Future Trends in Nuclear Power

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Among the uncertainties, doubts and discussions which have characterized the scene of energy in general and of nuclear power in particular, it is reassuring to find some points of general agreement which provide some guidance in trying to appraise the future prospects of nuclear power:

1. The world energy demand will be growing although the regional rates and modalities of this growth are difficult to predict with accuracy. Even with the most stringent efforts to achieve energy conservation, the world consumption is likely to rise from about 6 billion tons of oil equivalent (TOE) in 1977 to a range of 12 to 18 billion TOE by the turn of the century.
2. The highly uneven distribution of oil and gas reserves which provide the basis for about two-thirds of today's energy supply and will still represent the major portion of energy production by the year 2000 places many countries in a position of increasing dependence on imported energy.
3. Regardless of the possible and even probable new discoveries of hydrocarbon fields, these fuels will continue to rank first on the exhaustion list of energy sources available to mankind.

It is against this background that the role of nuclear power can be visualized:

1. Over the intermediate term nuclear power offers a substitution for the oil and gas which would otherwise be required for electricity production and it represents for many countries deficient not only in oil and gas, but also in coal reserves, a means of avoiding an overwhelming dependence on imports.
2. Over the long term, nuclear power may provide a technologically mature solution for meeting overall energy requirements, which by the middle of the next century might approach the 50 billion TOE range.

The two aspects are intimately interlinked, since a long-range penetration of nuclear power is dependent upon the progressive development of a large manufacturing and fuel-cycle infrastructure. It is necessary to recall the effort, timing and financing which were required to proceed from experimental power reactors to full-scale industrial production, and that it took 35 years from the time of the initial demonstration until nuclear plants made a contribution to the world energy supply of about the same order as hydroelectric stations. This point is best illustrated by a brief review of the present and expected status of nuclear power in industrialized and developing countries.

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NUCLEAR POWER IN INDUSTRIALIZED COUNTRIES

At the end of March 1977, the licensed capacity of nuclear plants in industrialized countries amounted to 95 GWe, of which about 50% was in the USA. Although this corresponded to only about 7% of the electrical capacity of these countries, nuclear power growth during the past five years has been at a rate of 28% per year [1].

Recent nuclear power growth data in OECD countries shown in Table 1 are taken from a Salzburg Conference paper by OECD/NEA [2]. These figures were corrected as shown to exclude data on Greece and Turkey and add the Republic of South Africa. An IAEA forecast for the USSR and German Democratic Republic based on data in the open literature is also given for comparative purposes. It is seen that the nuclear capacity of industrialized countries with market economies may reach the range of 830—1650 GWe by the year 2000. This forecast may be compared with an OECD/NEA-IAEA forecast of 1350—1600 GWe made last year [3]. The reduced lower limit of the range reflects the uncertainty now prevailing among nuclear power planners.

NUCLEAR POWER IN DEVELOPING COUNTRIES*

Although many industrialized countries will rely on conservation and reduced rates of growth in energy consumption as a means of alleviating the problem of energy supply and demand, developing countries can ill afford such an approach. For them increasing energy supply is a necessity and where indigenous energy sources are lacking, the only solution is nuclear power and the use of imported oil or coal. Thus, it is not surprising that many developing countries are anxiously looking forward to the time when nuclear power plants can be introduced into their electric power system.

Despite this great interest, however, as of March 1977, only five developing countries had nuclear plants in operation with a combined net output of 2000 MWe (2 GWe). This represented only about 1% of the installed electrical capacity of all developing countries and only about 2% of the world nuclear capacity. However, these and eleven other developing countries plus Taiwan have nuclear plants under construction or planned for operation by 1985 with a total capacity of 28 GWe. If all of these plants are built on schedule, the near-term commitment of nuclear power in the developing world will provide electricity equivalent to a saving of 43 million tons of oil per year [4].

Current IAEA estimates of the longer term growth of nuclear power indicate a range of 200 to 300 GWe of nuclear capacity by the year 2000 in developing countries with market economies. The CMEA developing countries might have from 80 to 120 GWe of nuclear power in that same year. These forecasts are only about one-half the potential market for nuclear plants estimated by the IAEA in early 1974 [5].

THE PARADOX AND ITS CAUSES

The decrease of nuclear power objectives in the face of a five-fold increase of the price of oil represents a paradox which calls for some explanation.

If we leave out such accidental causes restricted in time or space as, for instance, the 1974—75 recession which led to stagnation of electric power consumption in most of the world

* Developing countries are defined as those eligible to receive technical assistance from 1977—1981 under the United Nations Development Programme.

