made to maximize the inherent safety of reactor installations, both through careful design of the reactors proper and through methods to provide protection in the unlikely event of serious malfunction. A major program involves deliberately letting trial reactors "run away" in order to study their self-control mechanisms and the degree of damage if self-control is insufficient. The efficient design of containment vessels must be studied and exploited with a view to decreasing costs. Continuing study must also be made of the possible spread of fission products in case they do escape from the reactor and its containment vessel.

The effectiveness of the solution has important economic implications going beyond the installation costs themselves. Until experience is gained and adequate safeguards are proved out, prudence dictates that large reactor installations be fairly far removed from population centers. This adds both to transmission system costs and to expensive power losses in the lines. It also reduces the availability of sites, already low for large plants because of the need for ample supplies of cooling water.

Not only must developments be pursued with vigor and inherent safety rigorously assured, but also convincing demonstration must be made that the desired results have actually been achieved. Such demonstration will, in the final analysis, probably depend upon proof by actual operation. The accumulation of enough operating experience to permit statistical evaluations should help eliminate much of the subjective type of safety evaluation required today. With adequate technical improvements and the accumulation of satisfactory experience, it should be possible to gradually remove many of the siting restrictions in force today.

One of the attractive possibilities to provide safe containment is that of placing the installation underground. The technical problems of such installations are solvable and, at least in many locations, the costs would not differ greatly, if at all, from well-contained above-ground plants. In addition to providing adequate containment this technique offers the special advantage of affording considerable protection to the plant against damage in case of nuclear attack.

Waste Management

With a growing atomic industry, two problems in waste management will assume growing importance. These are the disposal or concentration of large volume, low-activity wastes, and the permanent storage of concentrated, high-level wastes.

When nuclear activities were small in scale, wastes involving very low specific activities could be discharged to the environment without unduly raising the radiation background level. Freedom to so dispose of them may be increasingly restricted in the future, primarily because of the rapidly increasing amounts and, secondarily, because acceptable environmental limits have been reduced. Hence, it will be necessary for the waste management research and development program to develop, on an expeditious basis, improved and more efficient methods for decontaminating large volumes of low-activity waste and concentrating the radioactive materials removed. In a related sphere, continued support must be given to environmental investigations to: (1) determine the ultimate fate of specific radionuclides in land, in water and in air environments; (2) establish reasonable technical criteria for safe disposal of very low level radioactive effluents into the environment. Such programs are, and must be, pushed with vigor.

Of equal importance is the program of developing methods for ultimate storage, or other safe disposal, of concentrated high-level wastes. The problem is technically soluble but costs are not accurately known. The present approach is to convert such wastes to inert, water insoluble solid forms, case them in corrosion resistant containers, and store them in specific, stable and dry, geological formations, such as salt domes or other safely-containing media. This method must, in the near future, be carried from the research stage to that of pilot plant demonstration and field experiment. Aside from the central reactor development program proper, no other phase of the entire program is more important than that of waste disposal.

The fission products resulting from reactor operations also have a beneficial side. Certain of them are useful on an appreciable scale as sources of nuclear radiation for scientific, medical, agricultural and industrial applications. Others can serve as sources of heat to generate small amounts of electric power in satellites or in remote, unattended terrestrial devices such as buoys and automatic weather stations that transmit their data by radio. Considerable research and development is being conducted on applications and on packaging methods, the latter being closely related to similar developments for waste disposal purposes.

Legal, Financial and Administrative Matters

The success of the program and particularly its acceptance by industry will be strongly affected by decisions relating to a number of legal, financial, and administrative matters relating to: (1) Nuclear materials; (2) encouragement of the service industries; and (3) licensing and regulation, including reactor siting criteria.

Policies Relating to Nuclear Materials

Ownership of Special Nuclear Materials. Careful attention has been given to the relative desirability of removing the present legal requirement for Government ownership of special nuclear materials. Originally this policy was adopted primarily as a protective measure against the possibility that such materials would be diverted for military purposes. Although this reason still has force, it is believed that at the present time controls and regulations can give adequate protection.

