Nuclear power development: History and outlook

Events have changed the global prospects for nuclear power

by N.L. Char and B.J. Csik

To trace the history of nuclear power development, one can look back to four decades of effort in a changing world. Much has been done, much has been achieved, and many lessons have been learned. More than 400 nuclear power plants are currently in operation in 26 countries, supplying about 16% of the world's electricity demand, and some 4500 reactor-years of experience have been accumulated. In some countries, nuclear power has become the most important source for electricity. But the progress of nuclear power from an idea to a commercial reality has not been an easy one. It has been full of events, with many successes and also some failures. Unfortunately, the failures make better news for the media and therefore catch the attention of the public. The success stories are seldom publicized.

The 1950s have seen the start of the penetration of nuclear power into the electricity market. It was a period of great enthusiasm, intensive research and development, with hopes for providing the world with a cheap and practically inexhaustible alternative source of energy. The peaceful use of the atom became a symbol of progress and benefit to humanity, and co-operation between nations became a reality on an unprecedented scale. Science, scientific achievements, and scientists were looked upon with favour by the media and highly regarded by the public. By 1960, there were 17 nuclear power reactors in operation with a total electrical capacity of 1200 megawatts (MWe) in four countries: France, the USSR, the United Kingdom, and the United States. Nuclear power programmes had been launched in another six countries.

Early robust growth

During the 1960s nuclear power achieved the status of a technically proven and commercially viable energy source. By the middle of the decade, electric power utilities were placing their orders for nuclear plants on a routine basis, and by 1970 there were already 90 nuclear units operating in 15 countries with a total capacity of 16 500 MWe. The trend of expanding the use of nuclear power continued further during the 1970s. On an average, construction started on some 25 to 30 new nuclear units each year. By 1980 there were 253 operating nuclear power plants with 135 000 MWe total capacity in 22 countries. In addition, some 230 units with more than 200 000 MWe were under construction at that time.

It was the oil price shocks of the 1970s that gave a big boost to the promotion and further development of nuclear power. Energy planners started to accord a much greater role to nuclear power in their quest for suitable substitutes to burning oil and to assure a more diversified energy supply for the world. These plans, however, were often not realistic enough; other factors also tended to affect adversely the development of nuclear power.

The mark of higher oil prices

Rising oil prices also brought an all around price increase in commodities. As a result, the cost of energy from all sources, including nuclear plants, increased very significantly. The economy slowed down everywhere. Energy and electricity demand growth rates consequently decreased, and many countries, especially the highly industrialized ones, found that they needed less generating capacity additions than planned. Energy conservation measures were intensified widely in industrialized countries. This, in turn, had an influence on the overall demand growth rates for electricity. With the accumulation of experience in building and operating nuclear plants on an industrial-commercial scale, various technological problems made their appearance in early prototypes and demonstration nuclear power units. The generic problems that appeared had to be solved and consequently investment costs and construction times for new plants increased significantly. Utilities were often not adequately prepared to face the challenge of managing nuclear projects and operating their nuclear plants, and there were some signs of complacency. Concerns regarding nuclear safety also increased and regulatory requirements became more and more stringent.

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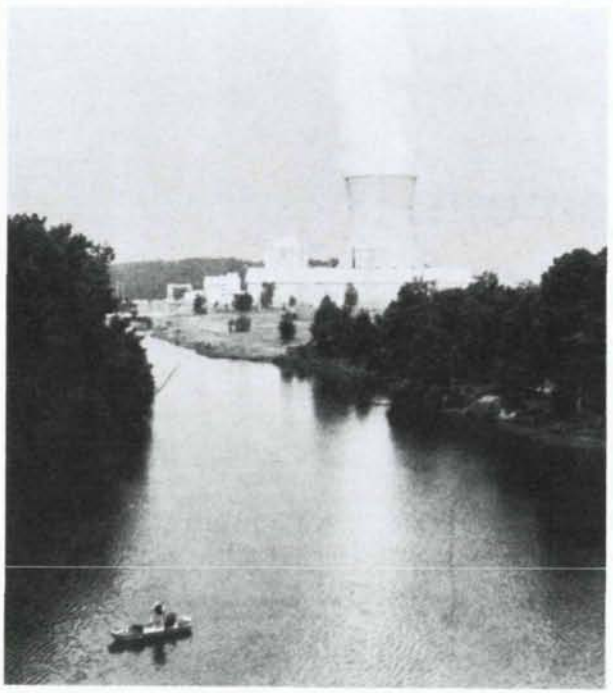


