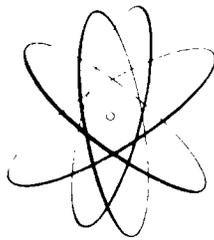


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ATOMIC ENERGY
IN
ECONOMIC DEVELOPMENT



PANEL DISCUSSION
Eleventh Annual Meeting
Board of Governors

INTERNATIONAL BANK FOR
RECONSTRUCTION AND DEVELOPMENT

September 27, 1956

K. S. Venkatraman

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Washington 25, D. C.

INTRODUCTORY NOTE

These pages reproduce the informal panel discussion on “Atomic Energy in Economic Development” which was held on September 27, 1956, at the Eleventh Annual Meeting of the Board of Governors of the World Bank.

INTRODUCTION BY
ANTONIO CARRILLO FLORES

Chairman of the Board of Governors

THIS SESSION OF THE ELEVENTH ANNUAL MEETING OF the Bank's Board of Governors will be devoted to an informal panel discussion on the subject of *Atomic Energy in Economic Development*.

I intend to call upon President Black to describe the discussion this morning, but before doing so, I wish to commend him and his advisers for selecting this important subject, and for obtaining our famous guests to present and discuss it.

We live in the atomic age. On the one hand, we hear of the great benefits that this new technological advance will bring to the world, and on the other hand, we read of the catastrophic destruction that

atomic and hydrogen warfare are capable of causing.

We, all of us, hope that the latter will never eventuate. But we must do more than that. We must bend our minds and our energies to the task of bringing the bountiful blessings of atomic energy to mankind everywhere, for by so doing we shall not only effect material progress, but, more important, we shall engender a spirit of mutuality and of trust which will do much to prevent war and, indeed, may abolish that term from the languages of men.

I wish to now call upon President Black to introduce our panel discussion on the subject, *Atomic Energy in Economic Development*.

REMARKS BY
EUGENE R. BLACK

President, International Bank for Reconstruction and Development

IN MY SPEECH AT THE TENTH ANNUAL MEETING AT Istanbul last year, I mentioned that the Bank was following the subject of atomic energy with interest and that we would continue to keep ourselves informed on developments. Today we are going to hear about recent advances in this field from four leading experts: Admiral Lewis L. Strauss, the Chairman of the United States Atomic Energy Commission; Sir Edwin Plowden, the Chairman of the United Kingdom Atomic Energy Authority; Sir John Cockcroft, the Director of the Atomic Energy Research Establishment at Harwell, England; and Mr. W. Kenneth Davis, the Director of the Reactor Division of the United States Atomic Energy Commission.

On behalf of the Bank, I should like to express our appreciation of the readiness of these eminent and very busy gentlemen to put their knowledge and experience at our disposal.

We believe it will be helpful to our member governments and to the Bank to hear first-hand about the great potentialities of the peaceful use of the atom; how member countries with intensive programs for the development of atomic power are progressing with the technical problems involved; what are the prospects of international cooperation in this field, and how, as a result of their experience, they view the economic possibilities of this new source of energy.

Now, the Bank is not interested in atomic power as an academic exercise. We are not an academic or research institution. We are an international development bank whose activities are directed towards aiding our member countries to develop their economic strength through the establishment of well based policies and practices so that they may make the best use of their investment and other resources.

Experience in modern technology teaches us that

what is today but a gleam in the eye of a scientist or engineer is tomorrow's investment. So if we are to provide sound advice to our members, we must, as it were, look over the shoulders of the scientists and engineers who are developing today what will be the subject of tomorrow's investment.

We are following atomic energy developments also, because over thirty-six per cent of our development lending has been for electric power projects. We already have a very large stake in conventional power and this stake is continuously growing. We are constantly reviewing new projects for hydroelectric and thermal plants, and we must take into account the possibilities of atomic power as a field for future investment.

Moreover, the world's demands for energy are steadily mounting. The world's resources of hydro power and the world's reserves of nonrenewable energy resources—oil, gas, and coal—must be supplemented to meet that growing demand in the coming years. I think after hearing from the Members of the Panel, we shall, all of us, have a greater awareness of

the upper and the lower limits within which nuclear power can best be economically exploited and, as a result, shall be able better to assess the place of this new energy resource in our new economic planning.

I am glad to know that in our audience today is Professor Francis Perrin, who is the High Commissioner of the French Atomic Energy Commission. I hope we shall have the pleasure of hearing from him in our discussion.

I would like now to present to you the Moderator of our Panel. He is Mr. Corbin Allardice, the Bank's Adviser on Atomic Energy. Before joining the Bank last fall, he was Executive Director of the Joint Committee on Atomic Energy of the United States Congress and he was associated with the United States atomic energy program in various official capacities for over nine years. The Bank is very fortunate in having been able to obtain a man so well qualified to act as its eyes and ears in this new exciting field.

I will now call on Mr. Allardice to begin the Panel's presentation.

PRELIMINARY REMARKS BY MODERATOR,
CORBIN ALLARDICE

Adviser on Atomic Energy, International Bank for Reconstruction and Development

IT IS A SINGULAR PLEASURE FOR ME to have the opportunity to act as Moderator of this Informal Panel Discussion on *Atomic Energy in Economic Development*. In the course of these discussions you will no doubt hear some terms and ideas not fully familiar to you. May I say that the terms of finance and banking—and the concepts behind that special language—are at least as novel to most practitioners in the atomic energy field. Our meeting this morning provides a most unusual opportunity for communication between these disciplines, and will, we hope,

result in a fruitful cross-fertilization of ideas.

The procedure we will follow is to call first upon the representatives of the United Kingdom and then upon the representatives of the United States to present their prepared remarks.

Following the presentations by the four Panel Members, the Chairman plans to recognize the Delegation of France for the purpose of hearing from the distinguished High Commissioner of the French Atomic Energy Commission. The Moderator will then briefly summarize the discussions.

REMARKS BY
SIR EDWIN PLOWDEN,
Chairman, United Kingdom Atomic Energy Authority

IN THE TIME AVAILABLE TO ME I shall say something about the United Kingdom's nuclear power program and the conditions that have made it possible. I wish also to try to compare British conditions with those prevailing in some other countries.

In February last year the United Kingdom Government issued a White Paper called *A Program of Nuclear Power*. This set out a plan for the construction of nuclear power stations over the next ten years and indicated the possible developments over the next twenty years. There were, as I shall explain, compelling reasons leading us to work out this program when we did. They were economic reasons. They did not spring from any unique or spectacular advance in nuclear technology. Other countries, also, will, I believe, bring nuclear energy into commercial use—distinct from experimental or demonstration use—when it is appropriate to their economic needs and economic resources. When this will be depends on a variety of factors—for instance, the cost of fossil fuel and of hydro power, and also the availability and cost of capital.

The United Kingdom is an industrial country. Its survival depends on the development and use of its industrial skill. Its economy has been, and still is, based on coal. But the easily worked coal has now all been used. Future supplies will only be obtained with continually rising costs.

Our rising industrial production will require an increase in energy supplies of perhaps up to forty per cent over the next fifteen years. Towards this, our National Coal Board's plan for developing the coal industry envisages an increase of coal production of

only eleven per cent—from nearly 225 million tons today to about 250 million tons in 1970—and this will only be achieved at an investment cost of well over £1,000 million. The gap left in our supplies will have to be filled by oil, or by nuclear energy, or by a combination of both. Oil means increased imports and a severe strain on our balance of payments. As soon, therefore, as there appeared a reasonable chance of nuclear energy becoming competitive in our own conditions, we treated its development as a necessity.

The nuclear power program published last year called for the building of twelve nuclear power stations by 1965. These were to have a total capacity of about 2 million kilowatts. The program was intended to be flexible and it is already apparent that changes will be made in it. In particular, we now hope that we will be able to increase the total capacity installed by 1965 to a significant extent.

The prologue to our program is Calder Hall—the gas-cooled graphite-moderated station which H. M. The Queen is to open next month. This station—whose gross electricity output will be 90,000 kilowatts—is a dual-purpose station. It produces plutonium as well as electricity. It has not therefore been designed in the most economic way for the production of electricity. Moreover, the design was conservative. Three more plutonium producing stations identical to it will be completed by 1960.

In our 1955 program we assumed that most of the stations to be built in the next ten years would be based on Calder Hall. We also assumed that, when redesigning Calder Hall for commercial use, industry would be able to make substantial improvements

Sir Edwin Plowden has served as Chairman of the U. K. Atomic Energy Authority since 1954. He was educated in Switzerland and at Pembroke College, Cambridge. During the war, he worked with the Ministries of Economic Warfare and of Aircraft Production. He has served as Chief Planning Officer and as Chairman of the U. K.

Economic Planning Board. He was a member of the Aircraft Supply Council, and served as Vice Chairman of the Temporary Council Committee of N. A. T. O. In 1953, he became an adviser to the U. K. Government on Atomic Energy Organization.

upon it. Four groups of industrial firms have now completed their redesign and will submit tenders for the first stations to our Electricity Authorities within the next few days. The tenders will be for the construction of stations to be completed by the end of 1960. Present indications are that the engineering improvements are greater than we felt we could count on—though not greater than we hoped for—when the 1955 program was published.

It seems likely that the output of the stations will be between 200,000 and 300,000 kilowatts each. The exact figure depends, of course, on the individual design selected. Even though the temperatures reached in these early reactors will not be very high, the thermal efficiency of the stations is likely to be over 25 per cent. We expect that the capital cost per kilowatt will not exceed £120. To this must be added the initial investment in uranium fuel; that might be about £30 per kilowatt. The capital cost of coal or oil-fueled stations of a comparable size in the United Kingdom is now estimated at £55 per kilowatt. The capital cost of the nuclear stations will, therefore, be substantially greater than that of conventional stations. For this reason the competitive position of the nuclear stations will depend partly on the extent to which capital is available at reasonable rates and partly on our ability to keep their fuel costs low.

As Sir John Cockcroft will tell you, there is, however, plenty of scope for reducing the capital cost of this type of station. Some of the other types that we may be introducing commercially by the end of the next ten years will also have substantially lower capital costs per kilowatt.

We believe that we are on fairly firm ground in estimating the capital costs of our early stations. Unfortunately, there are much greater uncertainties when we come to estimate fuel costs. These depend not only on the cost of the ore and of fabricating it into cartridges, but also on the amount of heat we can extract from each ton of metal before we have to remove it from the reactor—the “burn-up” as the scientists call it. Burn-up can be of critical importance. We are studying it intensively and we believe that

from each ton of uranium we can extract heat equivalent to that from 10,000 tons of coal. We hope and expect eventually to improve on this figure, but exactly how much heat we shall get from the first uranium we use is still uncertain. It will depend upon the success of our development work.

At present, power station coal costs about £4 per ton in the United Kingdom. If each ton of uranium is equivalent to 10,000 tons of coal, the cost of coal producing the same amount of heat as one ton of uranium will be £40,000. One ton of uranium ore will, however, cost only about £10,000. We must allow for the cost of fabrication and for the rather lower thermal efficiency of the earlier nuclear stations. But, even if we double the cost of the uranium to allow for these things, you will see that the fuel costs of an early nuclear station should be substantially lower than the fuel costs of a coal-fired station in the United Kingdom.

