Worldwide nuclear power status and trends

Nuclear's contribution to electricity supply is growing

by Leonard L. Bennett and Robert Skjoeldebrand

During 1985, the total installed nuclear power capacity in the world increased by 14%, with 32 new nuclear power units having a total capacity of 30 gigawatts-electric (GWe) being connected to grids. At the end of 1985 there were 374 nuclear power plants, with a total capacity of just under 250 GWe, in operation in the world. In energy terms, nuclear power plants generated about 1400 terawatt-hours of electricity during 1985, an increase of 19% over 1984, and accounted for about 15% of the world's electricity generation during 1985.*

How large a contribution is this? The electricity produced by nuclear power plants worldwide during 1985 is of the same order as the total electricity generated in the 10 Member States of the European Economic Community in this year. Another way to look at the present situation is to recall that the 1400 terawatt-hours produced by nuclear power in 1985 was the level of *total* electricity production in the world in 1954. This corresponds to the use of 570 million tons of coal. For Western Europe, the nuclear generation in 1985 of 551 terawatt-hours equalled the total electricity production in 1960.

Nuclear shares of electricity

The nuclear share in electricity generation varies greatly from country to country, and also from region to region in some countries (for example, USA). As shown in the accompanying map, there were 19 countries in which nuclear power plants contributed 10% or more of the total electricity production during 1985. In countries belonging to the Organisation for Economic Co-operation and Development (OECD), around 20.4% of the total electricity generated in 1985 was produced by nuclear plants.

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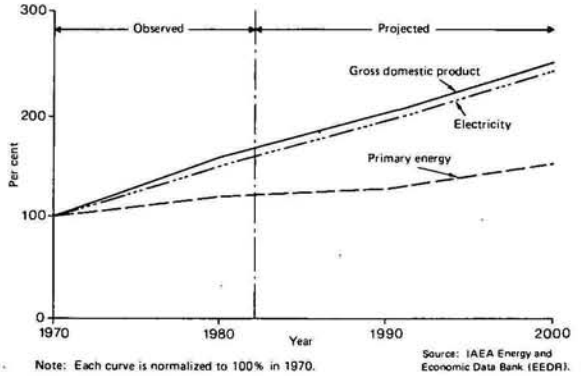
* A gigawatt is 10^9 watts; a terawatt is 10^{12}.

It is worth noting that while the contribution of nuclear plants to electricity in Canada was 12.7% in 1985, it was 42% in the province of Ontario. Also, although nuclear contributed 15.5% of the overall electricity produced in the USA, it was over 50% in six of the country's states. (See map and table on page 44.)

The present rapid increase in the contribution by nuclear power to the world's energy supply is a result of orders placed in the 1970s, which would also maintain the nuclear power growth for a few years. If this growth is maintained, the worldwide nuclear power capacity is expected to be around 370 GWe by 1990, with a contribution of 20% to the world's electrical energy supply, unless there are cancellations or slowdowns of planned projects.

