SOME TOPICAL ATOMIC POWER QUESTIONS

by

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When will atomic power start to play its part in earnest; that is, when will a significant fraction of new power plants be based on nuclear systems? This is in my opinion the key question today. It is still early to try to give a definitive answer, but recent developments in the nuclear power field now make it still more urgent to give this question thorough consideration. In order to do so it is necessary to make a survey of the need for power as it exists now and as it is likely to develop in the future; one must also find out what possibilities exist to meet this demand from known energy reserves or such reserves as can be expected to be available in the future. Such a survey made on a global basis will give a balanced picture, but the conclusions obtained in such a way cannot, of course, be applied to individual and local situations. If it were to be proved that our reserves will be insufficient, nuclear power would clearly seem to have an important role in meeting the need, but it is at the same time of the utmost importance to find out if energy reserves hidden in the world's resources of uranium and of thorium are adequate or if technological development can make them so.

But already at the present time, when the conventional resources are sufficient to meet our everyday needs, it would seem that atomic power is competitive or almost competitive with conventional power plants in special situations. Some general points of view relating to the special characteristics of atomic power must also be considered - its exceptional adaptability to meet certain special power needs because of the small quantities of fuel needed for the operation of nuclear power plants, which alleviates fuel transport problems and costs; to the absence of air-polluting wastes, etc. On the other hand, one must not overlook some other considerations, viz. - the use that atomic power has for military applications and the international complications that result from this, the unique situation represented by the fact that only three countries at present are in a position or willing to sell enriched uranium; the very strict safety regulations which are still attached to atomic plants; the still prevalent uncertainty as to the cost of chemical reprocessing of burnt atomic fuel and the re-sale price for the plutonium produced in reactors.

Present Energy and Electricity Consumption in the World

A discussion of the world's energy needs mus be based on data concerning current consumption of energy, its growth rate and its causes and the geographical distribution of sources of energy. Consideration must also be given to the world's energy resources as we know them today.

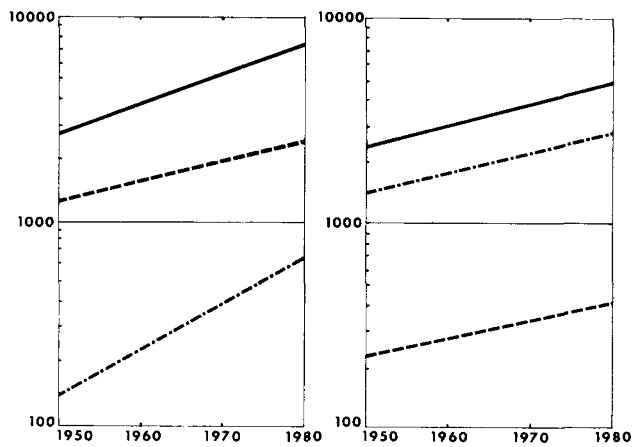
Figure 1 shows the well-known graph of the world's yearly energy needs, which currently grows exponentially, doubling approximately every twenty years. It also shows the population growth in the same period of time. Curves have been added in both cases for North America as an example of an industrially highly developed region, and for Asia, containing many of the countries commonly called developing. The high energy consumption of North America is evident in spite of the relatively small share of population. The energy consumption per capita in North America reaches a value representing about six tons of coal per year, whilst the corresponding figure for Asia is 0.1.

Apart from the rapid growth in the world's population, currently at a rate of a doubling in 44 years, we must thus also reckon with a rapid increase in the per capita consumption of energy. It is not surprising that this growth rate has proved to be less rapid in already developed countries than in the developing countries. Figure 2 shows the total energy consumption in North America and Asia for the years 1952, 1960 and the expected consumption in 1970. The consumption trend in the form of electricity, shown in the graph, is of special interest. In the industrially developed countries there has for a long time been a

Figure 1

(Left) Energy production (million tons coal equivalent)
(Right) Population (millions)