In estimating the cost of power from our first power stations we have to decide what credit should be taken for the by-product—plutonium. Plutonium contains the same amount of heat as three million times its weight of coal and is of great potential value in the nuclear power program. It should be possible to feed it back into the reactor that produced it. This would reduce the amount of natural uranium required. Alternatively, and more important, it should be possible to use it as a means of enriching reactors instead of using costly uranium 235 from a diffusion plant. But there are many detailed problems to be solved before it can be used. These are being tackled vigorously by our scientists. The credit that it is right to take for the plutonium produced will, therefore, depend both upon our success in developing the best ways of using it and on the achievement of cheap and simple methods of extracting it in a usable form from the irradiated fuel elements of the reactor in which it is produced. Taking all these variables into account, we believe that it is reasonable to assume a credit for the plutonium by-product equivalent to about 0.1 pence per unit of electricity sent out.

On the basis of the figures I have given, the total cost of power from our early nuclear stations should

be approximately the same as that from coal- or oil-fired stations in the United Kingdom. They should produce power at about 0.6 pence per kilowatt-hour or, in U. S. terms, at about 7 mills per kilowatt-hour. These calculations are made using capital charges of 8 or 9 per cent—say, 5 per cent interest and a fifteen- to twenty-year life—which is a reasonable life to assume in United Kingdom conditions and is indeed higher than is normally used for conventional power stations.

This brings us to the question why, if these stations are economic in the United Kingdom, they would not be economic everywhere. What, in other words, are the economic criteria which determine the advantages of nuclear power, compared with conventionally-generated power?

The first factor is, as I have said, that the capital element in the cost of nuclear power is heavy. This means not only that sufficient capital must be available but also that the relative cost of nuclear power will be adversely affected in countries where it is appropriate to take higher figures than those I have mentioned for the capital charges. In the United States and elsewhere capital charges on power stations are often taken at 12 to 15 per cent as against the 8 or 9 per cent I have mentioned for the United Kingdom.

The relatively heavy capital cost—and the low running costs—also means that nuclear power is likely to be most competitive where the stations can be run at a high load factor—preferably continuously throughout the twenty-four hours. This can be done only where the stations are used in conjunction with a large electricity distribution system.

The next point is that with nuclear power stations there are great economies of scale. The larger they are, the cheaper per kilowatt. Probably this will not be as true of the later types of stations as it will be of the gas-cooled ones, but even the later types are likely to be competitive first in large sizes.

Finally, nuclear power as produced by stations like the early British ones is unlikely to be able to compete with hydroelectric power—which can usually be produced for around 4 mills or less. Equally, nuclear power at the cost of the earlier British stations will

not be attractive where fossil fuels are available abundantly and cheaply.

On the criteria I have suggested, other highly industrialized countries without sufficient indigenous fuel should not be far behind the United Kingdom in introducing nuclear power. We would expect France, Germany, and Japan to install significant amounts of nuclear power in the early 1960's. A few commercial stations may also be installed in the same period in Italy, Spain, and South Australia; perhaps in Ontario, Canada, as well. But some industrial countries will probably wait longer. Scandinavian countries should not require nuclear electricity until the 1970's, although they are now thinking of using nuclear reactors as a source of heat. The USSR is probably in a similar position to the United States. They will have a number of "power demonstration" stations in operation by 1960; but, with their large energy resources, the needs of these two countries for commercial nuclear electricity in the 1960's should, we believe, be limited to a few special areas.

In most of the so-called underdeveloped countries power is produced in comparatively small blocks, except where hydroelectric potential is available. A thermal station of 30,000 kilowatts is usually considered a large station. We believe it will be at least ten years before competitive nuclear power stations of this size have been fully developed and tested and are available for large scale use. There are, however, some countries such as India, Turkey, and Egypt where a few large thermal power stations of the order of 100,000 kilowatts have been built or are planned. In some of these countries one or two nuclear stations might be constructed in the next ten years. We must also bear in mind that the demand for electricity grows so rapidly—it doubles every ten years in many countries—that the size of the stations required is likely also to increase substantially.

In many underdeveloped countries a high proportion of the power is produced by small diesel stations of 5,000 kilowatts output or less. A recent analysis of the performance of forty of these stations has shown that their average load factor was only 27 per cent

and that the average cost per kilowatt-hour was about 1.9 pence, or 22 mills. This cost rises to perhaps 30 mills at a few remote stations. We do not know yet when it will be possible to design nuclear power stations of this small size so that they will be competitive with these diesel costs.

One of the difficulties is that the small nuclear stations are likely to require the use of highly enriched fuel. This is expensive. If the small reactor can be designed to burn one-third of the enriched fuel charge before the chain reaction ceases and the charge has to be replaced, then the fuel cost itself would be 10 mills at the present United States costs of \$25 per gram of uranium 235.

To beat the average diesel cost of 22 mills which I have just given, capital charges and operating costs together would have to be reduced to about 10 to 15 mills per kilowatt-hour—let us say 10 mills for the capital costs alone.

With a load factor of only 27 per cent and capital charges of 10 per cent, this would require the capital cost to be as low as £80 per kilowatt. This calculation allows no credit for the unspent fuel. If credit is taken for this and account taken of transport and refabrication costs, the effective fuel costs might be reduced by about 25 per cent so that the capital costs could be increased to £100 to £110 per kilowatt. It seems likely to be some years before this is achieved.

From what I have already said, you will realize that we in Britain do not feel that nuclear power is likely to be used on any substantial scale in the underdeveloped countries for at least ten or fifteen years, although a few large stations may be built.

Our own British program is still at an early stage and is designed to meet our special economic circumstances. These, as I have said, are favorable to the use of simple large nuclear power stations.

In the meantime, both in the United States and in the United Kingdom, different types of reactors are being developed, some of which are likely to be more suitable for operation in small- or medium-sized units.

I have felt it only right to warn you that so far as we see it, the widespread use of nuclear power cannot help taking a considerable number of years. I have felt it the more necessary to give this warning because nuclear technology offers such glamorous possibilities that there is a serious danger of assuming that the potential improvements visualized for the future can be obtained now. Many years will be required for the development of the various exciting systems to the stage at which they can be used commercially on a large scale.

But, having given my warning, I must also say that we realize and welcome the challenge to skill and to initiative which the coming of nuclear power brings with it.

In spite of the ifs and buts, on which I have had to dwell, the adding of a new source of power to the world's store of wealth is an occurrence of enormous significance.

Our British program is flexible, and because of this, we shall be able to take full account of the technical development which we know will occur in the next few years. As well as developing our own use of nuclear power, we are anxious to do all we can to promote its development in those countries that can make effective use of it.

REMARKS BY
SIR JOHN COCKCROFT,
Atomic Energy Research Establishment, Harwell.

SIR EDWIN PLOWDEN has spoken about the United Kingdom's nuclear power program, and the expected performance and economics of the nuclear power stations which will come into operation about 1960.

The World Bank will also be interested in the longer-term prospects for nuclear power, so I will undertake the more speculative and difficult task of looking five and ten years further ahead and try to predict how the course of development may proceed.

As Sir Edwin has said, our first commercial nuclear power stations will be characterized by a high capital cost per kilowatt compared with coal- or oil-fired stations, but fuel costs are likely to be appreciably lower, so, on balance, in the United Kingdom they are likely to be competitive with coal- and oil-fired stations.

The natural and usual course of development of pioneering projects is that capital costs fall rather rapidly in the early stages.

The capital cost of steam power stations has fallen from over £4,000 per horsepower when they were first invented to about £40 per horsepower today. These figures have been adjusted, of course, for the fall in the value of money.

A rather similar fall has occurred for land-based oil engines, the cost per horsepower falling from about £100 in 1900 to about £10 by 1940, quite a substantial fall.

We will achieve a first stage in this reduction in cost in going from the pioneering Calder Hall Station to the first commercial station for the Central Electric Authority.

Sir John Cockcroft, Director of the U. K. Atomic Energy Research Establishment at Harwell, was educated at the University of Manchester, and St. John's College, Cambridge. His work in the field of physics has won international acclaim. Among his degrees and honors are included the Royal Medal of the Royal Society, the Faraday Medal, and the U. S. Medal of Freedom. He is

The gross power output of these stations will be raised by a factor of about three to a level of up to about 300,000 kilowatts, depending on the design.

So the capital cost per kilowatt has been correspondingly reduced. This has been achieved by a number of straightforward engineering developments.

The first picture (Fig. 1, overleaf) shows you the state of the Calder Hall Power Station a few months ago. In this power station the heat is provided by two large nuclear reactors. One of them can be seen in the center of the photograph. Surrounding the reactor are four steam generators. On the left-hand side of the picture are the conventional cooling towers. There is a further reactor out of the picture to the right.

The next illustration (Fig. 2, page 11) shows the general construction of one of the reactors. There is a large kettle or drum in the center of the drawing. This drum is about forty feet in diameter. It contains the graphite core and in channels in the graphite core hang the uranium metal rods sheathed in magnesium alloy.

The rods get hot, and heat is circulated from them to the steam generators, one of which is shown as the large cylinder on the right.

Now, the point of this is that after the experience of building the Calder Hall reactor and in particular in developing the experience of building up this very large pressure drum on the site, we found that it was possible to increase the thickness of steel forming the pressure drum, which could be welded on the site, by about 50 per cent.

This meant that in the next models of the reactors for the Central Electric Authority, we could increase

a Chevalier of the Legion of Honour, and was awarded, with his colleague Professor Walton, the Nobel Prize for physics in 1951. During the war, he was Chief Superintendent, Air Defense, Research and Development Establishment of the Ministry of Supply, and Director of the Atomic Energy Division of the National Research Council of Canada.