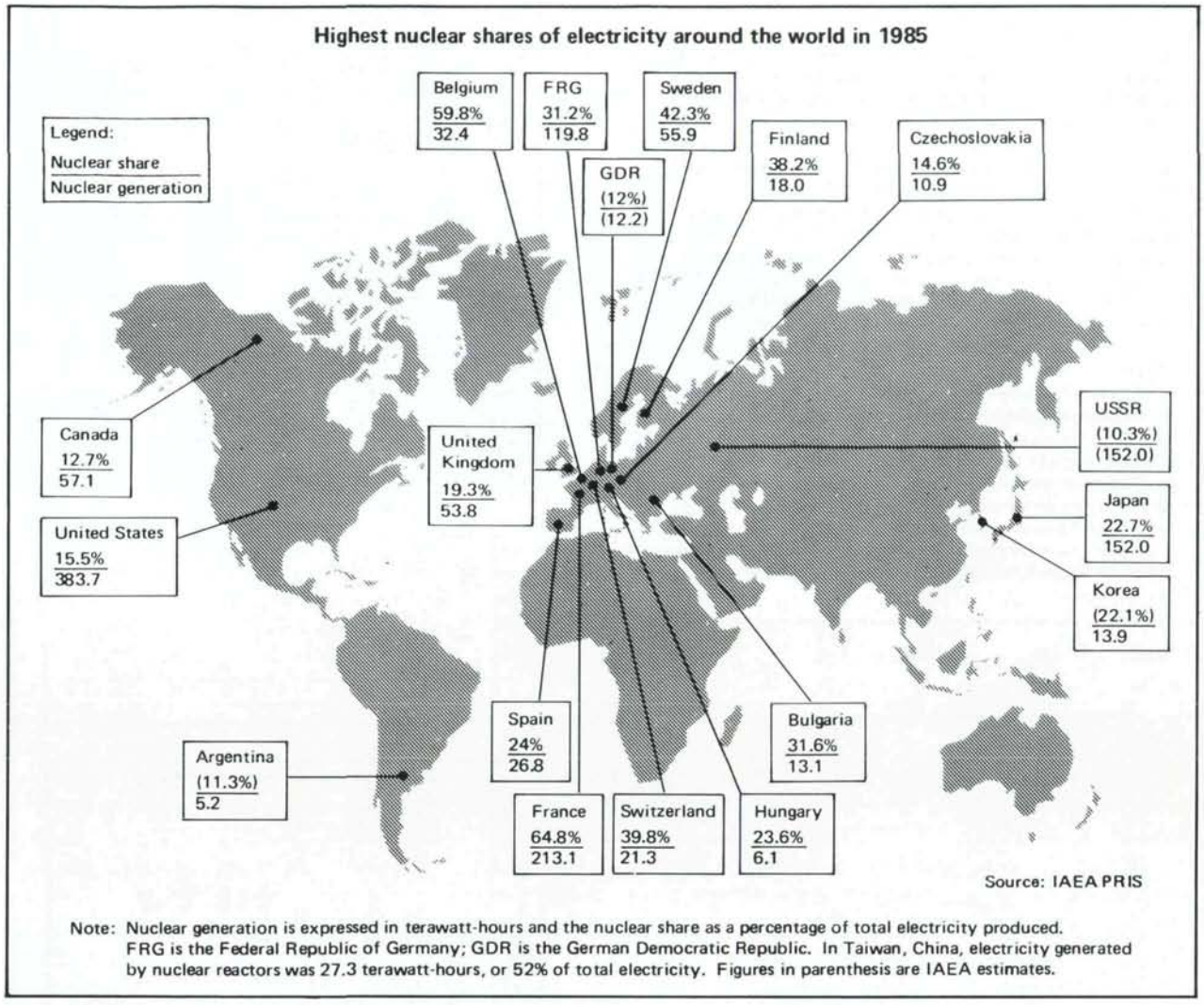
National plans and objectives will certainly be subject to re-examination and debates following the reactor accident at the Chernobyl plant in the USSR. Notwithstanding this accident, there remain energy demand and economic factors which should favour the continued expansion of nuclear power through the 1990s and into the next century. Some of these factors and trends are discussed in following sections.

Economic and energy trends in OECD countries



Note: Each curve is normalized to 100% in 1970.

Source: IAEA Energy and Economic Data Bank (EEDB).



Note: Nuclear generation is expressed in terawatt-hours and the nuclear share as a percentage of total electricity produced. FRG is the Federal Republic of Germany; GDR is the German Democratic Republic. In Taiwan, China, electricity generated by nuclear reactors was 27.3 terawatt-hours, or 52% of total electricity. Figures in parenthesis are IAEA estimates.

Energy supply patterns

In industrialized market-economy countries, there is now a significant decoupling of primary energy consumption from the gross domestic product (GDP). However, there are clear indications of the importance of electricity in energy conservation through its higher efficiency in end use, which in practice has meant a close coupling of electricity demand with GDP. In the OECD countries GDP increased by 27% between 1974-84. This was accompanied by a small decrease of total primary energy consumption but an increase of 30% in electric energy consumption. That means that the primary energy saving has been achieved through a shift in end use, in particular from oil to electric energy. This trend is expected to continue through the 1990s.

For individual countries the results have been even more striking. In 1974 France depended on imports for 84% of its energy supply. In 1985 this had decreased to 64%; electricity corresponded to 38% of the primary energy supply with nuclear contributing almost 65%. The importance attached to nuclear power in France is well known, also in stabilizing the electric energy prices at one of the lowest levels in Europe and thus serving as a motor for national development, besides making possible the decrease in energy imports. (See a related article in this edition.)

