Nuclear Power Development: Present Role and Medium-Term Prospects

by R. Krymm and J. P. Charpentier

INTRODUCTION

At the beginning of 1979 there were, throughout the world, 224 nuclear power plants in operation whose total capacity accounted for 190 000 MWe. A breakdown by country is provided in Table 1. The significant role of nuclear energy in the total electricity supply of some countries is clearly apparent from Table 2 which summarizes nuclear electricity production in different countries and its percentage share of total electricity for the period extending from mid-1977 to mid-1978. For the world as a whole, however, nuclear energy accounted in 1978 for only about 2% of primary energy supply and for about 7% of electricity production (see Tables 3, 4 and 5).

WORLD ENERGY SITUATION AND ROLE OF NUCLEAR POWER

An assessment of the need for nuclear power can only be made in the light of the world energy situation as it is today and as it is likely to develop in the future. The evolution of total primary energy consumption between 1950 and 1975 was characterized by two features:

(a) a rapid rate of growth of about 5% per annum on average which led to more than a trebling of total world energy consumption from 1.7 to more than 6 billion tons of oil equivalent during those 25 years;
(b) a substitution of hydrocarbons for coal until they came to account for almost 2/3 of total energy supply by the end of the period.

What about the future? Without engaging in detailed quantitative forecasts, which always contain substantial elements of uncertainty and arbitrariness, it seems unavoidable that the growth of world energy demand will continue over the next decades although the rates of growth will certainly be different from those witnessed in the past in the various regions of the world. This increase will take place even if the maximum efforts at conserving energy are applied by industrial countries, as indeed they should be, and even if more efficient methods for energy conversion and final utilization are developed throughout the world.

Until his death in December 1979, Mr. Krymm was Head of the Economics Studies Section, Division of Nuclear Power and Reactors, IAEA; Mr. Charpentier is a staff member in the Economics Studies Section.

Table 1. Nuclear power reactors in operation as of 1 January 1979

Country	No. of Reactors	Capacity (MWe net)
Argentina	1	345
Belgium	4	1 676
Bulgaria	2	816
Canada	10	4 755
Czechoslovakia	1	110
Finland	2	1 080
France	14	6 353
Germany, Democratic Republic of	4	1 287
Germany, Federal Republic of	13	6 074
India	3	602
Italy	4	1 382
Japan	19	11 009
Korea, Republic of	1	564
Netherlands	2	499
Pakistan	1	126
Spain	3	1 073
Sweden	6	3 700
Switzerland	3	1 006
Taiwan	2	1 208
UK	33	6 982
USA	68	49 659
USSR	28	8 616
22 countries	224	108 922

The reasons for this expected growth of energy demand can be grouped under four main headings:

- a general increase in population, especially in developing countries;
- the economic development of these countries;

Table 2. Total electricity production from nuclear power plants for the period 1 July 1977–30 June 1978

Country	Nuclear Electricity (10^9 kWh)	Estimated Share of Nuclear Electricity (%)
Argentina	2.4	6.5
Belgium	12.5	22
Canada	30.9	10
Finland	3.2	9
France	23.5	10
Germany, Federal Republic of	33.5	8
India	2.1	2
Italy	3.5	2
Japan	35.3	6
Netherlands	4.2	6
Pakistan	.2	1
Spain	6.6	6
Sweden	23.1	22
Switzerland	8.1	17
Taiwan	1.0	–
UK	37.9	10
USA	268.9	11
USSR and Eastern Europe	53	3.5
Total	550	7.8

- the time lags inherent in the implementation of energy conservation measures in industrial countries;
- the increasing recourse to poorer mineral ores and to waste recycling.

The present distribution of the world's population and the expected trends in its growth are summarized in Table 6. It will be seen that under conservative assumptions this population is expected to increase by more than 50% over the next 20 years from its present level of 4.2 billion to about 6.4 billion by the turn of the century. During this period, the population of the developing countries will increase to about 5 billion people, rising from 72% to 78% of the total.