World
North America
Asia



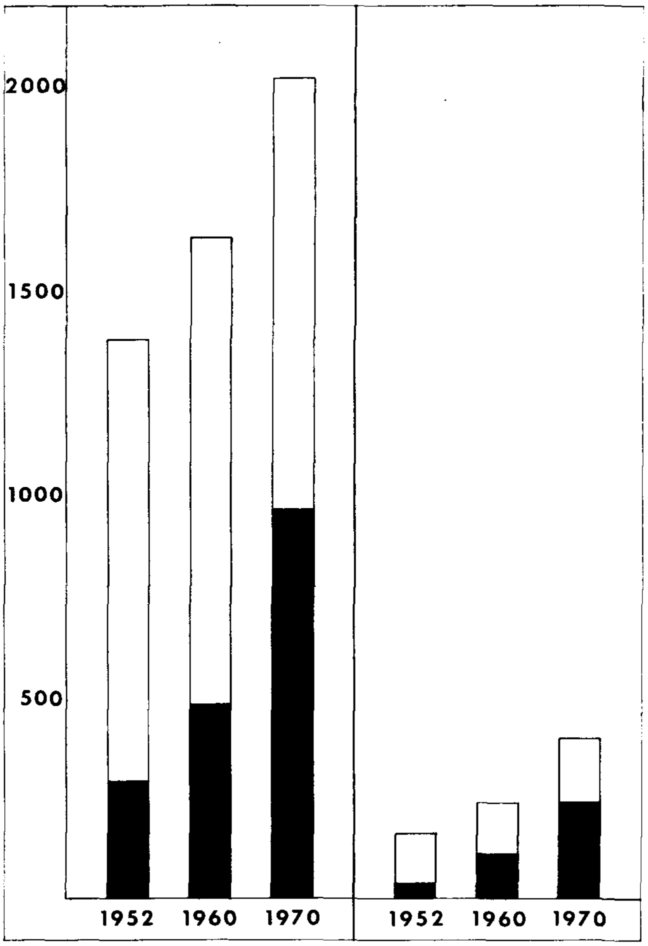


Figure 2
Energy production (million tons coal equivalent)
■ Electricity
□ Other
(Left) North America (Right) Asia

clear tendency for the energy consumption to move from simple, primary kinds of energy, like coal and oil, to secondary and more advanced kinds such as electricity. It is only natural that this trend should be even more accentuated in the developing countries trying to pass rapidly through technological and economic stages of development which have taken centuries for the developed countries. To mention some striking figures: the USA having about 6 per cent of the world population has at present about 33 per cent of the total world electricity consumption. It is also interesting to note that the consumer price for electricity in the USA is about 26 mills/kWh whereas one kWh in, for instance, Togo costs 120 mills. The great discrepancies between these figures show the enormous growth in energy production and especially in the secondary form of electric power, which will be needed when the developing countries start to become industrialized, and also the economic benefits which can be expected when cheap energy becomes available in these countries. It must be remembered that developing countries contain the major part - more than two thirds - of the present world population, estimated at 3 000 millions.

This trend towards an increasing share of electricity in the total consumption of energy is particularly interesting in relation to atomic energy. The most important industrial application of atomic energy at present is in fact electricity production.

World Energy Resources

An estimate of the world's fossil fuel resources which can be economically exploited, given in a survey presented to the World Power Conference in 1962, is shown in Table 1.

A few explanatory notes to the figures are needed. The world's total reserves of fossil fuels are estimated at higher figures than those presented in the table. Mining costs or technological difficulties connected with the use of low-grade resources will, however, make it necessary to leave a considerable part of the resources unexploited, at least for a very long time to come. The degree to which it is economic to mine coal of low quality, for instance, is of course a function of the price that can be obtained for the final product.

It is also possible that the amount of unexploited energy resources and the extrapolated reserves given in the table might be considerably increased as a result of the intensive prospecting now being undertaken, particularly as regards oil. It is a well-known fact that almost every estimate which has been presented in the last forty years concerning remaining oil reserves has resulted in finding that the resources would be sufficient for another 20 to 30 years' consumption. It is, therefore, important to bear in mind that there is considerable uncertainty as to both the total quantity of the world's existing fossil fuel resources and the fraction thereof which can be technically and economically used. Other figures than those given here have been published, but the orders of magnitude are about the same.

There is of course also hydro power, which is not consumed, but is replenished year after year. It is estimated that the world's hydro power reserves amount to about 1 650 million kW of usable generating capacity; this corresponds to a consumption of about 2 500 million tons of coal per year. Hydro power represents only a small fraction (2 per cent) of the present annual global energy consumption, although its importance may be very great indeed in countries lacking fossil fuels.

How long will the world's energy resources last?

Assuming that the world's total energy resources amount to 3 500 000 million tons of coal equivalent, this would be sufficient for the next 800 years at the present rate of consumption of 4 200 million tons annually. The rapid growth in the yearly energy demand which has been demonstrated earlier, shortens, however, this period considerably. Although it is true that the uncertainty factor in the estimates, both for the total supplies and the consumption, is fairly large, one can nonetheless draw some qualitative conclusions. That is, we must face the fact that the world moves towards a deficiency situation in respect of fossil fuels, a situation which is accentuated in certain areas and which highly industrialized countries must now take into account. Although it is true that the period of time given to us is longer than earlier prognostications, as made at the Geneva conference in 1955 for instance, this period is in any case not very long.