Generating capacity and reserves

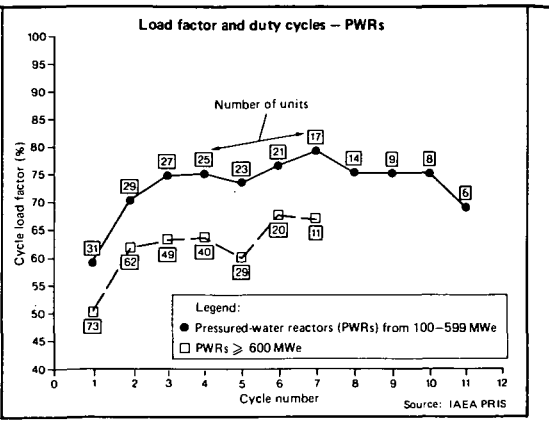
References are often made to the large generating capacity reserves which are said to exist now in the OECD countries. In a study published in 1985 the International Energy Agency (IEA) in Paris warned that this reserve could disappear quickly in many OECD countries in the 1990s and that there may be capacity shortages even before 1995. The reasons are that many of the plants in the present reserve are oil-fired and many are

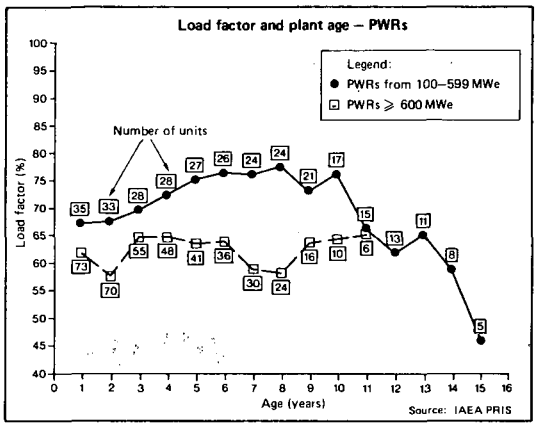
Performance and plant age

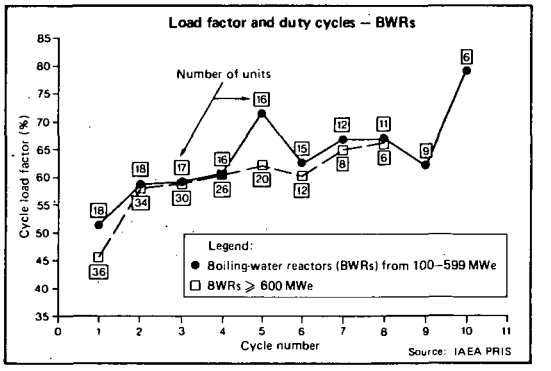
In the IAEA report *Nuclear power status and trends: 1985 Edition,* it was shown that the classical presentation of the load factor as a function of the calendar year age of the plant has been very misleading. In particular, the calendar year display has not shown the maturity effect of improving performance after an initial "shakedown" period which is a normal characteristic in the operation of complex plants, as shown in the accompanying figure.

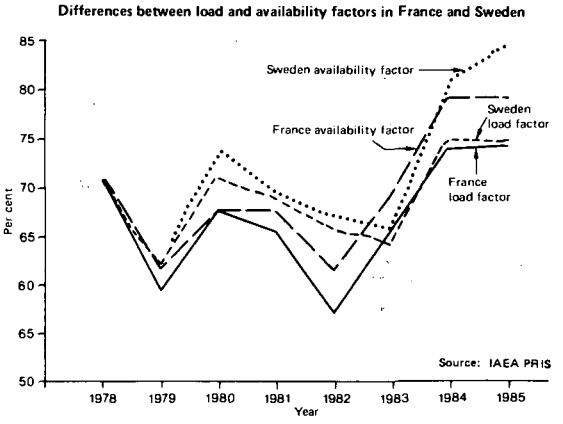
A nuclear power plant operator would use the duty cycle of the plant, defined as the period from the start-up after a planned refuelling and maintenance outage up to the end of the next such shutdown. If the duty cycle is used instead of the calendar year age, the normal maturity effect appears clearly, as the figures show. The reason is to be found in the present shift from 12 months' duty cycles to longer ones for an increasing number of plants.