Table 3. Estimates of the development of installed electrical and nuclear* capacity by main country groups (in 1000s MWe)

	1978			1985			2000		
	Total Electric	Nuclear	(%)	Total Electric	Nuclear	(%)	Total Electric	Nuclear	(%)
(1) OECD North America	674	54.4	(8.1)	770–900	110–125	(14)	1400–1600	300–450	(21–28)
(2) OECD Europe	410	29.8	(7.3)	530–610	90–100	(16–17)	1000–1200	270–400	(27–33)
(3) OECD Pacific	156	11	(7.0)	200–220	25–30	(12.5–13.5)	400–500	100–150	(25–30)
(4) Centrally Planned Economies (Europe)	342	10.9	(3.2)	600–700	50–80	(8–11)	1200–1400	250–450	(21–32)
(5) Asia	117	2.5	(2.1)	170–200	8.5–9.6	(5)	640–750	60–75	(9–10)
(6) Latin America	80	0.3	(0.4)	110–130	3.1–5.3	(3–4)	350–450	40–100	(11–22)
(7) Africa & Middle East	51	0	(0)	70–90	2.4–3.0	(3–3.5)	240–300	10–25	(20–27)
World Total	1830	108.9	(6)	2450–2850	289–352.9	(12)	5230–6200	1030–1650	(20–27)
(8) Industrialized countries	1598	106.1	(6.6)	2120–2455	276.8–336.8	(13–14)	4050–4760	925–1460	(23–31)
(9) Developing countries	232	2.8	(1.2)	330–395	12.2–16.1	(4)	1180–1440	105–190	(9–13)

(4) includes Yugoslavia.
(5) includes China and Taiwan.
(8) is composed of (1)+(2)+(3)+(4)+South Africa.
(9) is composed of (5)+(6)+(7)–South Africa.

* Based on data obtained for the International Nuclear Fuel Cycle Evaluation.

Sources for 1978 data: for Total Electric – UN Statistical Office, New York.
for Nuclear – IAEA.

Table 4. Estimates of total world electric and nuclear energy consumption in terawatt-hours (TWh). (1 TWh = 10^9 kWh)

	1978			1985			2000		
	Total Electric	Nuclear	(%)	Total Electric	Nuclear	(%)	Total Electric	Nuclear	(%)
(1) OECD North America	2649	289	(11)	3200–3800	620–710	(19)	5900–6700	1700–2500	(29–37)
(2) OECD Europe	1617	151	(9)	2200–2600	510–570	(22–23)	4200–5000	1500–2200	(36–44)
(3) OECD Pacific	673	32	(5)	840–900	140–170	(17–19)	1700–2100	570–850	(34–40)
(4) Centrally Planned Economies (Europe)	1641	48	(3)	2500–3000	280–450	(11–15)	5100–5900	1400–2500	(27–42)
(5) Asia	513	10	(2)	700–850	45–55	(6)	2700–3100	300–400	(11–13)
(6) Latin America	308	2	(1)	450–550	15–30	(3–5)	1500–1900	200–550	(13–29)
(7) Africa & Middle East	211	0	(0)	290–350	10–15	(3–4)	1000–1300	50–140	(5–11)
World Total	7612	532	(7)	10180–12050	1620–2000	(16–17)	22100–26000	5720–9140	(26–35)
(8) Industrialized countries	6670	519	(8)	8900–10300	1550–1910	(17–19)	17100–20000	5120–8140	(30–41)
(9) Developing countries	942	13	(1 4)	1280–1750	70–90	(5)	5000–6000	600–1000	(12–17)

(4) includes Yugoslavia.
(5) includes China and Taiwan.
(8) composed of (1)+(2)+(3)+(4)+South Africa.
(9) composed of (5) +(6)+(7)–South Africa.

Notes (i) The 1978 data source is the UN Statistical Office, New York.
(ii) To connect this Table with Table 1, related to installed capacities, the following assumptions have been made for 1985 and 2000

- average utilization factor of electric system 48%
- average utilization factor of nuclear stations· 65%.