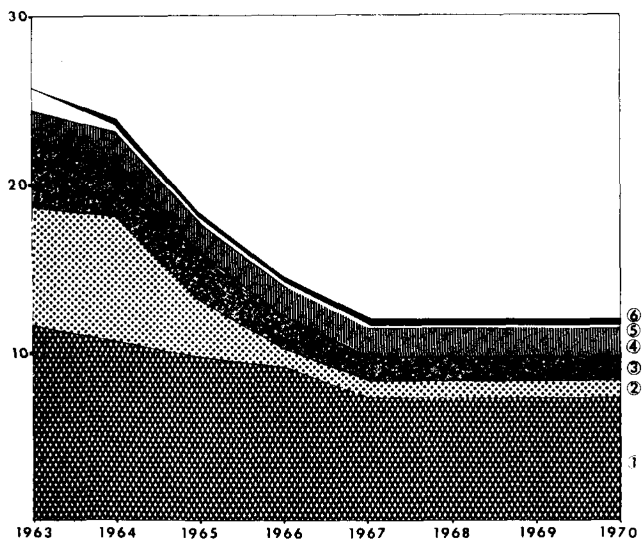
It is evident that the steadily increasing need of energy, in conjunction with the limitations of our existing energy resources, makes it necessary to find new sources of energy. At a United Nations Conference in 1961, a survey of some non-conventional (non-fossil) sources of energy was made; it was concerned, for instance, with wind power, tidal power, sun energy and geothermal energy. Many of these sources are interesting, but none shows such potential as nuclear energy, particularly as the development potential of the latter is based upon considerable assets of raw materials.

World Resources of Fissile Materials

Let us now look at the world's resources of uranium, defined as those from which it is possible to extract uranium at a cost of between $18 and $22 per kilogram of uranium oxide (Table 2). The production figures given in the table are either current figures or extrapolations for the whole of 1963 from the production at the beginning of the year. Data are in this case available only from the western world.

Figure 3

Estimated world production of uranium (thousands of tons). 1. USA 2. Canada 3. South Africa 4. France 5. Australia 6. Other countries.



Production is now being reduced in all countries because of lessened demand for military purposes, and it might be expected to reach its lowest mark in 1968 with approximately 10 000 tons (Figure 3). After 1970 one can expect production to increase again because of a growing demand for civilian purposes.

As to the price trend, available information on prices paid for uranium oxide in the period 1945-55 is sparse. It would probably not be far from the truth to state, however, that an average price of about $27 per kg was paid. In the period 1958-62, the price has been around $22 per kg and this might be expected to come down to about $18 in the 1962-66 period and in 1970 sink further to about $15-$11 per kg. Supply agreements have been entered into for quantities up to 15 tons at prices as low as $9 per kg. One might expect that the probable higher demand for atomic power stations after 1970 will cause the prices at that time to increase again.

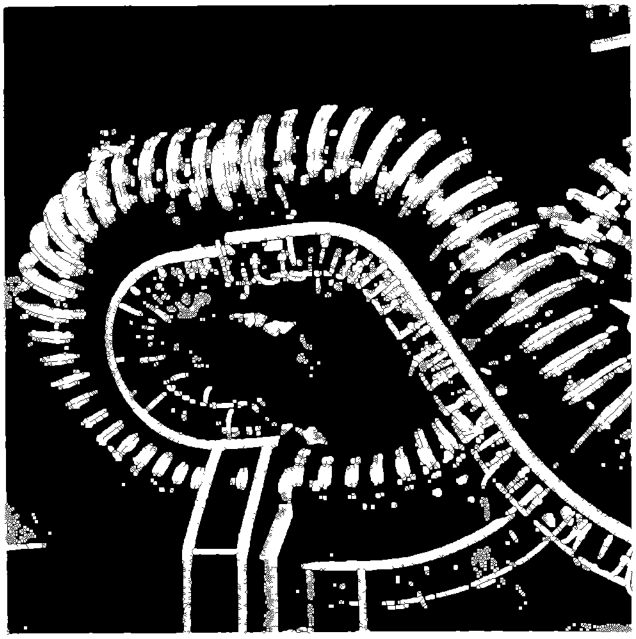
It might be reasonable to assume that the total supply of uranium which can be extracted at low cost amounts to about 1 500 000 tons in the whole world. It should be emphasized, however, that the supplies of uranium would be at least tenfold if one were to include such ores as can be mined at two or three times higher cost.

It is thus evident that available resources of uranium are quantitatively important. How much energy can these ores yield? If one assumes a burn-up of about 10 000 MWd per ton of natural uranium, one would find that the 600 000 tons accounted for in Table 2 only would correspond to 17 000 million tons of coal. If, on the other hand, we assume that the uranium would be utilized in breeder reactors one would reach a burn-up figure of 200 000 MWd per ton, conservatively estimated. In that case, one could also use uranium from poorer ores than those included in Table 2 because of the decreased importance of the price of the raw material; the resources of uranium would then amount to 15 000 000 tons which would be equivalent to 2-3 times the fossil fuel reserves as estimated earlier. Furthermore, should one also exploit low-grade thorium deposits (which are considerably larger than corresponding uranium resources), the energy content of atomic fuels would be 10 to 20 times greater than in the fossil fuels resources we now know.