In connection with the current discussions about determining the lifetimes and extensions of nuclear power plants, the declining part of the curve (for small pressurized-water reactors from 10 years of age or from the tenth duty cycle) has been a cause for concern. A study is being initiated to determine the reasons for this decline and whether it is technically significant, especially as it does not appear for boiling-water reactors. At the same time, the logical change from load factor to availability factor as a performance measure will be made.









also old and obsolete. Thus, it can be expected that at least some of these countries will need to further expand their nuclear power capacity during the 1990s.

In the countries of the Council for Mutual Economic Assistance (CMEA) in Eastern Europe, nuclear power now contributes about 10% of the electric energy, and the programmes for installing new nuclear plants continue to be increasing in importance. It is notable that in the latest Party Congress of the USSR, plans were announced to add about 40 000 MWe nuclear capacity to the existing 28 000 MWe until 1990.

The accident at the Chernobyl nuclear power station in the USSR will no doubt cause the nuclear industries in all countries to look for ways to further guarantee the safety and reliability of nuclear power stations. However, it is noteworthy that the USSR authorities have stated the accident will not affect the implementation of nuclear power development plans in the Soviet Union. Also, the seven Heads of State or Government that met in May 1986 in Tokyo similarly stated their conviction that properly managed nuclear power is and will continue to be an increasingly widely used source of energy.* About 15% of the world's electricity is today produced by nuclear power plants, and both the USSR authorities and these other world leaders are of the view that it will remain an important energy source.

* Countries represented were Canada, France, Federal Republic of Germany, Italy, Japan, UK, and USA.

Nuclear plant availability factors by country (in per cent)

	1977	1978	1979	1980	1981	1982	1983	1984	1985
Argentina	51.9	96.9	85.3	74.1	90.2	59.8	80.3	98.7	93.2
Belgium	77.6	81.9	74.2	81.5	83.9	82.0	77.7	86.8	87.4
Bulgaria	76.6	78.4	80.2	79.6	82.0	87.2	89.7	88.1	89.8
Canada	87.3	79.5	81.2	83.7	90.2	86.9	86.3	76.5	70.4
Czechoslovakia				73.9	65.9	77.8	82.0	83.9	72.2
Finland		79.0	81.8	60.3	81.3	83.5	86.9	90.3	90.1
France	73.4	70.2	64.5	66.4	65.0	62.2	70.3	80.1	77.9
Germany, Federal Republic of	65.0	59.4	57.1	61.0	67.9	69.4	71.7	81.0	85.4
Japan	38.1	51.7	48.6	61.4	60.5	68.3	70.1	71.1	72.5
Sweden	58.7	70.6	62.2	73.3	72.3	67.3	72.4	81.1	84.7
Switzerland	86.6	89.3	87.7	80.0	84.6	84.4	87.1	89.4	84.2

Source: IAEA PRIS.

Nuclear plant availability factors by utility (in per cent)

	1977	1978	1979	1980	1981	1982	1983	1984	1985
BG&E (USA)	69	69.9	68.1	76.3	79.9	71.8	80.9	79.8	69.0
BKW (Switzerland)	86.7	88.0	88.3	88.5	89.5	93.3	89.8	88.3	88.2
EBES (Belgium)	78.2	79.2	81.4	81.9	83.6	83.3	78.2	84.1	92.8
INTERCOM (Belgium)	77.1	83.8	67.7	80.8	84.2	80.9	76.7	85.1	82.3
NOK (Switzerland)	86.6	90.0	87.4	84.7	87.1	86.3	87.3	88.8	85.8
NSP (USA)	81.8	85.4	85.3	74.2	75.6	76.2	87.8	62.2	85.9
OH (Canada)	87.3	79.5	81.2	83.9	90.2	86.9	86.3	74.9	68.4
OKG (Sweden)	66.8	77.7	73.5	82.7	76.0	81.3	84.5	87.4	80.3
SYDKRAFT (Sweden)	54.2	77.6	61.9	76.1	82.3	89.4	81.8	81.7	95.7

BG&E = Baltimore Gas & Electric
BKW = Bernische Kraftwerke AG
EBES = Sociétés réunies d'énergie du bassin de l'Escaut SA
INTERCOM = Société intercommunale belge de gas et d'électricité
NOK = Nordostschweizerische Kraftwerke AG
NSP = Northern States Power
OH = Ontario Hydro
OKG = Oskarshamnsverkets Kraftgrupp AB
SYDKRAFT = Sydsvenska Kraftaktiebolaget

Nuclear power in developing countries

In developing countries, the introduction of nuclear power has been slower than expected. In these countries, there are only 21 nuclear units in operation and 18 units under construction, and about half of these are in only two countries, namely India and the Republic of Korea. Electrification is, of course, at a much lower level in the developing world, but a rapid increase in installed electric generating capacity must be expected. The importance of electrical energy in these countries is particularly noteworthy as electricity consumption is growing not only faster than primary energy consumption, but also more rapidly than electrical energy consumption in the industrialized countries. Still, it must be recognized that there are great differences among these countries. Ten developing countries now account for 63% of the total electricity production in the developing world and, significantly, 8 of these have nuclear power programmes.