Table 5. Estimates of total world primary and nuclear energy consumption in exajoules (1 exajoule (EJ) = 10^{18} joules)

	1978			1985			2000		
	Total Energy	Nuclear	(%)	Total Energy	Nuclear	(%)	Total Energy	Nuclear	(%)
(1) OECD North America	86.4	3 16	(3.7)	95–110	6 8–7.7	(7)	115–130	18.5–27 3	(16–21)
(2) OECD Europe	51.7	1 64	(3 2)	60–70	5.6–6 2	(9)	95–105	16.4–24.0	(17–23)
(3) OECD Pacific	17.5	0.35	(2 0)	26–32	1 5–1 9	(6)	40–50	6 2–9 3	(16–19)
(4) Centrally Planned Economies (Europe)	68 4	0.52	(0 8)	85–100	3 1–4.9	(4–5)	120–165	15.3–27.3	(13–17)
(5) Asia	42 6	0 11	(0 3)	40–50	0 5–0.6	(1.2–1 3)	75–90	3.3–4 4	(4 4–4.9)
(6) Latin America	15 3	0 02	(0.1)	21–25	0 2–0 3	(1 0–1 2)	50–60	2 2–6 0	(4 4–10)
(7) Africa & Middle East	13 6	0	(0)	14–17	0.1–0 2	(0.7–1 2)	25–30	0 5–1.5	(2–5)
World Total	295.5	5.80	(2.0)	341–404	17 8–21 8	(5 2–5 4)	520–630	62 4–99 8	(12–16)
(8) Industrialized countries	226.8	5.67	(2.5)	269–315	16.9–20 8	(6.3–6.6)	375–455	55 9–88 8	(15–20)
(9) Developing countries	68.7	0.13	(0 2)	72–89	0.8–1.0	(1 1)	145–175	6 5–10.9	(4.2–6 2)

(4) includes Yugoslavia.
(5) includes China and Taiwan.
(8) composed of (1)+(2)+(3)+(4)+South Africa.
(9) composed of (5)+(6)+(7)–South Africa.

Notes (i) The 1978 data source is the UN Statistical Office, New York
(ii) Electricity supplied by nuclear stations was converted to primary energy equivalent by using an average efficiency factor of 0 33.
(iii) Total energy consumption means primary energy consumption plus net secondary energy import (Import-Export), i.e total energy requirements

Table 6. Estimates of world population (millions)

	1978	1985	Average Annual Growth Rate between 1978–1985 (%)	2000	Average Annual Growth Rate between 1985–2000 (%)
(1) OECD North America	243.5	262	1.05	296	0.8
(2) OECD Europe	390.3	412	0.78	460	0.7
(3) OECD Pacific	132.3	142	1.02	157	0.7
(4) Centrally Planned Economies (Europe)	395.5	421	0.90	466	0.7
(5) Asia	2 194.0	2 575	2.31	3 361	1.8
(6) Latin America	346.0	424	2.95	618	2.5
(7) Africa & Middle East	489.9	649	4.10	995	2.9
World total	4 191.5	4 885	2.21	6 353	1.8
(8) Industrialized countries	1 191.9	1 268	0.89	1 420	0.8
(9) Developing countries	2 999.6	3 617	2.71	4 933	2.1

(4) includes Yugoslavia.
(5) includes China and Taiwan.
(8) composed of (1)+(2)+(3)+(4)+South Africa.
(9) composed of (5)+(6)+(7)–South Africa.

Notes: Estimates made by the UN Statistical Office, New York.

The present distribution of commercial energy consumption reflected in Table 7 shows the total and per capita energy consumption in industrialized and developing countries and their striking disparities. The average per capita consumption in industrial countries is more than 8 times larger than that of developing nations. To this disparity corresponds a similar gap in the standards of living which can only be reduced by economic and industrial development. This process of development will necesarily involve rapid growth of commercial energy demand since the initial stages of industrialization are particularly energy intensive. Thus, even if by a miracle of active conservation and restrictive policies, the industrialized nations were to maintain zero energy growth, the pressure of demand from developing countries would bring about a substantial increase in world energy needs.

However, zero energy growth in the industrial countries is an illusion, at least over the short term, because most of the measures designed to achieve greater efficiency in energy production and greater economy in energy use require long periods of time to achieve their full impact. The renewal of the housing or transportation stock in accordance with energy saving designs may range from one to several decades. Life styles and social infrastructure do not change overnight. Consequently, the growth of energy demand can be expected to continue in industrialized countries although it will proceed at rates substantially lower than those which prevailed during the last 30 years.