Unit two of the Arkansas Nuclear One power plant in the USA. The intake canal about a half mile from the Arkansas river is a popular fishing spot. The plant provides electricity to about 280 000 customers, and is among more than 100 operating nuclear plants in the USA. (Credit: AIF)

Heightened awareness and concerns

As nuclear power emerged from the rarified atmosphere of the laboratories, as its "scientific" glamour diminished, and as it was transformed during the 1970s into a hard industrial reality, the public became increasingly aware, interested, and concerned. Association with the bomb, destruction, danger, invisible radiation, secrecy, and fear of the unknown added to the disfavour towards nuclear power. Environmental concerns had increased sharply, especially in the highly industrialized countries, and environmentalist organizations blossomed and quickly turned their attention to nuclear power as a suitable target to be attacked. The media, and a part of the public and many politicians gradually developed a sometimes reasoned but mostly emotional opposition to nuclear power in many countries. Public acceptance became a major issue for the promotors of nuclear power. The often quoted "China Syndrome" became a cliché for the anti-nuclear lobbies everywhere. It was then, in 1979, that the first major accident in any nuclear power plant occurred, at the Three Mile Island (TMI) plant in the United States.

This shook up the nuclear industry worldwide. The negative (to nuclear power) trends of the late 1970s were further reinforced, and though installed nuclear capacity kept increasing as plants went into operation, new construction starts became fewer and many projects on order or even under construction were suspended or cancelled.

However, attitudes toward nuclear power differed among countries. Some countries maintained their vigorous programmes, a few countries stopped further expansion in nuclear power, while many others proceeded with a slowed-down programme. The reasons were not only due to safety concerns but to other factors as well, such as financial constraints, reduced demand growth rates, and issues of public and political acceptance. The impact of TMI was not just negative. There was also a positive side to it. The lessons learned undoubtedly resulted in many improvements in the design, construction, and operation of nuclear plants, both with respect to safety and reliability. IAEA took much initiative in enhancing international co-operation in these aspects.

Then followed a period when nuclear power showed signs of good recovery and the statistics improved. At the beginning of 1986, 7 years after the TMI accident, nuclear power plants all over the world had collectively crossed 3500 reactor years of operational experience without a single fatal accident, and the target of 4000

Nuclear power growth: 1951–86

Year	Construction starts		Connections to the grid	
	Units	GWe	Units	GWe
1951	1			
1952				
1953	2	0.1		
1954	6	0.5	1	
1955	3	0.1		
1956	9	0.8	1	0.1
1957	12	1.5	1	0.1
1958	7	0.6	3	0.2
1959	6	0.9	5	0.3
1960	10	1.0	6	0.6
1961	6	1.1	2	0.1
1962	8	1.3	10	1.0
1963	5	1.4	7	0.4
1964	10	3.0	8	1.1
1965	10	3.5	9	1.6
1966	16	7.4	8	1.2
1967	23	15.2	10	2.1
1968	38	26.1	6	1.1
1969	17	12.7	11	3.5
1970	37	24.9	6	3.3
1971	22	16.1	16	7.3
1972	22	19.3	16	8.8
1973	23	18.3	20	12.5
1974	35	29.8	26	16.9
1975	40	38.0	15	10.2
1976	29	27.2	19	14.1
1977	15	14.5	18	13.3
1978	21	18.2	20	15.8
1979	21	19.7	8	7.0
1980	23	21.4	21	15.3
1981	12	11.6	23	20.4
1982	20	19.1	18	14.3
1983	20	14.5	23	19.1
1984	10	9.3	34	31.7
1985	13	9.9	34	31.8
1986	1	0.8	23	23.3

Note: Reactors cancelled or suspended are not considered.
GWe = gigawatts-electric

reactor years was keenly anticipated in the nuclear community to wipe off the memory of the TMI accident.