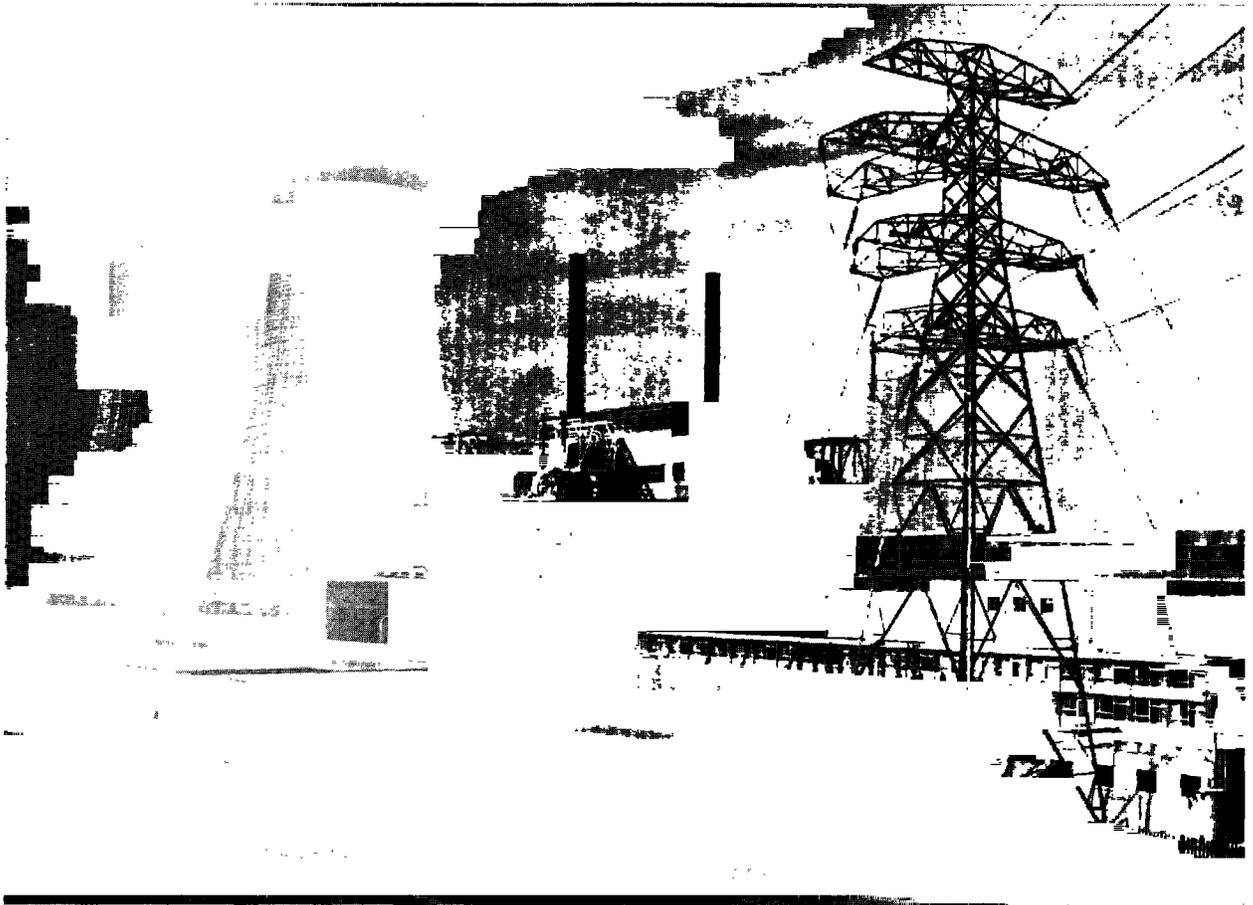


Fig. 1. Calder Hall Nuclear Power Station.

the diameter of the core. This, of course, increases the amount of heat which can be developed.

Secondly, owing to the peculiar character of nuclear power stations, it means that heat can be developed more uniformly across the core so that we get further gain in that way.

Then, finally, because the thickness of the pressure drum can be increased, the pressure of the gas which is used to circulate the heat can be increased about 50 per cent. That allows for more heat to be extracted from each ton of uranium metal or from each unit of volume of the core.

It has also been possible to make improvements in the shape of the fuel elements by changing the shape of the surfaces to give greater heat extraction possibilities, and also to increase the temperature of the fuel elements slightly.

The result of all these rather modest steps has been that we have achieved, or expect to achieve, significantly increased output.

We think that this normal course of engineering development by straightforward and fairly obvious steps might well lead to a still further reduction in capital cost in the next models which we expect will be built eighteen months later.

Beyond this we can foresee the possibility of a more substantial reduction by taking a bigger jump, by increasing the temperature of operation of the reactor fuel elements by about 100° Centigrade. This may require a change in the materials used for sheathing. We may change from a magnesium alloy to a beryllium alloy. The development work we have been doing for the last two or three years has shown this is likely to be possible. At the same time we are likely to make

further improvement in the shape and heat transfer capabilities of the fuel element.

We believe, therefore, that by a combination of these steps, and provided that the consequential development problems are also solved by 1960, we may obtain a further increase in the heat rating, that is, the amount of heat by unit volume of the core, by a factor of, say, two. So, therefore, we feel there is a prospect of capital cost falling towards the cost of fuel-fired stations by 1965. At any rate, this is our objective.

Fuel costs are the other important component of costs. If we adopt more expensive sheathing materials this will increase fuel costs. On the other hand, it seems likely that the primary cost of uranium may fall somewhat, and just about offset that.

The main prospect for decreasing fuel costs is, however, by increasing the amount of heat we can extract from each ton of uranium, the "burn-up", as

we say. Sir Edwin said we are expected in our first reactors to extract from each ton of uranium the heat equivalent of 10,000 tons of coal. Now, this limit is set by the fact that, as the nuclear chain reaction proceeds, the uranium 235 in the fuel is burned, but it is partially replaced by plutonium, which is a good secondary fuel. In other words, there is regeneration.

Then the waste products of fission accumulate and tend to damp out the chain reaction, so after a time when the heat extraction has reached its limit, we have to change the charge. We can send the fuel to a chemical separation plant; we can extract the plutonium, and we can extract the depleted uranium. In the first stage of our program we may stockpile those products for a time, but later we will expect to recycle all the plutonium as is shown in stage 2 of the diagram (Fig. 3, overleaf).

If we do that, then it seems likely that the makeup feed of the uranium to the reactor will be reduced

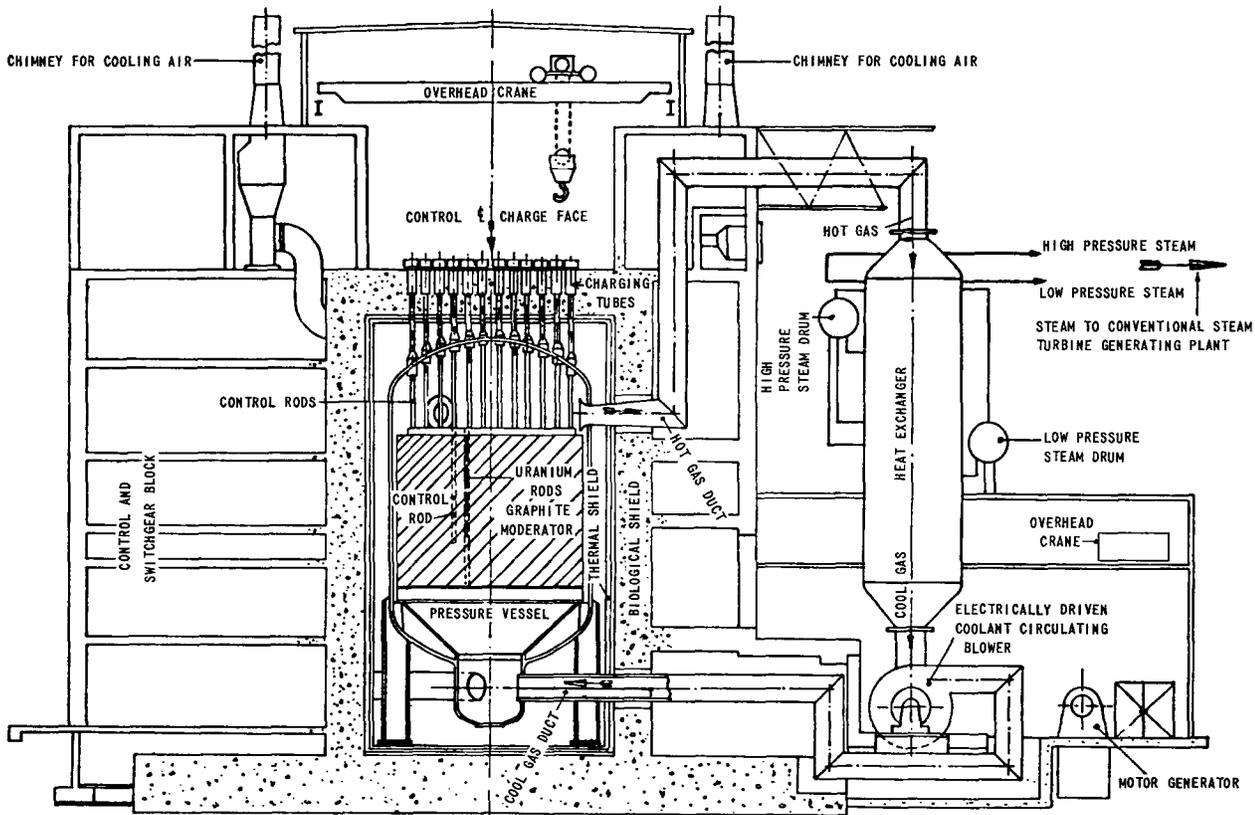


Fig. 2. A gas-cooled Power Reactor.

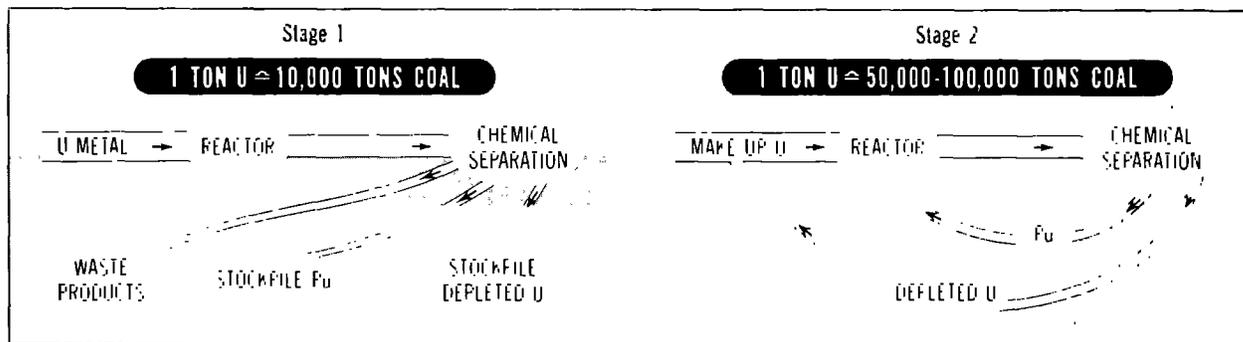


Fig. 3. Fuel Cycles.

about three times. This will mean that primary fuel costs are reduced by that factor.

On the other hand, we should have to add the cost of the chemical separation process and the cost of refabrication, but since we don't know enough about the economics of recycling, all we can say is that we hope by recycling we could achieve a further reduction in fuel costs.

An alternative way of increasing the utilization of the uranium is to burn it *in situ* in the reactor. This will be done if the reactor converts its uranium 238 fuel to plutonium with a very high degree of efficiency and if, also, we can produce fuel elements which will withstand the severe punishment they get when they stay a long time in a reactor.

If we do achieve the expected reduction in capital cost and make some saving in fuel cost by recycling or increasing the burn-up, then in Britain the cost of nuclear power should fall appreciably below the cost of coal-fired stations by the mid-1960's. In the United States with higher capital charges this would correspond to achieving parity with 7 mill power. We should, however, be still far from competitive with hydroelectric power at 4 mills.