Table 1: Nuclear Growth Forecasts for Industrialized Countries

Region or Country	GWe 1985	1990	1995	2000
OECD Europe	125–168	200–286	284–418	307–560
OECD America	141–172	215–309	305–514	370–810
OECD Pacific	27–49	52–85	92–158	152–270
Total OECD	239–389	467–680	681–1090	829–1640
Less Greece and Turkey	293–388	465–676	674–1084	821–1628
Republic South Africa	1–2	2–5	5–11	7–17
USSR and German Dem. Rep.	41–69	82–121	143–226	210–340
Total Industrialized Countries	335–459	549–802	822–1321	1038–1985

and to a postponement of new plant additions or the discovery of oil and gas fields which permitted countries like the UK and Mexico to deter their nuclear power expansions, the main causes can be classified in two categories:

1. Social and political factors arising from sometimes irrational anxiety over the environmental effects of nuclear power plants and their fuels and from an increasing concern over a potential link between civilian nuclear power and proliferation of nuclear weapons.

2. Technical and economic factors leading to substantial increases in the capital and fuel costs of nuclear stations.

With regard to capital costs, safety and environmental protection requirements were increased to an extent which could hardly be foreseen in the earlier years of commercial nuclear power.

This is particularly visible in the USA where the amounts of many important commodities (e.g. concrete, steel, pipes, cables) had to be practically doubled in order to meet regulatory requirements. The amount of man-hours of construction labour per kWe has increased proportionally. Because of extended schedule and increased complexity of nuclear power plant construction, the indirect costs have grown even more than the direct ones. More temporary structures are required to store and protect equipment and construction materials. About twice as many engineers, etc., are required for longer time per project to perform engineering and construction management services.

Quality assurance and quality control is another example of substantially increase requirements. The number of standards applicable to the design and construction of a nuclear power plant in the USA grew from about 100 in 1970 to about 1600 in 1976. Analyses of the combined effect of regulatory requirements lead to the conclusion that they have increased the real capital costs of nuclear power plants by a factor of two since the early years of commercial nuclear power.

In addition, before 1970, reactor manufacturers and architect-engineers were willing to undergo substantial commercial risks to enter a new and very promising market. A number of low-priced contracts reportedly led to substantial financial losses of the vendors. After the quadrupling of oil prices in 1973, they found themselves in a much more favourable situation. Consequently, their prices have been rising to a level suitable to cover their usual commercial risks.

With regard to nuclear fuel costs, uranium concentrates prices experienced a sharp rise which for immediate deliveries outdid even that of oil, while enrichment costs rose by a factor of about three.

CURRENT COMPETITIVENESS AND OUTLOOK FOR LIGHT-WATER REACTORS

A general discussion of this subject would be beyond the scope of a short article, but an illuminating insight can be obtained from a meeting of experts from advanced and developing countries held in June 1977 by the IAEA to review recent capital cost experience on nuclear and conventional power plants [6]. Based on data from this meeting, it now appears that even without the addition of first-of-a-kind costs, 600 MWe nuclear plants are going to find it very difficult to compete with oil-fired plants at present day costs of heavy fuel oil. Table 2 gives some representative investment and generating costs of 600 MWe and 900 MWe nuclear and oil-fired plants. It is seen that generating costs for 600 MWe LWR's are about 2 mill/kWh higher than costs for the same size oil-fired plants. At 900 MWe , however, the nuclear plants have lower generating costs by about the same margin and this margin increases further with increasing size.

It should be emphasized that generalized economic comparisons of this nature can be very misleading because they rarely represent real life conditions. The capital cost data, for example, are based on an ideal hypothetical site in the USA and do not include such items as escalation taxes and duties, the construction or improvement of facilities outside of the plant (roads, bridges, harbour, railroad) and the training and housing of construction workers.

When it comes to future prospects, several factors seem to militate in favour of an improvement in the competitive position of nuclear power plants:

1. With regard to capital costs, the safety and environmental protection requirements seem to have reached a maximum so that a shortening of licensing procedures applying to standardized units may permit nuclear stations to achieve the savings inherent in the up-to-now elusive learning curve. In contrast, the environmental costs for coal-fired stations are still increasing.

2. With regard to nuclear fuel costs, new discoveries as a result of the intensive prospecting efforts for uranium in unexplored areas are likely to bring about a stability of prices, which is far from assured in the case of oil.

Table 2: Economics of Light-Water Nuclear Plants and Oil-Fired Plants[1]

	LWR		Oil-Fired Plants	
	600 MWe	900 MWe	600 MWe	900 MWe
Plant Investment ($/kW)	1150	910	540	510
Generation Costs (mills/kWh)				
Capital[2]	24.2	19.2	11.4	10.8
Fuel	7.0	6.8	18.3[3]	18.3[3]
O. + M.	2.2	2.0	1.4	1.2
Total	33.4	28.0	31.1	30.3

1 All costs are in constant US mid-1977 dollars.
2 65% plant factor, 12% annual charge.
3 Based on high sulphur fuel oil at $11/barrel.