The present system has both advantages and disadvantages to industry. The Government monopoly subjects industry to rigid control and price-fixing by the Government of the materials most basic to the utilization of reactors. Furthermore, policies in these regards are not completely predictable in advance by industry, thus leading to uncertainties. On the other hand the utility industry enjoys certain advantages under the present system since: (1) Because of the Government's large enrichment plants the costs serving as the base for lease and "burn-up" charges for enriched uranium are less than could have been attained by industry alone for many years to come;* (2) the lease charge rate for the fuel inventory is less than carrying charges under private financing; and (3) it is not necessary for a utility to raise the large amount of capital required for the fuel inventory, at a time when it must raise funds for construction of a plant that is more costly than conventional ones.

A change permitting private ownership would be a step toward substituting the natural laws of supply and demand for Government control of prices and of availability. Indeed, for reactor products, plutonium and uranium-233, the step would be complete; prices for these products would seek their natural level and one source of distortion of the technology would be removed. A complication is, however, that for a considerable

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*An offsetting factor is that the AEC is presently committed to purchase raw uranium at prices somewhat above the open market value.

time, at least, the Government would have an actual, though not a legal, monopoly on the means for producing enriched uranium-235 and thus would fix the price of this basic and most widely-used material. Hence, the situation would be one permitting private ownership but not constituting free enterprise in its broadest sense.

The Government would benefit from private ownership in that it could free itself from the obligation of owning rapidly increasing supplies of materials being used by other parties. A growing investment running ultimately to many billions of dollars could be avoided.

On balance we believe it is a step that should be taken and consequently we have recommended that legislation be enacted to permit private ownership of these materials. In order, however, to prevent any sudden dislocation, we recommend that such ownership not be made mandatory for a decade or so, in order that appropriate adjustments can be made by industry. Meanwhile, we will adjust our prices to be consistent with the true value of the materials.

Toll Enrichment. A further step to be considered is that of undertaking "toll enrichment." With this available, industry could buy its raw materials on the open market, use privately-owned plants to prepare them for enrichment, and depend upon the Government only for the actual enrichment process in the diffusion plants. Since there is ample capacity and since Commission policy has been to do such service work at cost, industry could be assured of adequate supplies at prices in which the only element in Government control would be relatively small and would be reasonably stable and predictable. Assuming that private ownership is indeed made possible, the step of providing toll enrichment service, an equivalent purchase and sale arrangement, or some other alternative should certainly be taken. Such a step would, of course, affect future AEC uranium procurement policies. Any toll enrichment service should be extended to our friends abroad, subject to proper safeguards against diversion for military use.

Plutonium Prices. A related problem is that of the values set upon special nuclear materials for leasing purposes, the prices paid by the Commission for such materials produced in private reactors and, if and when private ownership is permitted, the prices to be charged in the sale of such materials. At the present time, the value assigned to enriched uranium for leasing purposes is approximately the cost to the Commission, taking appropriate account of overhead, plant depreciation, etc.

We expect to continue this policy in the future. Values for U-235, which have been reduced twice in the past 18 months, now run from approximately \$5 per gram for very low enrichments to \$12 per gram for very high enrichments.

The guaranteed plutonium prices (or, more properly, allowances, in view of mandatory government ownership), which by law are set at "fair value for the intended use", have gone through several changes. For several years they followed a sliding scale depending on isotopic constitution. More recently the value has been fixed at \$30/gram regardless of isotopic content. This price is guaranteed until June 30, 1963.

The Commission has recently concluded that, following that date the guaranteed base price should be in accordance with the "near-term value" for plutonium as reactor fuel. This is calculated to be approximately \$9.50/gram, for average reactor product in metallic form, using the cost of U-235 as a base, and assuming that the plutonium would be used in thermal reactors. We believe that consideration should be given to scaling the prices in accordance with the isotopic content,* and that the same policy should apply to purchases abroad of plutonium made from uranium enriched in the United States.

A similar basis would be used for setting the value of U-233; a sliding scale might well be used because of the extra handling and processing costs when radioactive U-232 is present.

If and when private ownership is permitted, the Commission would continue for a time to set a guaranteed price, but, of course, the utility producing the material would be under no compulsion to sell it to the Commission, so that the offered price would constitute a market floor. Presumably that price would be adjusted from time to time in accordance with the market value.