It was this kind of consideration and long-term prognoses which led to the rapid expansion in atomic energy programmes in several countries in the middle 1950's. Competition with conventional energy sources was made more difficult, however, because there was no acute shortage of energy resources, and the expected increase in prices of fossil fuels turned into its opposite; high rates of interest in many cases also proved to be particularly burdensome for nuclear plants, which demand high capital investment. Conventional power stations have also developed technologically in particular towards bigger units, which has led to reduced production costs. When the gaseous diffusion plant at Oak Ridge was constructed in 1943, a power plant of 300 MW was built to serve it, which was then the largest power unit ever built in the United States. Today conventional plants of 600-1000 MW are being planned and built on a routine basis. It is also fair to admit that the technological problems involved in nuclear power plants - and not least in the conventional parts of these plants - have proved more difficult than was once assumed. The cost of atomic energy did not fall as rapidly, therefore, as was originally hoped; atomic energy programmes have consequently met with delays and been stretched out over considerably longer periods of time than was planned and scheduled in the reports presented, for instance, to the Geneva atomic energy conferences in 1955 and 1958.

From the above one can clearly discern a short- and a long-term programme for atomic energy development. To the former can be referred the development of reactors, which, although not completely utilizing the uranium fuel, still provide a reasonably good fuel economy. These types of reactors do not, however, solve the energy problems in the longer term; one might even say that they provide a wasteful exploitation of uranium. A real solution can only be found with reactors which utilize more fully the uranium fuel, and thus permit prices which make it possible to extract fissile materials from low-grade ores, or the utilization of thorium. One should also remember that the possibility of using fusion energy in the future as an alternative to the atomic fission process, with which we are now concerned, cannot be excluded.

A "Figure 8-shaped Stellarator", used in research on nuclear fusion, formed part of the US exhibit at the Second Geneva Conference (UN photo).



Present Status

The International Atomic Energy Agency publishes at regular intervals a directory of reactors. From the information that was available to us as at January 1964, we know that eleven power reactors, with a capacity of more than 100 MWe each, were in operation for purely civilian purposes with a total capacity of 1800 MWe. These reactors belong to the groups shown in Table 3.

At what rate will new atomic power plants be built? In the United States, Canada, the United Kingdom and the countries of the Euratom community, to mention a few advanced countries in this field, plans have been worked out for the probable expansion of electric power production, including atomic power plants, on the assumption of given developments both as concerns conventional and atomic power. The results will be found in Table 4 and are presented here with all the reservations that must accompany prognostications in the atomic power field.

It has been estimated that 30 000 tons of uranium would be needed annually for an installed nuclear capacity of 100 000 MWe increasing at the rate of 20 per cent annually as might well be the case around 1980. As was shown in Table 2, the current production is of the same order of magnitude. The supply of uranium for these reactors, which only partially exploit the fuel, does not therefore present any problem and ought not to demand any new investments until 1980.

Another and much more complicated question is: How is the competitive situation today as regards construction and running costs for atomic power plants as compared with conventional power stations?

A couple of years ago, IAEA collected data for a number of reactors and these are shown in Table 5; there one can see the net capacity, investment costs, and cost per installed kW. [*]

One should note the difference in the cost figures given for the power stations in Tarapur and Oyster Creek. The contractor, who is the same in both cases, explains that the cost differences are caused by the lower capacity of the Tarapur plant (380 MWe as compared with a guaranteed minimum capacity of 515 MWe for Oyster Creek), its isolated location and special complications at the site of construction.

It is difficult to make direct comparisons between capital costs for different types of atomic power plants, but even more difficult to compare the prices per kWh between different plants, because there are

[*] Information on reactors in the USSR has been included wherever possible, but no economic data are available.

so many varying factors, such as load factor, rates of interest, effective life of the plant, etc. A recent comparison, made by IAEA, is given in Table 6.

Most of these figures would show that atomic power plants are not competitive with conventional plants. In February of this year, however, detailed cost figures were revealed for the atomic power plant of Jersey Central at Oyster Creek. This can be expected to produce electricity as cheaply as the most competitive alternative conventional power station that could be built. The Oyster Creek station will therefore be discussed in somewhat more detail.

A single boiling water reactor feeds the station, which will have a guaranteed minimum capacity of 515 MWe with an expected final capacity of 620 MWe.