Reactor construction times

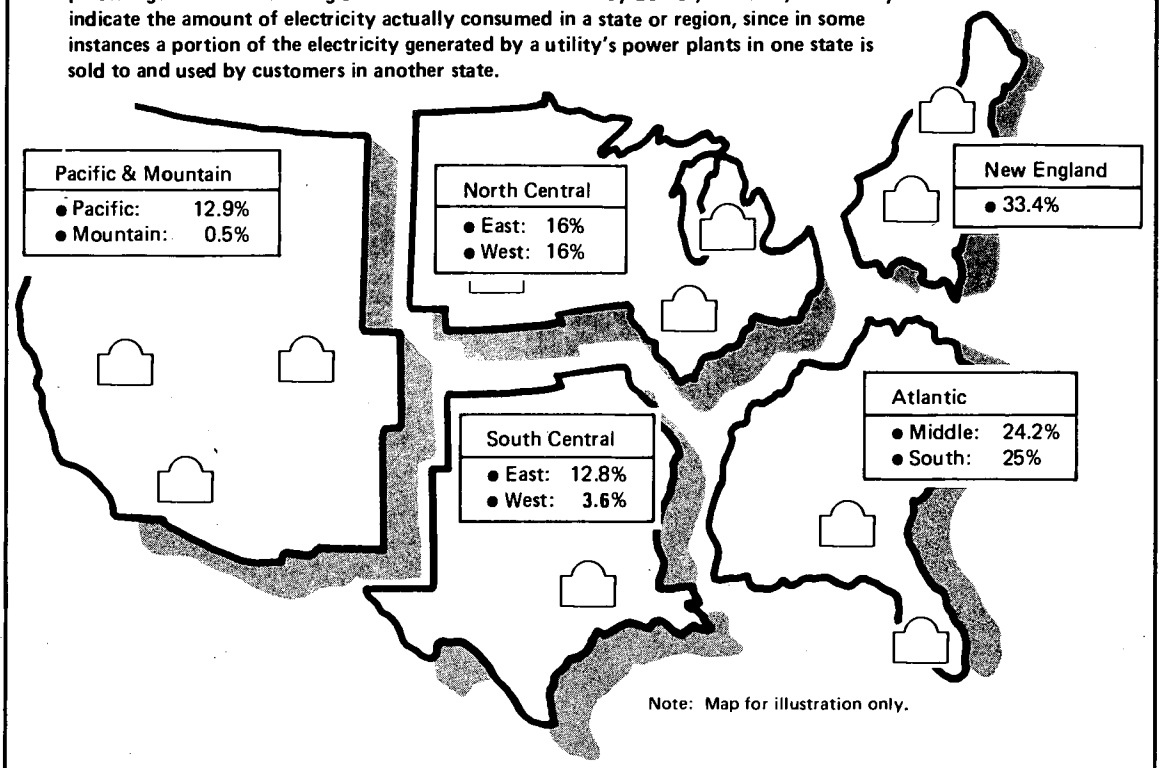
The plant status file in the IAEA Power Reactor Information System (PRIS) can be used to obtain information about the construction time for nuclear power plants, in this case defined as the time period between the first major placement of concrete for the plant and its connection to the grid. There are significant differences between countries in the average construction times and their trends over the past decade, as shown in the table on page 45.

Although the averages show very significant differences, it must also be pointed out that individual projects have been completed in very short times. Between 1980-85, not less than 64 plants were completed in less than 7 years construction time.

The remarkably short construction times achieved in both Japan and Sweden have been explained by very careful project management and new construction techniques, such as shop subassembly on the site and use of

Nuclear power generation in USA: 1985

In the USA, 31 states have nuclear generating capability. The table indicates the amount of electricity generated by nuclear power in 1985 in those states; the map shows the nuclear share by region. Data are expressed as a percentage of the state or region's total kilowatt-hours. They do not, however, necessarily indicate the amount of electricity actually consumed in a state or region, since in some instances a portion of the electricity generated by a utility's power plants in one state is sold to and used by customers in another state.