Finally, mankind is progressively exhausting its best deposits of mineral ores and as it turns to ever lower grades of minerals or to the recycling or various metals, the demand for energy in the mining industries is likely to increase progressively.

An impressive number of attempts have been made by private, national and international organizations to translate the possible impact of the factors discussed above into quantitative terms. The results agree on the trends but there is of course a wide dispersion of figures for individual countries and for particular years. There is no cause for surprise here considering the myriad assumptions which underlie the calculations. Consequently, Table 5, which is essentially based on a critical review of the World Energy Conference's estimates, should not be interpreted as a hard forecast but simply as a plausible framework within which future energy demand might be discussed. What this Table shows is that the 1978 energy demand level of about 295 exajoules (or to use a more familiar standard, about 7.0 billion tons of oil equivalent) is expected to rise to about 520–630 exajoules (approximately 12 to 15 billion tons of oil equivalent) by the year 2000.

What are the potential sources of supply on which mankind can draw to meet this conservative estimate of an approximate doubling of demand over the next two decades? The replies to this question usually take the form of a variety of tables summarizing reserves and resources for different energy sources. Unfortunately the figures presented are always qualified by such adjectives as "proven", "estimated", "inferred", "speculative", "potential", "economically recoverable", "ultimate", etc. which are not always helpful in drawing clear conclusions. Here again, as in the case of demand projections, a better purpose may be served by concentrating on major trends than by debating the validity of specific figures.

Roughly speaking, if the estimates of Table 5 are taken as a basis, the cumulative energy consumption of the world over the next 20 years would be of the order of 250 billion tons of oil equivalent. If oil were to maintain its share of the market, it would require a cumulative production of more than 110 billion tons as against present proven reserves of

Table 7. Commercial energy consumption in industrialized and developing countries in 1978

	Total (10^{18} joules)	Per capita (10^{9} joules)
Industrialized countries	226.8	190
Developing countries	68.7	23
Ratio of energy consumption in industrialized countries/energy consumption in developing countries	3.3	8

90 billion tons. Of course, more reserves are likely to be found at ever increasing costs but these new discoveries could only postpone by a few decades the unavoidable ultimate exhaustion. A similar situation prevails for natural gas. Thus, the two energy sources which account for close to two-thirds of the world supply today are going to become increasingly scarce in the immediate future.

While resources of coal probably exceed those of oil and gas by an order of magnitude, they share with hydrocarbons the serious shortcoming of a highly uneven distribution among the various countries of the world. In addition, a rapid expansion of coal production would give rise to serious environmental and social problems so that it can only partially fill the increasing gap which the progressive depletion of oil and gas reserves will leave open.

Finally, renewable sources of energy must be developed at maximum speed wherever conditions warrant, but these resources are either already heavily exploited and locally bound, as in the case of hydroelectricity, or available in such diluted and irregular forms, as in the case of solar and wind energy, that they offer only partial and limited solutions to the general energy problem. Their combined share of world supply therefore is unlikely to exceed 10% of the total by the year 2000.

On the other hand, nuclear power appears technologically and commercially ripe for an immediate and expanding contribution.

FUTURE PROSPECTS OF NUCLEAR POWER

Without going into complex comparative analyses of electricity generation costs, which depend on the ground rules chosen and will therefore vary widely from country to country, the following major points may be made:

(i) In spite of sharp increases in the investment costs of both nuclear and conventional stations which have taken place over the last few years, usually as a result of increasingly numerous and stringent environmental standards, nuclear power plants of 900 MWe and larger capacities continue to enjoy a clear competitive advantage over electric stations depending on imported oil.

(ii) With regard to the competition between nuclear and coal-fired plants, the situation may be more complex and depends on the production and transportation costs. However, for a majority of industrial countries, nuclear stations continue to show an economic advantage in large sizes even at relatively low present coal prices.

(iii) As to the future, it seems very likely that both oil and coal prices will increase in real terms faster than those of uranium and of nuclear fuel services.