The total investment is 68 million dollars, which includes the purchase of the site, interest during the period of construction, training of the operational personnel and one million dollars for other expenses. The capital costs for the whole station will therefore be $132 per kW estimated at an operational capacity of 515 MWe, or $110 per kW if the higher capacity of 620 MWe is obtained. The fuel cycle costs during the first five years have been estimated at 1.66 mills/kWh and operating and maintenance costs at 0.56 mills/kWh. Although the accounting procedure is rather complex, fixed yearly charges on capital investment would amount to 2.03 mills/kWh, based on the 515 MWe capacity, a load factor of 88 per cent and an average fixed charge rate during the first five years of 10.37 per cent.

This would mean a total price before state tax of 4.25 mills/kWh at the guaranteed capacity; and should the higher capacity be achieved, the price would be 3.79 mills/kWh. The station will be owned and totally financed by a private power company without any direct Federal or state subsidies except those liabilities for nuclear damage assumed by the US Federal Government.

Anyone who has tried to interest financing institutions in investing in power plants is well aware of the very business-like considerations given to the profitability of a particular plant; these considerations are decisive in cases where one can choose between different forms of primary energy. At the moment when atomic power becomes competitive with conventional power, as is the case for instance with Oyster Creek, one has to expect a reaction, a price war from the producers of coal and oil, should they be unable immediately to find other markets. It is interesting to follow the discussion now taking place and to note the measures being proposed by the coal producers as a result of the decision last year to build the Oyster Creek plant.

The cost of coal in Oyster Creek used to be 29.5 cents/million BTU and was expected, on the basis of tenders, to decrease to 26 cents/million BTU. These were the figures used in the comparison of power costs between conventional and atomic power plants and which formed the basis of the Oyster Creek decision. In order to compete with nuclear fuel, the cost of coal would have to be about 20 cents/million BTU, which is not more than 10 per cent higher than what is paid in the coal districts of Pennsylvania.

Some ten years ago it was commonly said that the best way to lower costs for atomic power plants would be to lower costs for conventional power. The Oyster Creek tender, among other things, shows that we have now reached a situation in which the reverse seems to be true, that is the falling prices of atomic power constitute a certain guarantee that the prices of conventional fuels will be kept low. It is evident that the existence of an alternative to fossil fuels has led to price competition - one might almost say price control - on the part of the coal and oil producers, which in the final analysis has benefited the consumers.

If the cost of power generated from conventional and nuclear forces were equal, what then would be the comparison between these two alternative power sources? I do not think that the argument that, in the interest of future generations, we ought to save the complex hydrocarbons really influences the power companies to any significant extent, however valid the argument might be in itself. Humanity has, it seems, always wastefully exploited its resources whenever it has been in a position to do so, and it is not probable that one can note any change in the present generation. Nor does there at present seem to be any other major consumer of fossil fuels to fill the gap.

Instead it should be emphasized that experience so far of atomic power stations in the United Kingdom and the United States has been most encouraging as regards the operational simplicity and reliability of these plants. Experience has proved that the operation of atomic reactors is easier and simpler than one had dared to expect in the early days, and also that designs have been so conservative that it has proved possible to achieve considerable improvements in output and thereby decreases in costs. The first fuel change at Shippingport took 134 days, the third only 32 days; the output of Yankee was originally 141 MWe, it was raised to 160 MWe and a further increase to 175 MWe took place at the beginning of this year. This kind of experience speaks in favour of atomic power.

One should also remember that atomic power is not just an equal alternative to conventional power. Smoke would disappear with nuclear power and transport of fuels would be negligible. With the rapid urbanization which is now taking place in industrialized countries, it is not only possible but probable that regulations against air pollution will become so strict that conventional power plants cannot exist within city limits - as for instance in Los Angeles. Here atomic power might provide the solution when we reach the point of being able to look at the operation of reactors with the same confidence as we now look upon gas works and petrol stations within city limits.

Oyster Creek has caused quite some anxiety, and not only among the producers of coal. "Well-informed" competitors are saying that the tendered price is so low that the contractor will lose money. But at the same time, it is evident that new markets may have been opened - the current discussion in the United Kingdom about the choice of type for the next big nuclear power station is one indication of this.

The tender also invites a discussion about the validity of developing other reactor types, which only can be expected to achieve production costs comparable with those of Oyster Creek after several successive generations. For the sake of reactor technology, one must hope that shortsighted considerations will not be accepted in this connection by those who are responsible for development, either in the private or governmental sectors. Different reactor types have different characteristics - and differ in interest according to the points of view one takes. The graphite-moderated, gas-cooled high temperature reactor is an example of a reactor type the continued development of which towards bigger units one would like to see accomplished; several variants of heavy-water moderated reactors represent another line of development which is of special interest to those who do not wish to be dependent on enriched fuels.