In the United States and other countries other types of nuclear power stations using liquids to transfer the heat are being energetically developed. The reactors of these systems are smaller and should have lower capital costs than the gas-cooled reactors, but on the other hand they require more expensive enriched fuel.

We are conducting a feasibility study on one of these reactors, the sodium graphite reactor, a reactor

which has a graphite core in which liquid sodium is used to transfer the heat. At the present early stage of our study, it is uncertain whether this reactor will produce power at lower costs in Britain than the advanced gas-cooled reactors. However, the United States has done much more work on these systems than we have and I look forward with interest to Mr. Davis' views on this question.

We are also studying for a more distant stage of our program reactors which aim at still lower costs—say, 4 mills—but this rather glittering prospect is perhaps only a measure of our present inadequate knowledge of the technology of these systems. These advanced reactors have two main objectives. The first is to increase the heat ratings by another large factor, thereby reducing capital costs still more. In principle, this can be achieved by adopting the so-called homogeneous systems in which the uranium fuel and the moderator are mixed up. This should allow still more effective transfer of the heat from the fuel because the coolant can have greater contact with the fuel.

The second objective in these reactors is to reduce the fuel costs to the order of one mill by increasing the regeneration of fuel in the reactor, i.e., the production of secondary fuel. This is theoretically possible, but technological development, followed by experience of operation of these systems, is required to confirm this. We certainly would not expect to introduce nuclear power stations of this class into service in Britain before the late 1960's.

Thus, 4 to 5 mill nuclear power seems to us to be certainly ten to fifteen years away.

Sir Edwin referred in his talk to the prospect of producing economic power in the so-called under-developed countries and said that in several of these countries where power can be taken in blocks of 100,000 to 150,000 kilowatts, nuclear power may be competitive in a few places by the mid-1960's.

In other countries the problem seems to be more difficult. In Brazil or Pakistan, we are told that the maximum size of a nuclear power unit which could be introduced during the next decade will be about 30,000 kilowatts.

In Brazil, for example, hydroelectric power is available in the urban areas. The new thermal capacity, that is, capacity from coal or oil or nuclear stations, required during the next ten years, is about 800,000 kilowatts, of which about 300,000 could be generated in the southern areas from cheap coal. We were told at the Geneva Conference that most of the remainder would have to be generated by small blocks, say, 5,000 kilowatts or below, with an average size block of up to 20,000 kilowatts.

In Pakistan, we are told that there is likely to be a demand for an additional 600,000 kilowatts by 1965, which cannot be met from planned hydroelectric development. However, for the time being, there is no national grid and nuclear power can only be taken in blocks of 10,000 to 20,000 kilowatts.

This small size of the required power blocks in many countries is supported by the statistics of United Kingdom exports of generator sets. These show that 60 per cent of the export generating capacity from our country is in units of 30,000 kilowatts and below; however, with the well known doubling time of ten years for electrical loads, the upper limit of the range might increase to 50,000 kilowatts by 1965.

Our industry is at the present time studying the design of nuclear power stations with outputs of about 50,000 kilowatts and, in particular, is looking into the possibility of building the gas-cooled reactors on an economic basis for this kind of load.

The cost of power of conventional stations with a

capital cost of £90 a kilowatt, 12 per cent interest charges, and a load factor of 50 per cent, and oil at £10 a ton, is about 1.35 pence per kilowatt-hour. In order to achieve parity with oil, the capital cost of the 50,000 kilowatt nuclear power stations would not have to exceed about £140 per kilowatt.

As the size of the power block goes down, the problem becomes correspondingly more difficult. For the production of nuclear power in small blocks, it seems to us that the reactor which uses an organic liquid instead of water as a moderator to surround the uranium rods, is a promising starter because it seems likely to be a system which will be of a low pressure and will use less expensive components than reactors moderated by water. However, although we are studying this system, the United States has given much more attention to it than we have and, therefore, Mr. Davis should be able to give a better opinion.

The development of nuclear power in the under-developed countries is being preceded by the application of radioactive isotopes to the problems of agriculture, medicine, and industry. The United States and the United Kingdom are both committed to helping to establish pilot laboratories, one in the Philippines, the other in Baghdad. We hope to discover what contribution radio-isotopes can make to local economies in addition to the already well proved applications to medicine and biology.

Food preservation and insect control are obvious possibilities, since, in tropical countries, 25 to 50 per cent of stored crops are destroyed by insects. Two years from now we hope to know more about this.

I am very conscious that in making this report most of what I have said will be overtaken by events during the next five years. It is certain with the great power of creative technology today, that development will be rapid and capital costs of nuclear power projects will fall rapidly.

In spite of this, I personally think that it will be a long time before nuclear power is competitive with 4 mill hydroelectric power.

REMARKS BY
ADMIRAL LEWIS L. STRAUSS
Chairman, United States Atomic Energy Commission

IT IS A PRIVILEGE TO BE here this morning among so many good friends, including my learned colleagues on the Panel, Sir Edwin Plowden, Sir John Cockcroft, and Mr. Davis. Also, for me, as Mr. Allardice has indicated, there is a certain nostalgic quality about this occasion because I do see among you a number with whom I have had pleasant and, I might say, profitable associations during the years when I was in the banking business.

But I shall resist a strong temptation to indulge in reminiscence and confine my remarks to the engrossing subject of atomic energy and to the broad prospects and promises of that instrument for good, which an all-wise Providence has placed in our hands at this juncture in human history.

It is my hope that I may be able to contribute both now and in the future in some modest measure to the plans which the International Bank is making for its role in the development of the peaceful atom.

Before the proceedings of many more meetings of your Board have passed into your minute books, I feel confident that you will be taking an active part in spreading the benefits of atomic energy and that you will be financing atomic power projects in a number of countries.

It is now nearly noon of this September 27, 1956, and before the day ends the demographers tell us that the population of the world will have increased by some eighty thousand souls—eighty thousand more mouths to be fed; eighty thousand more people to be clothed and warmed and sheltered.

Admiral Lewis L. Strauss is Chairman of the U. S. Atomic Energy Commission and Special Assistant to President Eisenhower on Atomic Energy matters. Long associated with, and a partner of, Kuhn, Loeb & Co., he left banking in 1946 to accept appointment as a member of the first U. S. Atomic Energy Commission. Early in the thirties, he financed a pioneering surge generator at the California Institute of Technology for the purpose of producing radioactive isotopes to be used in cancer treatment. He is

It would be convenient if we could take such a statistic, multiply it by the per capita consumption of kilowatt-hours in a year and arrive at the figure of annual, necessary increase in installed generating capacity for the world.

It would be a large figure, but not very meaningful since, as we know, average annual per capita power use around the world varies so enormously by regions.

There is also another variable in the statistical increase in the per capita power demand, even in the highly developed countries.

Will that demand level off or will it continue to increase? We cannot answer except to draw on our imaginations or our optimism.

But of one thing we can be fairly sure. The atom holds the hope of remedying much of the world's imbalance in standards of living and as this imbalance is overcome to whatever degree, as more and more people enjoy the good things of life, the greater will become the world-wide civil use of electrical energy.

As of this moment, no large scale power plant, exclusively for civil use, generating cheap electricity from nuclear energy, exists anywhere in the world.

Very soon, however, our British friends, as we have just heard from Sir Edwin and Sir John, will have dual-purpose nuclear plants in operation at Calder Hall, producing primarily plutonium for weapons, but also in excess of 60,000 kilowatts of electricity as useful by-product.

Here in the United States within the approaching

President of the Institute for Advanced Study at Princeton, and serves as Trustee and in other capacities for numerous educational and philanthropic institutions. He is closely associated with the inception and the development of President Eisenhower's "Atoms for Peace" program, and is the original proposer of the 1955 International Conference on the Peaceful Uses of Atomic Energy which took place under the auspices of the United Nations in Geneva.

year, the nuclear plant at Shippingport, Pennsylvania, designed for commercial power only, will begin furnishing in excess of 60,000 kilowatts of electrical energy to homes and industries in the area of Pittsburgh.

These are truly pioneer projects. We have entered upon the era of the beneficent atom and it is no longer a dream of things to come. But we are just across the threshold and adjusting our vision to the broad vistas that are unfolding before us.

I shall not attempt to recite or even summarize the things that already are being done, and will be done in increasing measure, to apply the beneficent atom to medicine, agriculture, biology, and the improvement of the products of industry. These advances are concerned in the main with the rapidly expanding use of radio-isotopes.

I shall speak only of the prospects of economic and efficient nuclear power for it is in that area that both challenge and opportunity exist for bankers and for management, no less than for the scientists and engineers who are advancing the technology of nuclear reactor systems.

But here in the United States, because we are fortunately situated in the extent of our reserves of cheap conventional fuel, we are some distance away from our goal of competitively-priced nuclear power. The atom, as a source of commercial power, is up against much stiffer competition here than perhaps anywhere else in the world with the possible exception of a few locations where hydro-power is still plentiful and undeveloped. In most other areas of the world, for example in the home of my distinguished British colleagues on this panel, as they have explained, the road to competitive electric power from atomic energy is shorter. In fact, in fuel-short areas of the globe in special circumstances a power-producing reactor of existing design would probably be economic, even now.

You have doubtless noticed that speculations and estimates as to how soon we will have economic nuclear power in this country have resulted in a guessing game, a game in which any number of persons may play; the more the merrier. Some of these estimates are obviously too rosy. Others, in our opinion, suffer from an extreme of caution.

It is well to bear in mind, however, that the store of technological knowledge is being expanded so rapidly and we are engaged in research and development on so many different reactor concepts, that a major break-through, putting us at or near the goal of economic nuclear power, could come with some suddenness.

One has only to look back upon the very recent past to realize how hazardous it is to predict the rate of progress on this subject.

It has been less than fourteen years since Enrico Fermi and his team of pioneers first harnessed the power of fission in a primitive reactor in Chicago.

It was only ten years ago that a group of specialists began serious studies of the first power pile at our laboratory at Oak Ridge, Tennessee.

Only seven years ago one of the members of that group, Captain—now Rear Admiral—Rickover, first began to work on a project which is today the accepted familiar spectacle of the atom-powered submarine Nautilus, a vessel that has cruised upwards of 50,000 miles without refueling.

And in 1954, only two years ago, we began an experimental program embracing five different concepts of nuclear power reactors.

Progress in this brief span of time has been remarkable, and yet only a few years ago some of our most experienced advisers counseled that nuclear power for ship propulsion was visionary and that it would take between thirty and fifty years before atomic energy could substantially supplement the general power resources of the world.

Since that eventful day in December 1942 when Prof. Fermi's pile went critical, producing only a few watts of heat, we have built and operated in the United States some eighty reactors of various types and sizes, including experimental power facilities with millions of times the power of Fermi's first pile.

As early as 1951 an experimental breeder reactor at the Atomic Energy Commission testing station in Idaho was hooked up to a small turbine and generator and has since furnished useful—but far from cheap—electrical power for that installation.

Industrial participation, freed by the Atomic Energy Act of 1954 from the smothering embrace of government monopoly, is no longer a "study program" inquiring into the feasibility of nuclear power. It has become a program of action and bold enterprise.