But once again nuclear power was to receive a cruel blow. On 26 April 1986, the world's worst known disaster in nuclear power plants occurred at Chernobyl, in the Ukraine, with loss of life and much release of radioactivity which crossed national frontiers. The very foundations of nuclear power and its future took a severe jolt. The impact of this accident was strongly felt worldwide and all its consequences are yet to be perceived. More than a year, however, has passed since Chernobyl, and the immediate effects can now be evaluated with at least some historical perspective.*

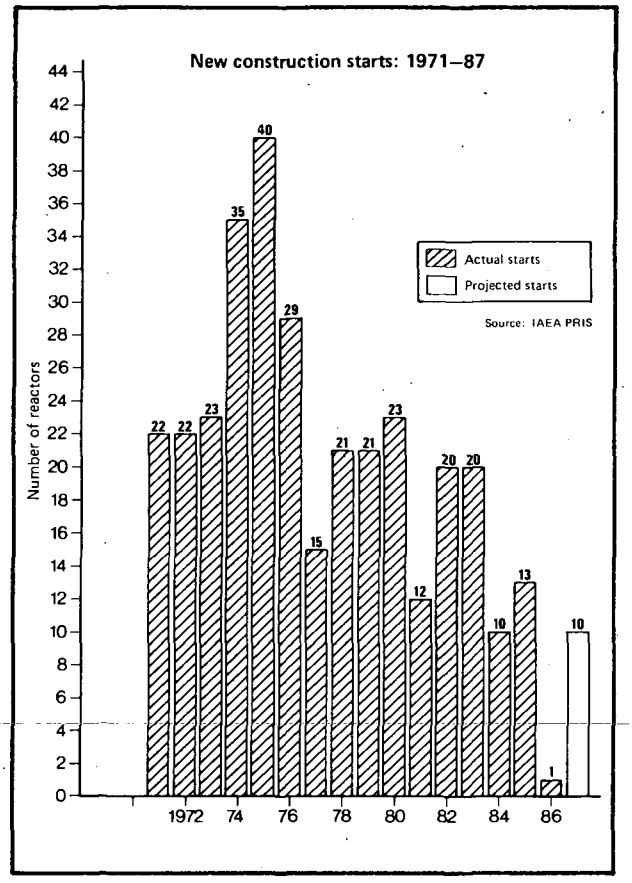
Recent trends

Current trends do provide some indications on what the outlook for nuclear power might be.

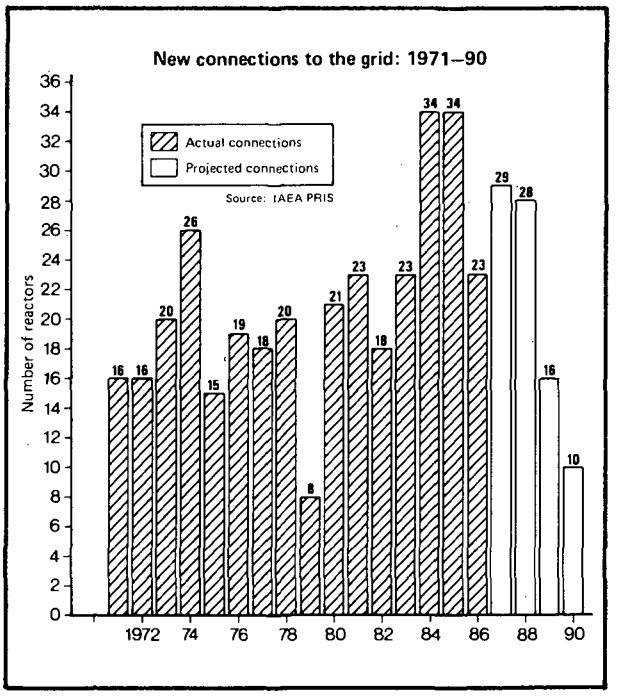
During 1986, 23 reactors with 23 300 MWe were connected to the grid in 8 countries; of these, 15 were connected after April. Connections to the grid in 1987 are proceeding reasonably on schedule. Only three reactors were suspended or cancelled while under construction (one in the Philippines and two in the USA). Except Chernobyl-4, no operating nuclear power plant was shut down. At the end of 1986, there were 133 reactors under construction with 118 000 MWe in 23 countries. There is every indication that the construction of most, if not all, of these plants will effectively proceed to completion. By 1990 a total of 480 units with 350 000 MWe are expected to be in operation. This means a 25% increase of current installed nuclear capacity. In addition, some 50 units will be under construction, without counting new construction starts.