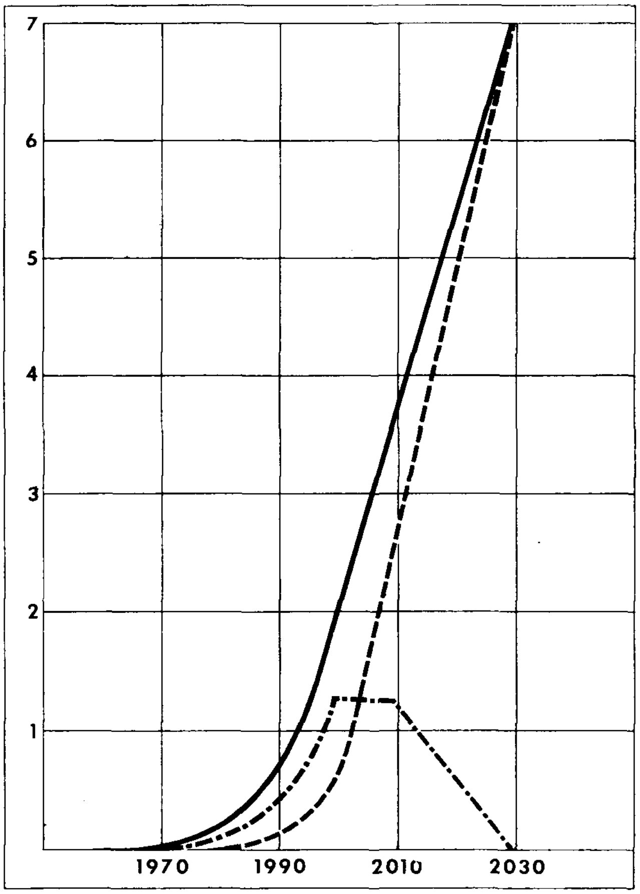
Figure 4

Thermal capacity (MW million)

_._._._._ Thermal reactors

_ _ _ _ _ _ _ Breeder reactors

_________ Total capacity



Questions are also likely to arise as to the tasks which should now be given to the large organizations, which have been created in many countries to "exploit the atom", as it used to be said. It is important to bear in mind that although reactor types which can compete with conventional power plants have now been developed, we still have found only a short-term solution; the commercial breeder remains to be developed. In this paper, the prognostications have on purpose been limited to the period before 1980, but Figure 4 is an exception. Here is shown the aggregate power of thermal reactors which will produce the plutonium later to be used in fast breeders, and the power of these breeders as a function of time up to the year 2030. One can see that the breeders only slowly take over from common thermal reactors; this is because it takes a long time - 10 to 20 years - before the original amount of fissile material is doubled by a breeder. Either one chooses the line of fast breeders using the uranium-plutonium cycle or thermal breeders using the thorium-uranium-233 cycle; this development work represents an important and big task in either case and national organizations facing this challenge are guaranteed full employment for a long time to come.

As industry takes over the development of thermal reactors, one might assume a lessened participation by national laboratories and that they instead might switch to advanced long-term work - for instance on breeders - or to more fundamental work - for instance radiobiological research.

It is not easy to strike a balance between the tasks that should be allocated to national laboratories, development departments of industrial concerns and the research laboratories of universities and technical high schools. The Oyster Creek tender will certainly stimulate a fresh discussion in this respect as well.

A few words on safety questions. The atomic industry has from the very start been so safety minded that there is every reason to believe that when more experience has been gained, the trend will be towards softening and simplification of present practices and measures. This would be in contrast to the customary development in industries which pollute air or water; in these, restrictive regulations have normally been laid down only when pollution reached such levels that the inconvenience or risks were clearly demonstrable. A continued study of siting and safety questions is important to the economics of atomic power and will no doubt lead to lessened capital costs for atomic power stations; intensified public information activity might also lead to increased understanding of and interest in the new technology.

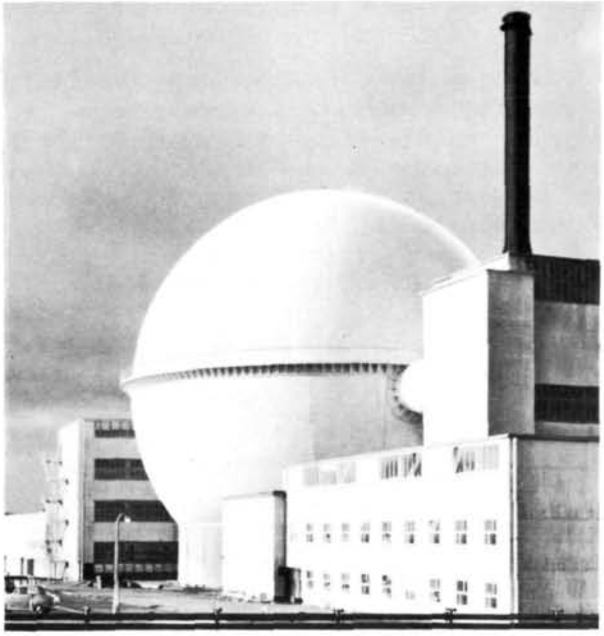
The public in many parts of the world still seems to fear atomic energy establishments of different kinds. Atomic weapons and their effects most probably play a part in this. If not, it would be hard to understand the public anxiety about radiation in a period when we accept as a matter of fact that thousands of persons are killed every month in traffic accidents or that 200 persons succumbed to New York's first attack of smog.