Industry in the United States now plans to install some 700,000 kilowatts of nuclear power and to finance it through normal banking channels, without calling on the Federal Government for any direct financial support.

Another 400,000-plus kilowatts are included in the Atomic Energy Commission's power demonstration program carried out jointly by government and industry; meanwhile the Commission's own experimental program for power reactors has grown from the five concepts which I mentioned as of two years ago to nine, as of today.

The fact that all of this has taken place within the short space of fourteen years, and most of it within the last three years, demonstrates two fundamentals:

The anticipated time lag between discovery and practical application has been greatly compressed where atom energy is concerned. This, it seems to me, is a phenomenon of our times.

Secondly, the rapidly increasing demands for additional sources of energy all over the world are exerting powerful economic, social, and political pressures on science, engineering, management, and on government, urging speed in establishing the atom as one of the chief sources for meeting those demands.

I shall outline briefly the response which the United States is making to this world-wide challenge by way of policy; and Mr. W. Kenneth Davis, the Director of our Division of Reactor Development, under whose able leadership so much of this progress is being made, will then tell you about our program in some detail, particularly the technical aspects.

Our program has domestic and international goals. Our domestic goal, as I have said, is a nuclear power development which will justify its financing without Government subsidy—installations which will be built and operated by industry—that is to say, by private utilities or local public power groups. To achieve this goal, we have a flexible partnership be-

tween Government and industry, and we believe, on the basis of progress to date, that this approach will achieve our goal within the shortest possible time. That aim, as I have said, is cheap or, at the very least, competitively-priced nuclear power.

Thus far, we have resisted pressures—mainly political—to establish arbitrary goals of installed kilowatts for a set date, since we are not entered in a numbers game. We seek to improve the technology of nuclear power reactors so that we may benefit our own people—and our friends—by providing the most efficient reactors.

To engage in a crash program of atomic power plants in the United States, based on the present state of our knowledge would, we think, be neither prudent nor would it fulfill our obligation to develop the atom for peaceful purposes. Furthermore—and this is important—we would be dissipating our very finite reservoir of scientific and engineering talent. We would be using the limited asset in the building of primitive plants, when we feel that that resource should be applied to the many yet unsolved problems of reactor technology.

Trained manpower, rather than money or uranium, is at present the element in short supply in the peaceful development of atomic energy all over the world. It is fortunate, therefore, that our reserves of coal, oil, and gas here are recoverable at comparatively low cost, and are in such quantity that we have time to investigate and experiment with the many types of power reactors. It will take time for the incentives of competitive enterprise to lower the costs of construction and operation and to train large numbers of nuclear scientists and engineers.

With these conditions in mind, here is the way we operate domestically:

The Government, that is to say, the Atomic Energy Commission, conducts in its own laboratories the basic research and experimentation necessary to prove that a particular reactor concept will advance the technology of nuclear power and, therefore, that the building of certain prototype plants for the commercial production of civilian power has become justified. Industry is then offered the opportunity to build and

operate such a plant. We know of no other way to obtain meaningful economic cost data, since plants constructed by Government on a cost-plus-fixed-fee basis do not represent the economies obtainable under competitive free enterprise conditions. However, if the building of a prototype should be indicated—on and beyond the experimental plant stage—and if industry should fail to come forward to share in the project with its time, talent, and money, then the Government would build the prototype plant.

I hasten to add, however, that industry has not failed to accept its role in the concept of partnership, but, on the contrary, has responded with enthusiasm to each proposal we have made thus far.

At the present state of the art, of course, the Government bears the cost of much of the research and development work necessary to build prototype reactors. However, as our store of technology is enlarged, and as research costs become more predictable, we anticipate that industry will assume this expense as it does in other fields of industrial development. In fact, it is already beginning to do so.

There are a number of areas related to reactor development where we expect to encourage industry to take over work heretofore done by the Government. These areas include the handling and disposal of radioactive wastes; the development and production of new and improved reactor materials, such as beryllium and zirconium; the design and manufacture of fuel elements, and the chemical processing necessary to separate the fission products from spent fuel elements.

This outlines the philosophy of our domestic nuclear power program. We believe it will enable us to continue to make important contributions to the development of atomic power throughout the world.

I will now turn briefly to the aspects of the program in the United States toward international cooperation.

During this past week, as you know, there opened at the United Nations in New York a conference of 81 Governments, and from that conference we hope will come agreement on the charter and working plans for an International Agency designed to promote the peaceful uses of atomic energy.

This International Atomic Energy Agency will represent the fulfillment of the historic proposal laid before the world in December 1953 by President Eisenhower. However, during the three years of patient negotiation that have elapsed, and in anticipation of the eventual success of this negotiation, the United States has pushed ahead vigorously on a program of cooperation with many nations in the development of the peaceful uses of nuclear energy.

Many of you will recall that the International Conference on the peaceful uses of Atomic Energy, which met in Geneva in August of last year, and reopened lines of scientific and technical communications that had been disrupted for many years, produced one subject of paramount interest among the 1,400 delegates from 73 nations who attended. That subject was the progress and possibilities of nuclear power. But even before the conference, our Government was using the authorization provided by the Congress in the Atomic Energy Act of 1954 for inaugurating a system of bilateral agreements of cooperation between nations interested as we are in the civil uses of atomic energy.

As of today, we have negotiated 39 research or power agreements with 37 nations.

The so-called "research bilateral agreements" provide for the exchange of unclassified information and for assistance in the development of a nuclear research program, including the supply of enriched uranium fuel for research reactors. A number of countries have contracted for, or are negotiating for, the design and construction of such reactors. At the suggestion of President Eisenhower last year, we have worked out a procedure in which up to \$350,000 in each case can be granted by the United States for a research reactor project in a country having an Agreement for Cooperation. Four grants have already been arranged; others are in advanced stages of negotiation.

This activity has a direct bearing on nuclear power development, since it provides nations with an indispensable tool for training their own nuclear scientists and engineers in what will become their own atomic power industry.

Seven of the agreements that I mentioned provide specifically for assistance in developing nuclear power programs. These so-called "power bilaterals" would have little meaning unless nuclear fuel was available. In fact, the one question most persistently asked towards the close and after the Geneva Conference was, "When, and on what terms, will enriched fuel be available for power reactors?"

President Eisenhower answered this question of availability of fuel on February 22 of this year when he designated 40,000 kilograms—40 metric tons—of uranium 235, to be used as needed, primarily for fuel in power reactors in our own country and abroad. The allocation was 20,000 kilograms for civil uses in the United States, and 20,000 kilograms for our friends overseas.

The Atomic Energy Commission is presently making a comprehensive study of additional information required by nations seeking to estimate the cost of nuclear plants to be fueled with uranium 235. We are aware that the surveys made by the Bank on the potentials of nuclear power have emphasized the importance of this information.

I hope that this data, including a pricing schedule, will be available in the near future. And while it is impossible for me to forecast this schedule this morning, I think that the example set by our announcement at Geneva last year, where we said that the price schedules there advanced were calculated so as to net us neither loss nor profit, may serve as the pattern. This would be in keeping with the spirit of President Eisenhower's program of developing the atom for peace.

In collaboration with Great Britain and Canada, we have made available an enormous amount of technical information, much of which is related to nuclear power development. And most of this has occurred within the past two years. Much more information, I am sure, will be released as time passes.

These are a few of the highlights of our program for international cooperation in developing useful economic power from the energy in the nucleus of the atom. What I assume may make this information of particular interest to you gentlemen is the fact that

in many areas of the world there is immediate pressure to obtain new sources of energy. A number of these areas must import, in whole or in large part, the coal and oil necessary to keep their economies moving even at current levels.

A new source of power in some of these areas would not only be a base for expanding technology, but also for elevating living standards. There are, as we have already noted, some communities abroad where even now the difference between the cost of power from conventional fuels and nuclear fuels is small or nonexistent.

Unfortunately, those countries which do not have sufficient power to insure a relatively good standard of living, or to support adequate industrial production, also frequently lack economic strength to undertake the installation of a nuclear power system without financial help. These may be among the first projects to come before you.

Such countries, however, may be found to have resources of uranium or other ores and no means for exploration, mining, or the building of mills for the extraction of the metal. These circumstances might furnish security and sources of sinking funds for long-term loans for power purposes.

In summation, I think it is apparent that there will be a large demand for nuclear power in other parts of the world before it becomes generally economic in the United States. The acceleration of experience and the accumulation of data from the versatile programs now being pursued here will continue to point the way to reduced costs. The technical and financial resources of each country will have to be weighed in determining when nuclear power is economically justifiable.

Judging by the progress that has been made in the past few years here in the United States, and the growing capacity of many nations to operate nuclear power systems, there should be a sound market for nuclear power installations within the near future. And I would emphasize the word *sound*.

It seems to me, gentlemen, that a major role is indicated for the Bank.

REMARKS BY
W. KENNETH DAVIS,

Director, Division of Reactor Development, U. S. Atomic Energy Commission

IT IS A PLEASURE to have an opportunity to discuss before this distinguished audience the power reactor program of the United States.

Our Chairman, Admiral Strauss, has told you something about the policies and objectives of our program and how it relates to our need for energy in the United States and to our international position. I would like to outline the program we now have under way and perhaps make a few observations with respect to the future.

In considering the United States reactor development program, two factors should be kept in mind. The first is our long-range objective of economically competitive nuclear power in this country. This goal is difficult to achieve because we have adequate supplies of relatively cheap fuel as well as large, efficient, and economical conventional generating plants. In developing economic nuclear power we must, therefore, seek levels of efficiency beyond those which would suffice in most other areas of the world.

The second consideration is that we have no reason to believe that any single type of reactor system will satisfy the variety of our needs. As a consequence, we are investigating many technical approaches to nuclear power. While this variety of approaches is partially attributable to the fact that we do not yet know which reactor concepts are the best, many other and equally important factors have influenced our program. For example, among these are the need for nuclear power plants in a wide range of generating capacities; the need for a balance between "burners", "converters" and "breeders"; the possibility that

natural uranium reactors may prove more desirable than enriched reactors in some instances, and preferences as to reactor types which may be dictated by geographical locations.

Our power reactor program can be considered as going through three development phases which follow one another in logical sequence. The first is exploratory, dealing with basic research and development in such fields as metallurgy, physics, chemistry, and heat transfer. The second phase is the reactor experiment. In this phase, a relatively small reactor is built and operated to prove the technical feasibility of a concept. Information is gained concerning such items as reactor and systems stability, control characteristics, actual corrosion rates, and mechanical component behavior. The third phase is the prototype phase. In this stage of development, large-scale reactors are built primarily for the purpose of demonstrating the economics of a certain system. While the prototype may not be economical itself, it will point the way toward improvements which will, in turn, lead to truly economical power. In addition, the prototype will give experience in the operation of a nuclear power plant which must meet certain commitments as to delivery of power on demand.

Perhaps a fourth stage, that of full-scale commercial utilization, should be included, but I think this might more logically be considered as an ultimate objective rather than as a development phase.