<u>Uranium Procurement</u>. Through a very successful series of bonuses and guarantees of long-term contracts, the uranium mining and milling industry was built from almost nothing in 1950 to a point where the country is now self-sufficient in this field and need not depend on foreign sources. This industry has, to date, relied almost entirely on the military program. Since new weapons can utilize the nuclear materials from retired, obsolescent ones, it is almost inevitable that the requirements for new uranium for weapon purposes will decrease within the next decade, even without the hoped-for success of disarmament negotiations. On the other hand our projections for nuclear power predict a significant and rapidly increasing need for such material beginning in the 1970's. By, perhaps, the early 1980's the requirements will equal or surpass present rates of use. There will, however, be an interval of decreased

*The Pu-240 is not fissionable, though it is fertile. Hence it is a diluent reducing the fuel value of the material.

requirement for perhaps a decade centered around the early 1970's.

Present contracts with uranium miners and processors, which carry to the end of 1966, will presumably result in a modest surplus of material by that time. If the same level of procurement were carried forward into the period of diminished requirements, the surplus could grow considerably. The Commission is, therefore, faced with the problem of how best to sustain the uranium industry during the slack period without accumulating too great a surplus. That it be sustained is vital to the future interests of the country; a strong industry will be required for the later period of accelerated commercial need. Furthermore, without the prospects of a sustained market following 1966, there might be a tendency among the miners to "high grade" during the next few years and sooner or later to abandon the lower grade mines with consequent permanent loss of substantial quantities of these vital resources.

Consequently, the Commission has decided to offer a "stretch-out" program to the industry. A commitment to purchase additional material after January 1, 1967 will be offered as an incentive to induce a company to delay until after that date delivery of part of the uranium presently under contract. If successful, this program will result in a leveling-off process which should carry through the period of slack use without injuring the industry substantially or resulting in an unreasonably large surplus.

Service Industries

In addition to a major equipment industry, a large-scale nuclear power program will require the building up of industry engaged in such activities as the fabrication of fuels, the manufacture of nuclear instruments and control equipment, and the chemical processing of used reactor fuels to recover the nuclear materials from the fission products and other wastes. Many of these are already underway since they could start on a small scale, and since they have been given considerable business by the AEC. They should be encouraged in every reasonable way. The AEC should give them as much of its own business as reasonable economy will permit, and, on no account, should it compete with them for private business, except as an accommodation to industry in cases where no private capability exists.

A special case is that of the chemical separation of used fuels, which is attractive to industry only on a fairly substantial scale, and for which there will be little private business until civilian reactors have operated for an appreciable period. The Commission, which has large plant capacity related to its weapon program, has been doing all such work. Strong encouragement is being given to private industry to embark into this field, with promise of success. As part of the encouragement the AEC has informally indicated willingness to provide sufficient business to require 100 operating days per year in a fair-sized private plant. We believe that as soon as sufficient private plant capacity exists, the Commission should withdraw from all such work deriving from industry and should utilize the private plants to fill its own requirements except, perhaps, for those related to materials for weapons.

Licensing and Regulation

Steps are being undertaken to simplify and streamline the licensing and regulatory procedures. A major step is the recent enactment of legislation that will reduce greatly the number of mandatory public hearings. The Commission is studying means to simplify its own licensing procedures by reducing the volume and complexity of administrative processes.

The Commission is also studying ways to modify current regulations so that better guidance can be given to utilities on the suitability of specific reactor sites prior to their making substantial monetary outlays.

In the future, efforts will be made to reduce the number of technical reviews required and to concentrate the reviews on those features which have a potential effect on the health and safety of the general public. This will be easier to accomplish as reactors become more standardized. Increased emphasis on the responsibility of the designer will permit him to exercise more scientific and engineering judgment. As standardization of reactors proceeds, published guides can provide assistance to manufacturers as to format and coverage required in site reports, hazard reports and technical specifications so that the quality of these reports can be improved and the cost can be reduced.

When sufficient data are available to permit statistical treatment of the probability and potential results of possible equipment failures, we will be better able to evaluate the economic impact of special safety features and hence address ourselves to steps to minimize their costs.