Other large areas of problems will also call for research and development efforts. Radioactive wastes is one such field, and the transport of radioactive materials, including spent fuels, another. In respect of spent fuel, one would like to see a development towards the establishment or organization of regional plants for the processing of such radioactive elements. This would simplify and lessen the cost of transport, introduce a necessary improvement in the economics of fuel reprocessing through bigger turnover and also lead to better possibilities for an international control of fissile materials. One might mention as an example that an installed capacity of atomic power of 25 000 MWe would require a processing plant with a capacity of ten tons of spent fuel per day. Such an establishment could be operated at only double the cost of a plant with a capacity of only one ton per day. The desirability of close co-operation between nuclear power producers, at first universally, later regionally, becomes evident from these figures.

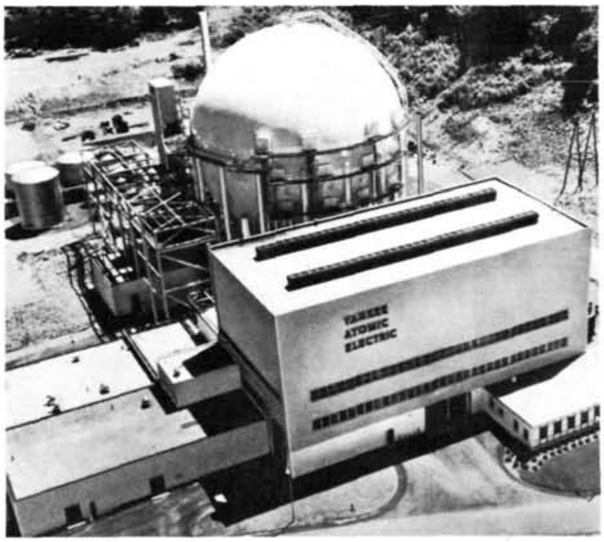
Finally, a few words about the possibility of obtaining enriched fissile materials (uranium-235 or plutonium) for reactors. Only the United States, United Kingdom and the Soviet Union are at present producers of uranium-235 and all three have supplied enriched materials across their borders. The production capacity is no doubt considerable; IAEA estimated last year that there were some 3000 tons of plutonium and uranium-235 available. Compare this total with the fact that the Dresden reactor of 205 MWe contains only 750 kg.

A price list for enriched uranium was established in its latest version in July 1962 by the US Atomic Energy Commission, which is prepared to guarantee the fuel supply of a reactor for its entire life span. The prices must however be regarded as somewhat artificial, as they are closely allied to weapons production. The question of toll enrichment is most interesting in this connection.

The artificial conditions reigning in this market are clearly shown in the competition between the presumptive vendors of plutonium to Euratom; this resulted in the award of the contract for a price of $42 per gram, whereas the original British offer was $112 per gram.



Experimental Fast Breeder Reactor at Dounreay, (UK). (UK AEA photo)



Yankee Power Station, USA.

The supply of fuel from USA and UK is in principle subject to the condition that the supplier country has the right to verify, through inspectors, that the material is being used for the specified, peaceful purposes. The United States is at present negotiating with several countries about the transfer of this inspection function to IAEA. It should be noted that IAEA's safeguards system has recently been extended to include reactors with a thermal capacity of more than 100 MW. This decision was taken without the many dissenting views which were so much in evidence three years ago when the safeguards system was first established. It was decided at the same time that the entire system would be reviewed; this is being done by a Committee of the Board of Governors.

The inspection of reactors, on which the entire safeguards system is based, causes some change in old concepts of exclusive sovereign rights. The expected expansion of civilian atomic energy programmes does, however, make fissile materials produced in reactors available on quite a new scale. In this situation it is of utmost importance that an international control system should be established which can guarantee the exclusively peaceful use of this material. The connection between this question and international disarmament was shown, for instance, by the fact that it was at a meeting of the Disarmament Conference in Geneva that the United States offered to put its Yankee reactor in Massachussetts under IAEA safeguards.

It is now 26 years since the discovery of the fission process, 22 years since the first reactor was started up and 11 years since the first light-water moderated power reactor was put into operation. As so many times before in the history of atomic power, we now stand at a turning point. After a period of pessimistic prognostications, there is now cause for optimism, as we can see that atomic power plants under certain conditions seem to be competitive. But we must not forget that atomic power works towards a moving target. Taking into consideration the retarding factors which are built into our economic systems, it seems probable that there will be only a gradual introduction of the new energy source. It remains after all to see how the producers of fossil fuels will react in the present situation.