All concepts proceed through these phases, unless they are eliminated along the line as unsuccessful or as lacking promise. The selection of concepts promis-

Mr. W. Kenneth Davis is head of the Reactor Development Division of the U. S. Atomic Energy Commission, and in that capacity he directs the Commission's programs for nuclear reactor development in the fields of naval and aircraft propulsion and military and civilian power. He was born in Seattle, Washington, and was educated at the University of California and the Massachusetts Institute

of Technology; he was Assistant Director of the MIT School of Chemical Engineering Practice, and Professor of Engineering at the University of California at Los Angeles. Immediately prior to joining the Atomic Energy Commission, he was Manager of Research for the California Research and Development Company, which was engaged in work for the Atomic Energy Commission.

ing enough to be carried through successive phases of development is one of the more difficult tasks faced by those administering a development program of this nature.

The Commission has assumed the responsibility of providing the basic technology for power reactor development. This work is complicated and costly, and the results are often uncertain. The design and construction of the prototype or demonstration reactors is another matter. Here the emphasis is on economics and reduction of costs. We know of no better way to achieve this end than to bring to bear normal business incentives. Hence, we have encouraged both the reactor designers and builders and the utility companies, to accept the primary responsibility in the construction of these prototype reactors. We have insisted on limited and well-defined amounts of assistance by the AEC. This is not because we wish to reduce our cost, but because we believe this leads to real progress on cost reductions. There is increasing evidence of the desire on the part of the industry to move into the field of nuclear research and development. We have encouraged such participation in the development of new reactor concepts which industrial groups may have originated, and in as wide a variety of feasible approaches as possible.

We may theorize as much as we will about reactor possibilities, but theory is of most value when put to the test of an experiment. It also seems clear that the need for different sizes of reactors in different locations could most likely be satisfied by more than one type of reactor.

I will attempt to appraise the various possibilities at hand.

We now have several power reactor experiments under construction:

- An experimental boiling water reactor. This unit will have an output of 5,000 electrical kilowatts and should be in operation early in 1957 at the Argonne National Laboratory.

- An organic moderated reactor experiment which will produce 16,000 kilowatts of heat. This is also scheduled for completion in 1957 at the National Reactor Testing Station in Idaho.
- An experimental fast breeder reactor with 17,500 electrical kilowatts capacity. This reactor is planned for operation beginning in 1959.
- Three aqueous homogeneous circulating fuel reactors. One of these is being built at Oak Ridge National Laboratory and is scheduled to be in operation by next February. The output will range from 5,000 to 10,000 thermal kilowatts.
The other two reactors of this type are smaller systems. One will have an output of 1,300 thermal kilowatts and the other 2,000 thermal kilowatts. They should be in operation at Los Alamos Scientific Laboratory by the end of this year.
- A sodium-cooled, graphite-moderated reactor experiment of about 7,500 electrical kilowatts output. This reactor is being constructed by Atomic International, Division of North American Aviation, under contract to the AEC, and should be operating late this year.

The reactor experiments we have under way are but one phase of our program. We are also going ahead with studies of a number of more advanced concepts. One such study is for the design of a circulating liquid metal fuel reactor to have an output of 5,000 to 10,000 kilowatts of heat. Another study is being made of the closed cycle gas system with a view toward the design of an efficient high-temperature unit.

We are also initiating further studies of the feasibility of heavy water, natural uranium reactors as power sources. The choice between reactors utilizing enriched uranium and those requiring only natural uranium is a marginal one, and we believe the natural uranium type warrants further serious study.

I have not mentioned the pressurized water system in the same category as the other reactors since it has already demonstrated its applicability and, to some extent, the economical limits within which it can operate. Each of the reactor systems I have mentioned

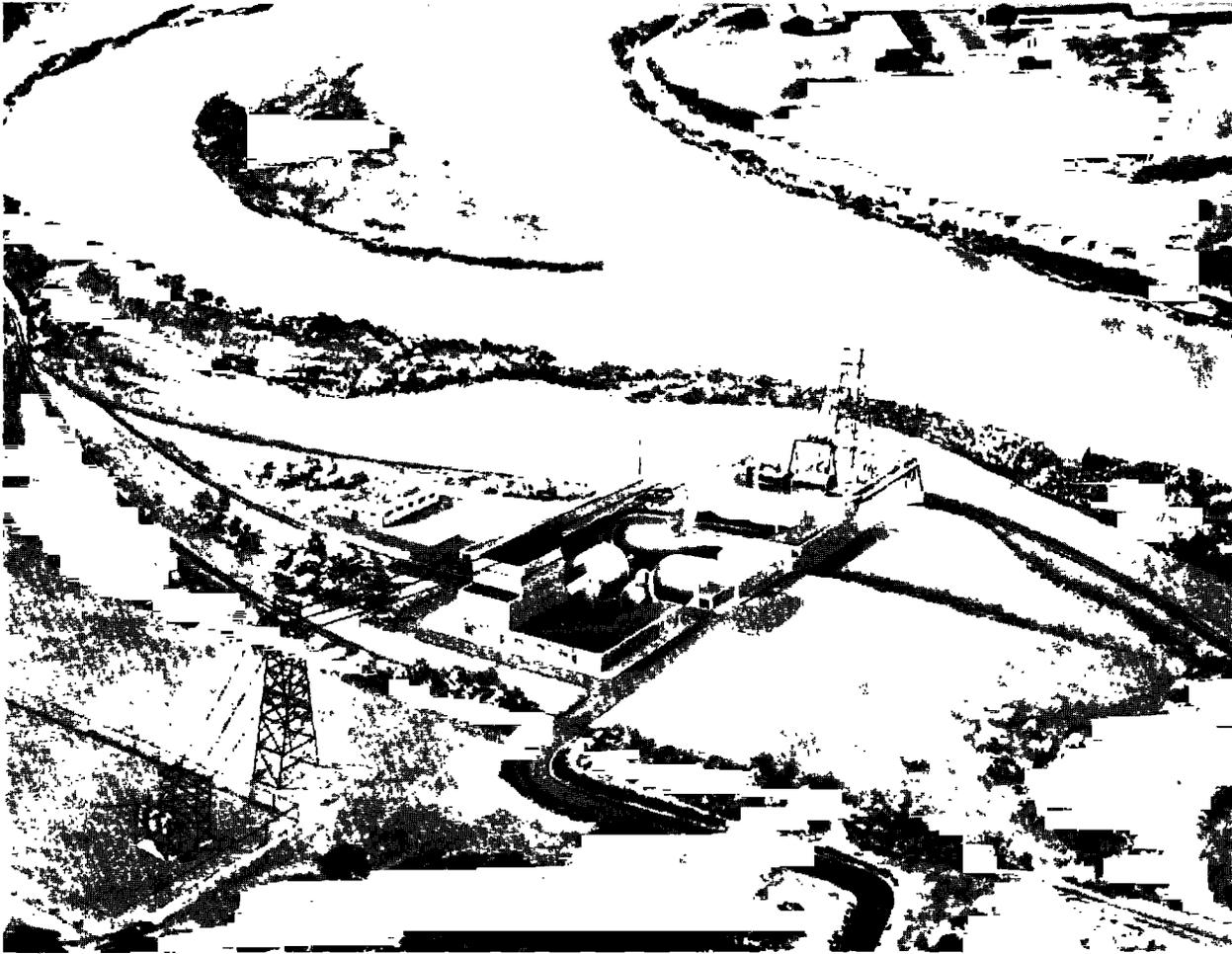


Fig. 4. PWR Power Station at Shippingport, Pennsylvania.

has certain advantages and disadvantages which must be carefully weighed when considering economic feasibility and the prospect of early utilization. We still do not have sufficient economic data on the basis of which any of these concepts can be eliminated. However, I will point out briefly the advantages and disadvantages of each type.

The pressurized water reactor (PWR) has one large advantage just now—we know how to build and operate it and we can make reasonable estimates of initial investment. From a technical point of view, as well as that of public safety, it is one of the more stable and inherently safe systems of which we have knowledge. Although we are most familiar with this type of reactor, there remain two major disadvantages

inherent in a pressurized water system, namely, high initial cost and low steam temperature. The first disadvantage can be overcome in a very large installation in which the high cost of the reactor may be spread over a large generating capacity. The PWR under construction at Shippingport, Pennsylvania, will provide further operating experience on this type of system. The generating capacity of this unit, the first large nuclear plant in the country, will initially be 60,000 electrical kilowatts, and it is expected that improvements in performance may raise this capacity to 90,000 electrical kilowatts. Financing is a joint AEC-industry affair. I have two photographs which will give you some idea of what we are doing here (Figs. 4, above, and 5, overleaf).

The reactor having inherent safety characteristics most similar to those of pressurized water systems is the boiling water reactor. In this reactor we permit boiling to take place in the reactor core. The steam is then formed at essentially the temperature and pressure at which it will be used. It is easy to see that since the reactor vessel must operate at a pressure of only about 600 pounds instead of 2,000 pounds to deliver 600 pound steam to the turbines, the fabrication cost of the reactor vessel will be much less than in a pressurized water system. This saving in initial cost will not be confined to the reactor vessel alone but will extend to a large part of the piping system. The resulting decrease in initial investment should lend

this type to applications in medium capacity generating stations. However, one present disadvantage of the boiling water reactor is the possibility of radioactive contamination of the steam, in turn, leading to contamination of the turbine machinery. A possible safeguard against this condition involves the expense of an intermediate heat exchanger.