Possible Industrial Impacts of the Nuclear Power Program

An important consideration in a transition such as that herein proposed is its possible impact on various segments of industry. We have already mentioned the fear that the existing nuclear equipment industry might suffer severely if construction of full-scale nuclear power plants does not accelerate at least somewhat. The strengthening of this industry through such an acceleration would not only improve the prospects for nuclear power but it would add strength to our general technological and industrial base and in particular would give added flexibility and capability for the construction of reactors needed for other purposes such as defense and the space program.

It is clear that no matter how great the acceleration in the nuclear power equipment field, there need be no fear of dislocation in the conventional power equipment industry in the light of the rate of growth in total power requirements. Furthermore, a substantial fraction of the companies in the nuclear power field are also engaged in the manufacture of conventional power equipment.

The Coal and Transportation Industries

Concern has been expressed lest conversion to nuclear power might cause severe dislocations in the coal industry and hence on transportation, especially the railroads. This is definitely not the case.

We have seen from earlier discussions, and from the curves of Figure 3, that even absorption of the total power industry by nuclear installations would still leave no dearth of markets for fossil fuels. Only a miraculous switch to nuclear energy by other industries as well could slow a rapid growth in those markets. Furthermore, the electric industry itself is growing at such a rapid rate that no possible growth of nuclear installations could prevent power generation from consuming greatly increasing amounts of fossil fuels for several decades—not, indeed, until the absolute rate of growth of nuclear power equals that of total power. By that time the consumption of fossil fuel for electric power alone will be several times what it is today. Curve A of Figure 4 illustrates that consumption, assuming Federal Power Commission predictions on rates of use of electrical energy (to 2000 A.D.) and our estimate of the rate of growth of nuclear power, as illustrated in Figure 3.