It may be argued that, while the present situation is perhaps favourable, little is known about the future. An analysis of possible changes in the main factors, however, does not affect in any way the case for nuclear power.

The present state of uranium resources with 2 million tons of reasonably assured and another 2 million tons of estimated additional reserves amply covers the needs of the maximum nuclear power programmes up to the year 2000. Of course, new discoveries are essential for maintaining forward reserves and meeting the lifetime requirements of those nuclear stations which will be operating beyond the turn of the century. However, the present price levels have brought about a major prospecting effort whose first results are rather encouraging. The search for uranium which had been limited to low-cost deposits in selected countries, has left wide areas of the world untouched, for instance in Latin America and South East Asia. Hence, there is no reason to believe that uranium prices could rise faster than oil prices.

Regarding the other sectors of the nuclear fuel cycle, neither the cost of enrichment, where several new processes will be competing with gas diffusion, nor that of fabrication are expected to rise faster than the general price level of industrial goods. Finally, while it is difficult to pinpoint the net benefit or cost of reprocessing and recycling, its influence on total nuclear generating costs can hardly be expected to be significant.

Naturally, in the longer run, increasingly costly uranium ores would have to be mined if today's power plants, which use less than 1% of the potential energy obtainable from a unit mass of uranium were to remain the main basis of expanding nuclear power programmes. However, the efforts presently being applied to the development of commercial breeder reactors in major industrial countries provide a solid foundation for a nuclear sector whose fuel resources would become practically unlimited. This would result from both a hundred-fold increase in the energy which could be derived from known uranium resources, and the economic possibility of mining much poorer uranium ores.

Consequently, the sharp drop in orders for new nuclear stations which occurred during the years 1975–1978, immediately following the oil crisis, can not be explained in economic terms (see Table 8). Nor can the explanation be found in technical difficulties, for despite the Harrisburg accident and its wide publicity, nuclear power plants have an operational record quite comparable to that of new coal-fired stations and a safety record unequalled by any other alternative for electricity production.

Under these conditions, explanations for the present slowdown have to be sought in human and political factors which have led to an accumulation of uncertainties affecting every phase of the construction and operation of nuclear power plants. Even greater uncertainties beset the nuclear fuel cycle and more especially the fate of irradiated fuel. As a result, decisions

Table 8. Orders for nuclear power reactors

	No. of units	MWe
1953 to 64	27	7 914
1965	14	7 600
1966	23	17 485
1967	33	26 814
1968	18	15 273
1969	19	14 899
1970	29	25 699
1971	30	28 713
1972	49	47 344
1973	44	47 818
1974	52	53 374
1975	32	32 238
1976	20	21 700
1977	12	13 600
1978	9	8 700

which clearly have nothing to do with economic considerations have been taken in some countries to the extent that in one case at least, a plant already built and paid for has not been permitted to operate.

The causes of the rise in opposition to nuclear power are not the subject of this report. It is to be hoped however, that a growing realization of the increasing shortage of hydrocarbon supplies and a more impartial approach to comparative risk analysis will lead to a greater degree of rationality being applied in the assessment of nuclear power.

CONCLUSIONS

Forecasts of nuclear capacity must be based on existing construction plans for the short term and on stated and constantly revised national objectives for the longer term. The latest exercise in this area has just been completed within the International Nuclear Fuel Cycle Evaluation; the projections of nuclear capacity for the years 1985 and 2000 contained in Tables 3, 4 and 5 are partially based on its results.

It will be seen that by the end of the century, nuclear power is expected to account for 26–35% of total electricity production and for 12–16% of total primary energy. While these objectives may appear relatively modest in comparison with earlier projections their achievement would nevertheless bring about a substantial alleviation of pressure on hydrocarbon resources. Production of nuclear electricity at these levels would represent the equivalent of 1.5 billion tons of oil in the lower case, and of 2.4 billion tons of oil in the higher, as compared to a 1978 world oil production of about 3 billion tons.

Even more important is the maintenance of a viable nuclear industry at a level of operation which could ensure the continuous expansion of this source of power. The presence of such a viable industry, along with the progressive introduction of more advanced nuclear power systems, would provide mankind with a source of energy depending more on human than on natural resources.