The initial costs due to expensive pressure vessels can also be avoided by utilizing some coolant other than water. One alternative is the use of sodium as a heat transfer medium. In a reactor of this type we can achieve high temperature at essentially atmospheric pressure. This high temperature may permit the generation of steam at temperature and pressure

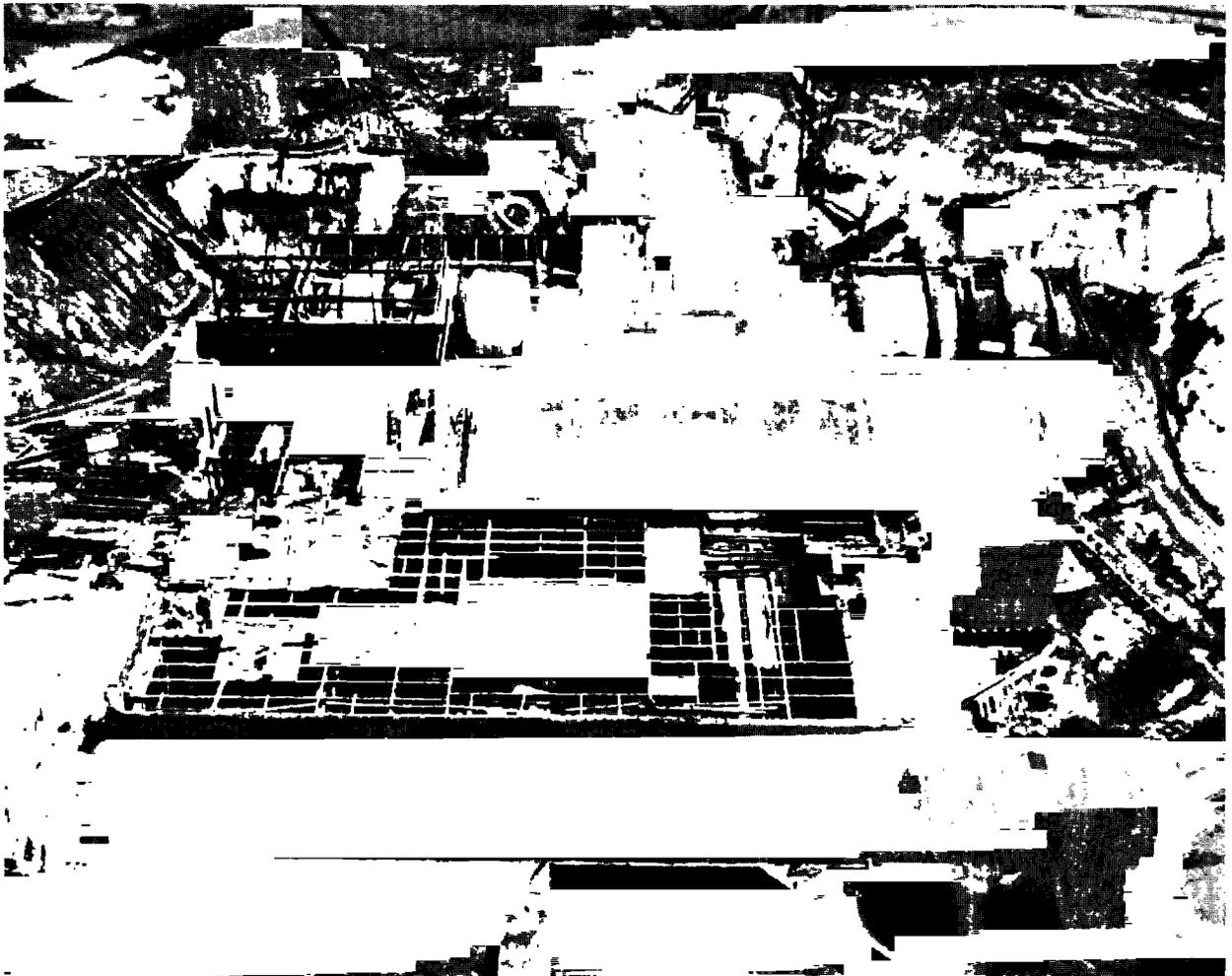


Fig. 5. PWR Power Station under Construction.



Fig. 6. Sodium Reactor Experiment at Santa Susana, California.

comparable to conditions found in the best fossil fuel generating stations. These advantages are offset to some extent by the necessity for more expensive containment materials, but it is still likely that the original cost of a power plant of this type will be no more than that of a boiling water system. The major economic advantage would then have to come from increased operating efficiency. A sodium-cooled system may prove to be quite flexible as to the power range over which operation will be economical. Both graphite moderated and fast reactors of this type are being developed (Fig. 6, above).

As an alternative to the use of sodium as a coolant, an experimental reactor is under construction in which an organic material will be used as moderator and coolant. It is expected that this material will not only allow a substantial reduction in pressure vessel costs but, since the material is essentially noncorrosive, cheap construction materials may be used and the

need for expensive fuel element cladding may be eliminated. The experiment now under construction will give data on radiation stability of the coolant and on the costs associated with the cleaning of the organic stream. These questions will have to be answered in order to evaluate the promise of reactors utilizing organics.

In all of the reactors I have been talking about, a rather severe limitation on utilization of fuel is imposed by fuel element damage and poisoning due to fission product build-up. The necessity for regular shutdown to allow fuel element replacement is an additional obstacle to efficient operation. This obstacle may be overcome by using a fuel which is not subject to irradiation damage, which may be enriched while the reactor is in operation, and from which fission products may be removed without reactor shutdown. These requirements are met by a circulating fuel reactor (Fig. 7, overleaf) and, as I



Fig. 7. Homogeneous Reactor Experiment at Oak Ridge, Tennessee.

mentioned previously, there are two distinct circulating fuel reactor types under development. In the aqueous homogeneous reactor the uranium may be in the form of uranyl nitrate, uranyl sulfate, or uranyl phosphate in a circulating water solution. The water acts both as a moderating medium and as a heat transport material. This system must be highly pressurized. The corrosion problem in all of these aqueous reactors is severe but appears capable of solution. Fuel inventories are small in these systems. The cost, a very high one, of re-processing used fuel elements is eliminated, which contributes to the overall operating economy of the reactor.

In the second circulating liquid metal-fueled reactor, we may find the solution to two major problems—high core pressures and corrosion problems. The fuel proposed for this system, a uranium-bismuth solution, will, we hope, permit the production of high temperature steam while maintaining the core at close to atmospheric pressure. It is believed that readily available construction materials may be used for the system and that fabrication will present no serious problem. The potential cost advantages of such a

system are obvious and, while the chemical processes are different, the economic advantages occurring from fuel stability and continuous cleaning and re-enriching will be the same as in the aqueous homogeneous type. Reduction in initial construction costs should allow the economic operation of smaller plants as well as those of higher capacity. Furthermore, since the fuel has no adverse reaction with water, there is no danger from this point in using such a system in a ship or submarine.

The gas-cooled reactor, especially when operating in connection with a closed-cycle gas turbine, appears in some respects to offer possible cost advantages over other types. Some of the potential advantages are light weight, compact arrangement, ease of containment, low corrosion rates, and high efficiency. But there are many problems associated with the construction of such a system. Among them are the inherently difficult problem of control and stability, and the fabrication of satisfactory fuel elements. At the present stage of gas turbine development, this reactor type seems to be limited to the lower capacity sizes—up to perhaps 20,000 electrical kilowatts. Our techniques are improving and we feel that in the reasonably near future we may be able to begin construction of a gas-cooled reactor experiment. We are interested in an efficient gas cycle and not in a unit where inefficient, low-temperature operating conditions lead to high operating costs.

Perhaps I have seemed to over-emphasize the problems which remain to be solved, and the great strides which must be made if nuclear power is to become competitive. It goes without saying that problems cannot be solved before they are known. A few years ago we could only imagine what problems might be faced. We now know that some of these imagined problems could have been ignored, but other much more real ones have taken their place. While we are sure that we have not found all the problems, we are confident that the solution of those we now recognize will move us well along toward our goal. These problems do not appear insuperable. They will not be solved easily, or overnight, or without considerable expense in time and money. The fact

remains, nevertheless, that we have identified them, and even this knowledge is in itself a major step forward.

I have limited my discussion so far to the production of electric power from reactors. While this appears to be the most immediate application of nuclear energy, it is not too difficult to foresee the day when reactors will be used by industry to supply process heat, and in the case of the food industry, as a sterilization and preservation medium. There is also a good possibility that radiation from reactors may be used to improve such processes as oil refining and to alter and improve the characteristics of many materials presently in use. There is at this time under construction at Brookhaven National Laboratory a reactor for medical research and therapy. The use of reactors of this type is certain to become more widespread.

I should like to turn for a minute to the subject of prototype nuclear power plants. In order to bring private industry into the field of power reactor development and operation, the AEC initiated the Power Demonstration Reactor Program in January 1955 with an invitation to industry to submit proposals for the construction of nuclear power plants. Encouraged by the response to this first invitation, the Commission issued a second in September 1955.

As a result of the proposals which were submitted, a contract has been signed with Yankee Atomic Electric Company covering the construction of a 134,000 kilowatt generating station. This will be a pressurized water system and will involve the use of AEC funds for necessary research and development.

Five other proposals have been accepted as a basis for contract negotiations. They are all of different types and are scheduled for completion in 1960 and 1961, adding another 217,000 kilowatts to the nuclear electrical capacity of the United States.

Additionally, construction permits have been issued to two public utility companies and to the General Electric Company for the construction of nuclear plants financed entirely with private funds. One of these will be a pressurized water reactor station of 136,000 electrical kilowatts nuclear capacity. The other two will utilize boiling water reactors, one a

small plant with a capacity of 3,000 to 5,000 electrical kilowatts, and the other a full-scale plant with an electrical output of 180,000 kilowatts. These nine plants, which should be in operation by 1960, will have a combined nuclear capacity of about 660,000 electrical kilowatts.

While this is indeed an encouraging beginning, it should be kept in mind that these reactors will not be, and are not required to be, economically competitive with conventionally fueled plants. They will, however, serve as prototypes on which to base the design of more economical plants. In some cases, the excess operating costs expected during the initial years of operation will be partially offset from payments by the AEC for technical and operating data.

I have defined an efficient nuclear power plant as being one which, when built and operated under standard industrial financing and operating practice, will produce power at costs equal to or less than the cost of power produced by the best conventional plant built at the same time and at the same location.

It is obvious that in order to meet this criterion, nuclear plants must be improved to the point where no special assistance, under any guise whatsoever, is needed. This does not mean that certain operations such as enriching of fuel cannot be carried out by the Government. It does mean that these services must be paid for, at their actual value, out of operation income.

In an effort to resolve the problems associated with the meeting of all expenses out of operating income, a vast number of studies of the economics of nuclear power have been made in recent years. In the absence of necessary development, information, and actual construction and operational costs, many of these studies, if not most of them, must be considered only as speculation. They have generally arrived at two conclusions:

First, that the particular type of reactor favored by those making the study is more practical than other types under consideration; second, that this better reactor can produce power competitively with conventional power plants.

Although, taken separately, such studies are of limited value, I believe that, collectively, they are important since they indicate a profound belief that nuclear power can be made competitive with conventional sources even in the United States where we have a relatively plentiful supply of cheap fuel.

While there is no law of nature which says that power from nuclear fuel must be competitive with conventional power, we do know the potential is present. Certainly, no one has discovered any fundamental considerations which would appear to make economic nuclear power unlikely of accomplishment.

However, many studies and proposals overlook the development effort required to actually solve the many technical problems involved as well as the industrial effort needed to attain the desired construction and operation costs. The solution of these problems is a time-consuming and costly business requiring the imagination and ingenuity of our very best scientists and engineers.

With our present program, we will soon enter an era in which we will gain a good deal of factual data on power reactor technology and costs. At that time it will be more appropriate to discuss the economics of such systems and to make predictions concerning future costs.

In any case, the assessment of relative costs of nuclear power in comparison with conventional power cost is a difficult matter even in the United States, depending as it does upon the cost of capital, tax rates, load factors, construction costs, and many local considerations. When such a comparison is attempted for reactor locations abroad, many additional factors must be taken into consideration.

However, it may be possible to make some general observations based upon our present state of development and upon our hopes for the future. I believe that large power reactors, construction of which is begun in the next one or two years, will, after completion and initial operation, show total power costs somewhat above those prevailing in any area of the United States which can utilize a plant of equal size. But the cost will probably be about the same as that from conventional plants in some fuel-short areas of the

world which need large blocks of power. Another two or three years should see construction begun on plants which will prove to be really competitive in relatively high fuel cost areas of the United States—and fairly generally in other areas of the world. The following five years or so should lead to nuclear power plants being started on a generally competitive basis with all except extremely cheap fuels in any area.