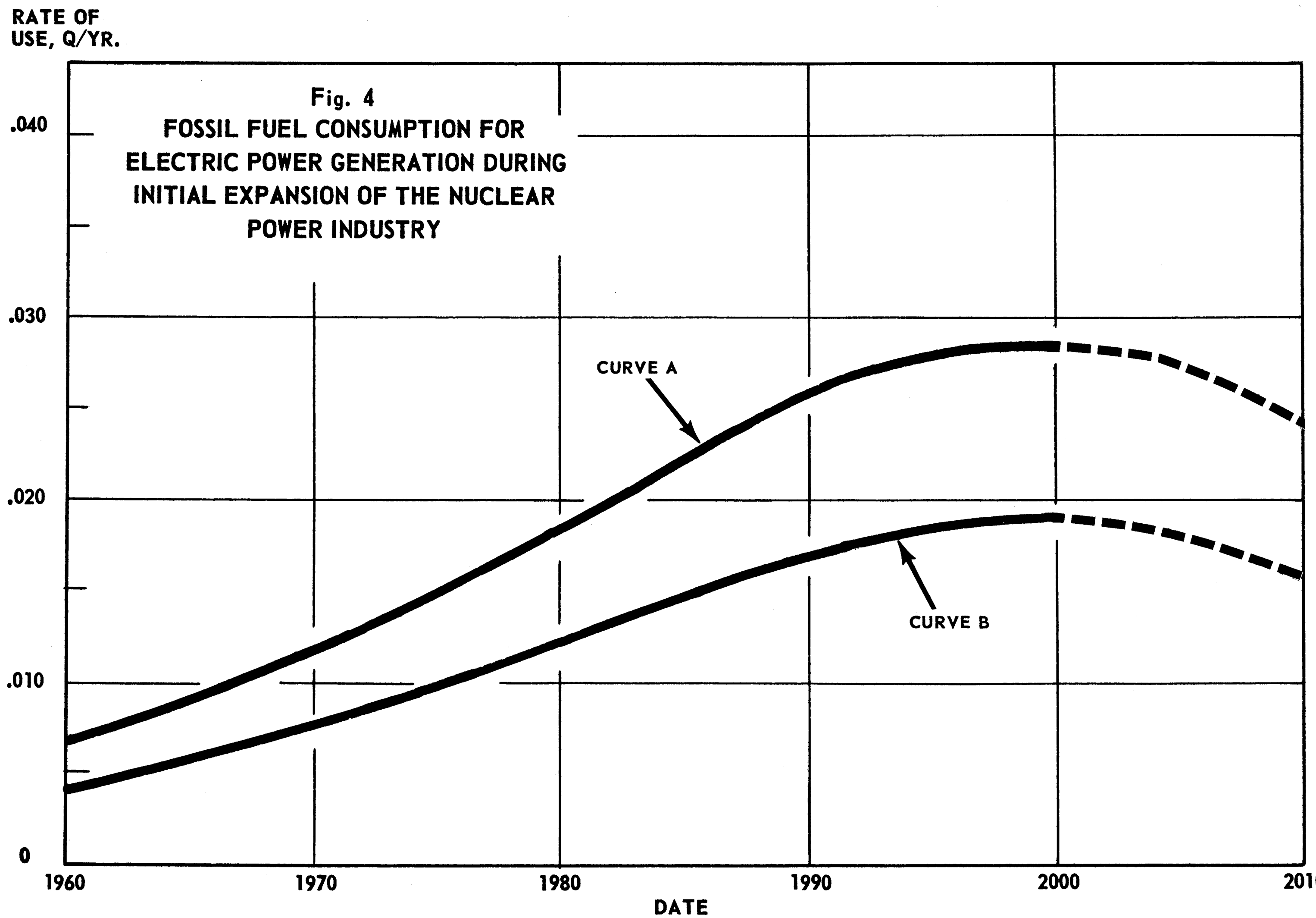

Fig. 4
FOSSIL FUEL CONSUMPTION FOR ELECTRIC POWER GENERATION DURING INITIAL EXPANSION OF THE NUCLEAR POWER INDUSTRY

CURVE A shows the consumption of fossil fuels in producing electric power. It is obtained from total energy requirements for electric power generation by deducting our estimates of nuclear electric generation, and the hydroelectric generation predicted by the Federal Power Commission.

CURVE B shows the consumption of fuel by coal-fired steam-electric plants on the basis that coal maintains its present fraction of the fossil fuel for power generation.

The concern of the coal industry has been brought about primarily by two factors. During the first decades of this century, marked increases in efficiency, especially in power generation, reduced the consumption required to carry out a given task. Although there is still room for improvement, this effect can never be so great again.

More recently the major factor in the decline of coal consumption has been a loss of markets to other forms of fossil fuels. During the past 15 years, annual consumption of coal decreased from 550 million tons to 375 million tons, in spite of an increase from 86 million to 180 million tons used for electric power generation.* The decrease was brought about by an essentially total loss of the railroad market and other heavy losses in manufacturing and home heating. The result is that, whereas in 1947 the electric utilities consumed only about 16 percent of all the coal, in 1961 they accounted for almost half. Even though the other losses should continue (many have shrunk so far there is not much more to lose), the growth in power installations will inevitably more than offset the loss.

In 1960 fuel burning electric plants in the United States derived 66 percent of their energy from coal, 26 percent from gas, and 8 percent from oil. These figures have remained constant within 2 or 3 percent for a decade or more, with coal changing very little and gas increasing slightly at the expense of oil. In view of the large reserves of coal compared to oil and gas and the preferred use of the last two for other purposes it seems certain that within a relatively short time the fraction of electric power based on coal will increase appreciably. This trend will be increased by the major, and successful, efforts of the coal industry to reduce transportation costs and by the possibilities inherent in the trend to very large centralized power plants which can in many instances be placed close to coal supplies. The probability of this trend is borne out by the fact that, whereas average coal prices to utilities have decreased some 20 percent (in constant value dollars) over the last 8 years, those for gas, its principal competitor, have increased by 40 percent.

Curve B of Figure 4 illustrates the rate of consumption of coal for electric power, using the figures of curve A for consumption of all fossil fuels for power and, conservatively, assuming the present distribution ratio between the various fossil fuels. It is readily apparent that, even though coal did not increase its share, a very large increase in coal consumption would nevertheless occur. Indeed, by 1970, consumption for this purpose alone would exceed all coal consumption at the

*Statistics in this section were supplied by the Department of the Interior.

present time. The increase would continue for 40 years or more and even under our assumptions would not recede to present values until the middle of the next century, if then. Well before that time the dwindling supplies of oil and gas will force increased coal consumption in other industries; coal and coal products will begin to recapture the markets they have lost. Indeed, as seen before, our concern is not that coal demands will be too small but rather that they will be so large that our supplies will be too rapidly exhausted.