Note: Map for illustration only.

Nuclear's share of electricity generation by state in the USA

Vermont:	71.7%	Maryland:	30.7%	Alabama:	19.7%	Missouri:	14.0%
South Carolina:	59.4%	Arkansas:	27.8%	Pennsylvania:	19.4%	Georgia:	12.5%
Maine:	58.6%	Wisconsin:	26.7%	Michigan:	18.1%	Washington:	8.6%
Virginia:	53.0%	Nebraska:	25.9%	Massachusetts:	16.9%	Iowa:	8.2%
New Jersey:	51.7%	North Carolina:	25.9%	California:	15.4%	Louisiana:	5.5%
Connecticut:	50.4%	Florida:	24.3%	Tennessee:	14.5%	Arizona:	2.4%
Illinois:	37.7%	Mississippi:	22.6%	Oregon:	14.3%	Ohio:	1.8%
Minnesota:	37.4%	New York:	21.6%	Kansas:	14.0%		

Source: INFO Data, AIF, April 1986

very big cranes in Japan. Some of these construction techniques could also enhance quality assurance in a cost-effective manner.

Nuclear power plant performance

Recent trends in nuclear power plant availability have generally tended to follow those shown in the 1985 IAEA report on nuclear power status and trends, thus also confirming the important general reasons for good performance proposed in that report:

- Degree of standardization in plant design and construction
- Quality assurance standards used
- Regulatory climate
- Competence of the operating organizations.

Average availabilities and trends for the period 1977-85 are shown in the tables (page 43) for countries and utilities which have shown either consistently good or steadily improving performance. The major feature of the data would appear to confirm that where good performance has been achieved in the past it continues, and where improvements have been achieved they also continue.

The apparently declining performance in Canada is partly explained by an average unavailability caused by external reasons — in this case labour strikes and hurricanes — which in 1985 amounted to 4.2%. The other

major factor influencing plant availability was the retubing of the Pickering 1 and 2 units which were down for all of 1985 for this purpose.

Some highlights of achievements are worth pointing out:

- In Belgium an average plant availability of 87.4% was achieved with seven commercial-size plants, two of which entered commercial operation in September 1985.
- Finland maintained its high average availability at 90%. Scheduled shutdowns averaged only 22 days per reactor in 1985.
- France continued with a high country average of 78% availability. The 900-MWe series plants performed particularly well with an availability of 81% in 1985.
- In the Federal Republic of Germany the average availability in 1985 reached 85.4%. This was mainly achieved by reducing planned outages by 3.5% and unplanned outages by 1.5%.
- In Japan, the remarkable improvement has continued to an average availability of 72.5% in spite of the regulatory annual inspection requirements, which mandate a planned unavailability of 26 to 27%. The unplanned unavailability was an average 1.5%. It is notable that some Japanese utilities now are planning to try to cut down the planned annual outage to about 65 days from 90 to 100 days. The scram frequency continued to be very low at 0.2 per reactor year.
- In Sweden availability continued to improve to 84.7%.
- In Korea, KN-2 set a record in 1985 of 214 days continuous full power operation.

Workers on electric power lines. (Credit: EPRI)

Reactor construction times

Country	Year of grid connection: up to 1979		1980 to 1985		from 1986	
	No. of units	Average months	No. of units	Average months	No. of units	Average months
Belgium	3	58	4	86		
Canada	8	72	7	98	7	87
Czechoslovakia	1	56	4	87	11	99
Finland	2	62	2	76		
France	11	63	31	66	19	79
Germany, Federal Republic of	10	63	6	97	6	81
Japan	21	52	11	52	14	69
Korea, Rep. of	1	81	3	73	5	76
Spain	3	50	5	113	2	101
Sweden	6	56	6	81		
Switzerland	4	51	1	124		
USA	63	68	27	127	26	151
USSR	14	69	19	96	31	81

Note: Only non-prototype reactors with capacities greater than or equal to 100 megawatts-electric are considered. Reactors currently planned and under construction are included; not included are reactors that have been shut down. There are 55 reactors where either the construction date or the grid date have not been reported to IAEA.

Source: IAEA PRIS.