The situation regarding the course of development of small reactors is even more hazardous to predict. In general, the economic considerations for a small unit are relatively less favorable than those for a larger reactor system.

For this reason, the utilization of small reactor systems may be generally behind that of the larger plants. However, it is not unlikely that there may be many circumstances in which a small reactor will have an advantage.

To repeat then, we are moving forward on many developmental fronts in order not to overlook any system which may, in time, prove successful as a source of economical power.

In conclusion, I would like to quote from an interesting article which I ran across the other day:

Pessimists like Sir Oliver Lodge shudder when they speculate on the future. Man is not yet spiritually ripe for the possession of the secret of atomic energy, he reasons. Technically we are demi-gods, ethically still such barbarians that we would probably use the energy of the atom much as we used the less terrible forces that almost destroyed civilization during the last war.

Others are convinced that the new insight into nature which will be granted when the structure of the atom is at last known, and with it the method of controlling its energy, must be accompanied by a spiritual advance. Each new discovery about the atom makes man more consciously part of the world about him—links him with the stars, which are themselves composed of atoms, and with the dazzling light of the sun, which springs from atomic activity—and thus impresses him with the littleness of his greed and the puerility of his disputes.

This prophetic quotation is from an article, *Atomic*

Energy—Is It Nearer, by Waldemar Kaempffert in *Scientific American*. The date—August 1932! The article deals with the historical importance of the then recent work on nuclear transmutations by “two young English physicists, Dr. J. D. Cockcroft and Dr. E. T. S. Walton”. It follows an article on the discovery of the neutron.

We are striving for the development of useful

nuclear power with enthusiasm and with optimism, and with the conviction that this vast new source of energy will, one day, raise the standard of living throughout a peaceful world. While we are not unmindful of the formidable difficulties which confront us, we believe that it is not a question as to whether we will achieve economically useful nuclear power but, rather, when we will achieve it.

REMARKS BY
PROFESSOR FRANCIS PERRIN,
High Commissioner of the French National Atomic Energy Commission

SINCE 1945 France has developed a steadily increasing atomic energy program directed towards the industrial use of this new source of power. This program has been of a much smaller magnitude than those associated from the outset with a weapon production program; it was nevertheless large enough to place France amongst the few countries which are now building atomic power stations on a really industrial scale. Considering that France is not only in a medium situation amongst the highly industrialized countries, but also that she has the responsibility for large underdeveloped territories, her experience may be of interest for the future development of atomic power production throughout the world.

After ten years of activity of the French Atomic Energy Commission—the “Commissariat à l’Energie Atomique”—the atomic situation in France is briefly the following:

Intensive prospecting has led to the discovery of several important deposits of uranium in France and of thorium in Madagascar. Four groups of mines are

already producing ores which, according to their grades, are treated in different chemical factories. The production of uranium in France is fast growing and should cover all the needs of this basic material for the probable atomic power production of France, at least for the twenty coming years.

The uranium is highly purified and transformed into metal in a factory at Le Bouchet near Paris.

The Pechiney Company has a production capacity of several thousand tons of nuclear grade graphite in its factory at Chedde in the Alps. A pilot plant for the production of heavy water by distillation of liquid hydrogen will be completed next month in Toulouse.

A large research center has been created at Saclay, twenty kilometers south of Paris. About 2,500 people, including five hundred scientists or engineers, are working there. Their equipment includes three research reactors, all three fueled with natural uranium and moderated by heavy water from Norway. One of these has a power of 2,000 kilowatts of heat, and is the first atomic reactor to have been cooled by a circulation of compressed gas, a technique which will

Professor Francis Perrin is High Commissioner of the French Atomic Energy Commission. He was educated in Paris at the Ecole Alsacienne, Lycee Henri IV and the Ecole Normale Superieure, graduating as a Doctor of Science. He was appointed Maitre de Conferences at

Sorbonne in 1933 and two years later a Professor. From 1941 to 1943 he taught at Columbia University in New York. In 1946 he was appointed to the Chair of Atomic and Molecular Physics at the College de France. He was made High Commissioner for Atomic Energy in 1951.

be extensively used in England and France for power production. Next year a very high flux reactor for testing materials will be completed. This equipment is used not only for research but also for training the large number of engineers needed by the growing atomic energy industry.

The French program for producing electrical power from atomic energy is based on the same principles as the British program: burning natural uranium in double purpose reactors, producing power and plutonium, and later, as soon as possible, making use of the plutonium thus produced as supplementary enriched fuel in more efficient reactors.

The production of plutonium has started in an establishment situated at Marcoule in the Lower Rhone Valley. The first reactor constructed there is an air-cooled, graphite-moderated reactor with a heat output of 40,000 kilowatts. The heat evolved is used to produce steam feeding a small turbine, but the electrical power thus produced—5,000 kilowatts—is smaller than the power used in the blowers forcing the air through the reactor.

Real power production will start with a second and a third reactor now under construction at Marcoule. These two reactors will be identical; utilizing graphite and natural uranium like the first one, they will be cooled by compressed carbon dioxide and they will have a net electrical output of 35,000 kilowatts each. They should be in operation in 1958, constituting then the first atomic power station in France. The chemical plant for the extraction of the plutonium produced in the three Marcoule reactors will be completed within the next six months.

To give the order of magnitude of the French effort in this field, it may be stated that the total appropriations for the development of atomic energy in the 1956 budget amount to more than \$150 million. This large investment is justified by the prediction of the difficult situation in which France would be in ten to fifteen years from now if the growing needs for more power were only to be satisfied by the conventional energy sources.

The production of electricity in France was 50 billion kilowatt-hours in 1955; it should be about 100

billion in 1965, and between 180 and 200 billion kilowatt-hours in 1975.

During the next fifteen years it should be possible to satisfy about 50 per cent of the new requirements for power by hydroelectric installations, but from 1965 on, the necessary increase in steam power stations would require large and growing importation of coal from the United States, or of crude oil, in addition to what is necessary for the production of gasoline.

In order to develop a large and cheap production of electricity from atomic energy by that time, it was decided a year ago that the French National Power Company, "Electricité de France", would build in the forthcoming ten years at least five atomic power stations, one every eighteen months, the construction of each one covering a period of three years. The construction of the first of these atomic power stations will start early next year and should be completed in the beginning of the year 1960. Its site is already selected and approved in the Lower Loire Valley, near Chinon. This atomic power station, although similar to the two power producing reactors of Marcoule, will be more powerful, having in one unit a power output of 60,000 kilowatts of electricity.

The later power stations of this program should include technical improvements, and perhaps some of them will use enriched uranium fuel supplied by the United States or by the International Agency for Atomic Energy which, we hope, will soon be created. This might be the best way to prepare for the time when it is possible to use the plutonium produced.

It is not only for the future of European France that the development of atomic energy may be of great importance. In overseas French territories or associated countries, large populations have a much too small supply of energy. But it will maybe require five or ten years more than in continental France to find there a real advantage to atomic energy over the conventional sources of energy. The fact that, in due time, practically unlimited supplies of power from atomic energy will be available, according to needs, anywhere in the world is nevertheless already very

important for the industrial development of underdeveloped regions. It should give us faith in the possibility of large industrial plants even far away from conventional sources of energy, and it might thus make easier the necessary investments.

From this point of view, it may be of importance to build a few atomic power stations in underdeveloped regions even before it is directly advantageous

from an economic standpoint. That is why the French Government will support the construction of an atomic power station near Algiers only a few years after the construction of the first atomic power station in continental France.

I hope that these examples may be useful for those who have to forecast the future development of the world economy.

SUMMARY BY THE MODERATOR

I SHALL NOT TRY to sum up in a few words the excellent individual presentations we have heard. Nor shall I attempt to give a précis of the individual national programs we have heard presented, but I do think it is possible to distill out some rather meaningful basic impressions which I shall state this way:

1. That electric power can be produced from atomic energy has already been demonstrated.
2. Several different power reactor systems are under advanced development, but it is too early to know which reactor system will ultimately prove best, if indeed there is a single "best".
3. The consensus seems to be that much more progress has been made in designing, engineering, and building relatively large nuclear power stations than in the case of smaller plants.
4. There seems to be general agreement that the fuel cost component of electric power from atomic energy sources will be less than the comparable cost components from coal, oil, or gas except in low-cost areas, such as the United States.
5. Because nuclear stations will require, at least for the next few years, higher investment per kilowatt than conventional thermal stations, their economics depends heavily on having reasonably low financial charges, and operation at high load factors.

6. Without minimizing technical problems, our speakers have, I think, been universally optimistic about the long-term economic possibilities of nuclear power. On the short-term, statements were made that in special circumstances even today nuclear power produced from plants of essentially present design would be competitive with conventionally-fueled thermal stations. This, I think, means a relatively large power plant, in rough terms, probably greater than about 100,000 kilowatts electric capacity.

On the basis of the statements made here today and studies we have conducted in the Bank, we believe it is possible to describe in general terms the circumstances under which a large nuclear reactor of essentially present design might have good prospects for producing electricity at costs competitive with that of electricity produced from fossil fuels:

1. The generation and distribution system into which the nuclear plant is to be integrated must be large, capable of permitting a 100,000 kilowatt or larger plant to operate as a base load unit.
2. The nuclear plant would have to be located in a country with relatively high fossil fuel costs, with poor hydroelectric potential, and with sufficient availability of capital so that relatively low-cost money could be obtained.

3. The country would have to execute such intergovernmental agreements as are necessary to assure a continuing supply of fuel, reprocessing and, if necessary, the import of components, unless, of course, it has these materials and technical abilities at its own command.
4. Power rates in the system into which the plant would be connected should be flexible enough so that if the nuclear plant should cost more than expected or should not perform as anticipated, the excess cost could be absorbed without a significant adverse effect.
5. Until further operational experience has been obtained, it would not be prudent, we think, to establish the nuclear plant in a system where it would represent a considerable proportion of the total system generating capacity.

In conclusion, I would stress a point made clear by all of our speakers. Progress of technological development in the atomic field is rapid. What has been said here today probably will be overtaken by events in the next five years.

If we are to be ready to make use of nuclear power when it is economic for us to do so, we must now begin to prepare ourselves.

CLOSING REMARKS BY
THE CHAIRMAN OF THE BOARD OF GOVERNORS

YOU HAVE HEARD the very illuminating discussion and the able summary by Mr. Allardice. On behalf of the Board of Governors, I wish to extend congratulations to our Panel, our other speakers, and Mr. Allardice for a most meaningful and enlightening discussion of atomic energy in economic development.

There can be no doubt that this new source of

energy will have great impact on our lives and upon the lives of our children.

You, gentlemen, have made that clear. We thank you for taking time from your very busy schedules to be with us this morning. As a result of your efforts we will all now be better able to judge where atomic energy fits in our own economic planning.