Appendix

Sources of Information

Recent published reports used during the course of this review included:

"Report of the National Fuels and Energy Study Group on an Assessment of Available Information on Energy in the United States," a September 21, 1962 study prepared for the Committee on Interior and Insular Affairs of the United States Senate.

U. S. Geological Survey Bulletin 1136, 1961, "Coal Reserves of the United States—A Progress Report, January 1, 1960," by Paul Averitt.

"Appraisals of Future Nuclear versus Conventional Electric Power Costs by Leading Industry and Government Organizations Released by the Joint Committee on Atomic Energy," press release No. 368 from the Office of the Joint Committee on Atomic Energy. The release is dated July 30, 1962.

"Development, Growth, and State of the Atomic Energy Industry," Hearings before the Joint Congressional Committee on Atomic Energy on March 20, 21, 22, and 23, 1962.

"Report of the Advisory Committee on U. S. Policy Toward the International Atomic Energy Agency," a May 19, 1962 report of an Advisory Committee Appointed by the Department of State.

"Report of the Ad Hoc Committee on Atomic Policy," a March 1962 report of the Atomic Industrial Forum.

"Report to the Panel on Civilian Technology on Coal Slurry Pipe Lines," a May 1962 report of Department of the Interior.

"Steam-Electric Plant Construction Cost and Annual Production Expenses, Thirteenth Annual Supplement, 1960, FPC-S-149" Federal Power Commission.

"Steam-Electric Plant Factors, 1961," Twelfth edition, July 1962, National Coal Association.

Other reports and communications used during the course of this review included:

"Supplies, Costs, and Uses of the Fossil Fuels," a June 29, 1962 report prepared for the Atomic Energy Commission by the Department of the Interior Energy Policy Staff. (Some information in this report was updated subsequently and informally by the Department of the Interior.)

A letter report of June 8, 1962 to the Atomic Energy Commission from Joseph C. Swindler, Chairman, Federal Power Commission.

"Summary Report on Natural Resources," an August 1962 draft of a report being prepared by the Committee on Natural Resources of the National Academy of Sciences.

"Energy Resources," a draft report prepared by a panel of the National Academy of Sciences Committee on Natural Resources.

"A Comparison of the Nuclear Defense Capabilities of Nuclear and Coal-fired Power Plants," BNL-6080, a May 1962 report prepared by members of the staffs of Brookhaven and Oak Ridge National Laboratories, assisted by the architect-engineer firms: Burns and Roe, and Sargent and Lundy.

A draft of "Economics of Permanent Disposal of Power Reactor Wastes in Tanks" by Stockdale, Arnold, and Blomeke. This report is expected to become available as ORNL-2873 in a few months.

Seminars on Civilian Nuclear Power were held at AEC Headquarters in order to provide the Commission and the Commission staff with as much current information as possible. Representatives of AEC contractor organizations and others made presentations of their own on prospects for civilian nuclear power. Presentations were evaluated by consultants and advisors to the Commission: members of the Subcommittee on Reactors of the General Advisory Committee were present at all seminars, and staff scientists and engineers from various National Laboratories were present as appropriate. The subjects and dates of these seminars were:

Boiling and Pressurized Water Reactors	April 19–20, 1962
Heavy Water and Organic-cooled Reactors	April 26, 1962
Gas-cooled Reactors	May 4, 1962
Liquid Metal Cooled Reactors	May 9, 1962
Plutonium Recycle and Thorium Utilization	May 10, 1962
Advanced Reactor Concepts	May 14, 1962

Many of the reports and presentations were identified as containing proprietary information. A number of the reports were incomplete in themselves, and intended to accompany the oral presentation. Since they were intended for the use of the AEC rather than for publication, they are not identified individually in this Appendix. However, they were helpful and they are acknowledged.

In addition to the discussions acknowledged in the Introduction, Members and Staff of the Atomic Energy Commission had helpful discussions with organizations such as the Atomic Industrial Forum, and with many individuals during the course of this review.