OUTLOOK FOR ADVANCED REACTOR TYPES

Present estimates of world resources of natural uranium which can be produced at costs up to US $30 per pound of U_3O_8 (1976 purchasing power) are of the order of 4 million tons [7], equivalent to about 60 billion tons of oil if used in light-water reactors. The oil equivalent of present uranium resources is less than present oil reserves.

Although this estimate is viewed by many experts as being too low because very large areas of the world remain to be explored, a world-wide nuclear expansion based entirely on light-water reactors would necessarily remain limited. Thus there is considerable interest in advanced reactor types which can utilize uranium (and thorium) more efficiently. Strategy studies for these systems have recently been carried out by an IAEA-sponsored "Thermal Breeders Consultants Group" to determine the resource requirements for different advanced reactors [8]. Table 3 shows the cumulative amounts of natural uranium required up to 2050 by market economy countries assuming that the different advanced reactor types are introduced in commercial quantities only after 1995. It is apparent from this table that only the fast breeder and/or the liquid fuel thorium breeder can reduce the cumulative uranium consumption to the range of estimated resources of low cost ores. The afore-mentioned strategy studies provide a firm basis for the continued development of advanced reactor types. Table 4 shows how heavily the world outside of the USA is commited to the development of LMFBR's.

Liquid fuel thorium breeders have been under development in the USA for more than 25 years, although relatively little effort is currently being devoted to such reactors. In spite of this, a group of U.S. industrial firms called the "Molten Salt Group" has recently completed a technical and economic analysis of molten salt reactors and reached the

Table 3: Cumulative Uranium Requirements for Market Economy Countries[1]

Reactor Type or System	Millions of Tons Natural Uranium — Low Nuclear Growth	Millions of Tons Natural Uranium — High Nuclear Growth
Light-Water – No Pu Recycle	38	60
Light-Water – Pu Recycle	25	43
Light-Water – Thorium Breeder	23	44
Thorium Cycle CANDU	17	30
Fast Breeder	10	15
Liquid Fuel Thorium Breeder	9	16
Liquid Fuel + Fast Breeder	5	10

[1] Up to the year 2050.

conclusion that such systems have a high probability of offering a good way to produce commercial nuclear power in the early 1990's [9]. Because of the non-proliferation features of molten salt breeders, as well as favourable safety and environmental characteristics, there is a possibility of renewed interest in their development.

TENTATIVE CONCLUSIONS

Although the prospects for nuclear power are almost always assessed on the basis of cost comparisons, it should not be forgotten that the whole field of energy has been characterized by an increasing discrepancy between prices and production costs.

This divorce of selling prices from costs of production had long prevailed in the oil industry, both at the crude and refined products level, and it has recently begun to expand to coal and to uranium.

It is therefore somewhat illusory to rely on economic analyses as dependable guides for nuclear power forecasting, especially if these comparisons extend over periods of time during which the continuing validity of the basic input parameters is highly doubtful.

Thus qualitative considerations of a short-term and long-term nature often carry more weight in energy choices than monetary estimates of future benefits and costs.

While some of these qualitative arguments, for instance with regard to environmental effects, may have slowed down nuclear power in the immediate past, others point strongly to a positive future. Chief among them are the following points:

Table 4: Liquid Metal Fast Breeder Projects Outside of the United States

Name	Country	MW(th)	MW(e)	Date of Power Operation
DFR	UK	60	14	1965
Rapsodie	France	40		1967
BOR-60	USSR	60	12	1970
BR-10	USSR	10		1973
BN-360	USSR	1000	350	1973
Phénix	France	567	250	1974
PFR	UK	600	250	1976
JOYO	Japan	100		1977
KNK-2	FRG	58	20	1977
BN-600	USSR	1470	600	1979
PEC	Italy	118		1979
SNR-300	FRG	736	312	1981
Super Phénix	France	2900	1200	1982
MONJU	Japan	714	300	1984
CFR	UK	3125	1320	1988–90
SNR-2	FRG	5000	2000	1988–90

1. Nuclear power depends much more on human resources than on natural resources. Indeed, if it is based on an efficient breeding cycle, it becomes practically independent from raw material inputs.

2. It offers to many industrial and developing countries a way to alleviate their present dependence on imports of energy. It should be remembered in this connection that each Gigawatt of nuclear capacity saves about 1.5 million tons of oil per year and that the minumum targets envisaged for the year 2000 will involve the economy of more than half of the current annual world oil production.

3. It can provide a general insurance policy against energy shortages beyond the end of the century provided a sufficiently broad industrial base and suitable fuel cycle have been developed in the interval.

Doubtless, the nature, scope and role of this infrastructure may vary from country to country depending on the one hand upon its degree of nuclear development and on the other upon its national wealth of fossil and fissile fuel resources.

However, regardless of the wide diversity of national situations which may arise in the future, the full contribution of nuclear power to the world energy supply will only be achieved if a climate of international confidence in such critical areas as nuclear fuel supply and safeguards is established throughout the world.

References

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