Table 1

World Energy Resources: in coal equivalent

	Million tons
Coal, brown coal and lignite	3 000 000
Peat	100 000
Oil and oil shales	290 000
Natural gas	90 000
	3 500 000

(World Power Conference, Survey of Energy Resources, 1962)

Table 2

Uranium and thorium resources and uranium production

Country	Resources (ton element in mineral)		Production 1963 (in equivalent tons of U-element)
	U	Th	
South Africa	250 000	15 000	3 500
West Africa	-	15 000	-
Canada	145 000	210 000	6 000
United States of America	132 000	50 000	11 000
France	26 000	-	1 000
Australia	10 000	50 000	800
Congo (Leopoldville)	8 000	-	-
Nyasaland	-	10 000	-
Portugal	5 500	-	300
Gabon	5 000	-	400
Argentina	3 800	-	-
Brazil	-	300 000	-
Italy	1 600	-	-
Spain	1 500	-	100
India	1 200	300 000	-
Ceylon	-	50 000	-
Japan	1 000	-	-
Germany, Federal Republic of	800	-	-
Others	1 000	-	200
Total	592 400	1 000 000	23 300

Table 3

Operating atomic power plants with capacity above 100 MWe as at January 1964

Type	Reactors	Stations	Capacity (MWe)
Graphite/gas-cooled	5	3	726
Graphite/water-cooled	1	1	100
PWR	3	3	611
BWR	2	2	330
Total	11	9	1767

Table 4

Introduction of electric power plants, 1960-1980

Region	1960-70			1970-80		
	Total electric power (MWe)	Proportion of atomic power MWe	%	Total electric power (MWe)	Proportion of atomic power MWe	%
USA	150 000	5 000	3	190 000	38 000	20
Canada	25 000	1 000	4	28 000	5 000	18
United Kingdom	40 000	5 000	13	65 000	12 000	18
Euratom	55 000	4 000	7	115 000	30 000	26
Other European countries	20 000	1 500	7	46 000	5 000	10
Others (including India, Japan and Pakistan)	60 000	4 000	6	100 000	10 000	10
Total	350 000	20 500	6	544 000	100 000	18

Table 5

Capital costs for atomic power plants

Station	Type	Start-up	Net output (MWe)	Capital cost (million $)	Cost per kWe ($)
Dresden, USA	BWR	1959	205	51.3	250
KRB, Fed. Rep. of Germany	BWR	1965/66	237	70.0	295
Tarapur, India	BWR	1966	380 (2 x 190)	101.5	267
Oyster Creek, USA	BWR	1968	515 (minimum)	68.0	132
Yankee, Mass., USA	PWR	1960	158	39.2	248
San Onofre, USA	PWR	1966	373	91.5	245
Conn. Yankee, USA	PWR	1967	463	84.9	183
Wylfa, UK	GCR	1967/68	1180 (2 x 590)	280.0	236
Candu, Canada	D_2O	1965	202	81.5	403

Table 6

The kWh prices for selected atomic power plants

Station	Start-up	Mills/kWh			Total
		Capital costs	Fuel	Operation	
Yankee 1	1960	5.50 a/	2.42 b/	1.15	9.1
Yankee 2	1962	5.50 a/	4.75 c/	1.15	11.4
Bradwell	1963	5.60 d/	2.80	0.60	9.0
Bodega Bay	1966	3.71 e/	1.79 c/	0.72	6.2
Candu	1965	3.41 f/	1.21	1.14	5.8

a/ Based on annual fixed charge rate of 14.6%, 84% load-factor and an investment of $248 per kW.

b/ Including re-purchase price of plutonium at $30/g Pu metallic. No lease cost for the uranium. Burn-up costs estimated on basis of US AEC prices for enriched uranium in the period 1.VII.61 - 30.VI.62.

c/ Includes re-purchase price of plutonium at $8/g Pu in nitrate form. Lease cost for the uranium is included. The cost of the burn-up of the uranium is based on US AEC prices as from 1 July 1962.

d/ Based on a rate of interest of 5.5%, 20 years effective operation time of the plant, which means an annual fixed charge rate of 8.37%. Assumes a load-factor of 80% and a capital cost of $465/kW.

e/ Based on a fixed charge rate of 13.2%, 80% load-factor and capital cost of $197/kW.

f/ Based on rate of interest of 4.5%, amortization of the heavy water over 40 years, amortization of the reactor itself over 15 years and the other parts of the plant over 30 years, which means a yearly fixed charge rate of 6.48%. It also assumes a load-factor of 80% and a capital cost of $403/kW.