Trends in the nuclear power field also show that emphasis is shifting from design and construction to plant operation. Efforts are certainly being put into improving current nuclear plant designs as well as developing new concepts. There are also efforts underway to streamline construction methods and procedures in order to reduce construction time and investment costs, and to improve quality.

More and more emphasis is being placed on plant operating performance as well. The last few years have seen a constant improvement of performance, a trend that is continuing. Safety, reliability, and quality are the principal aspects where improvements are being promoted and achieved worldwide by the nuclear industry. The Agency is also gradually shifting its emphasis towards the operations area, in line with the needs of the Member States. Activities in plant operations personnel qualification, man-machine interface, quality assurance, and especially operational safety are receiving increased attention.



Not only the number but also the age of the operating nuclear power plants is increasing. During the 1990s the nuclear industry will have to face the alternatives of plant life extension or decommissioning and this is another area that will gradually be receiving greater attention, also within the Agency's programmes.



* See the IAEA's *Nuclear safety review* for 1986 for a fuller discussion of the Chernobyl accident. The review is available for purchase from the IAEA Division of Publications. (See the *Keep abreast* section for ordering information.)

Future role

Regarding the future role of nuclear power, forecasts based on plants in operation and under construction can be made with reasonable accuracy. It can also be assumed that plants once connected to the grid will remain in operation until the end of their lifetimes, with some possible exceptions due to national policy decisions. Sweden is the only country which has a policy in effect of phasing out nuclear power. The question has been raised in a few other European countries, but to date no political decisions had been taken to phase out nuclear power in any of them. Austria is the only country in the world that after starting a nuclear power programme outlawed it, forbidding its only nuclear plant to be put into operation. In the Philippines, construction of the first plant was suspended.

Any forecasts beyond the middle 1990s have to take into account new construction starts, and this is where estimates become speculative. Assumptions have to be made regarding national policy decisions and the development of nuclear power programmes.

Currently, 23 countries have clearly stated intentions to proceed with their ongoing nuclear programmes, including identified projects in various planning stages, nine others may not have firmly defined follow-up projects, but it seems most of them intend to proceed. It is to be noted that 19 countries produce more than 10% of their electricity with nuclear plants; of these 12 produce more than 20%, with 3 countries at the top producing more than 50%. In addition to the countries which already have nuclear power programmes, some 15 other countries have stated the intention to go nuclear. All are actively engaged in planning studies,

Estimates of total and nuclear electrical generating capacity

	1986			Low and high estimates 1990			1995			2000		
	Total	Nuclear		Total	Nuclear		Total	Nuclear		Total	Nuclear	
	GWe	GWe	%	GWe	GWe	%	GWe	GWe	%	GWe	GWe	%
North America	801	95.8	12.0	881	117	13	970	123	13	1062	131	12
				943	117	12	1075	132	12	1188	148	12
Western Europe*	530	101.4	19.1	556	122	22	608	134	22	666	153	23
				590	122	21	660	160	24	721	190	26
Industrialized Pacific	216	25.8	12.0	233	31	13	262	40	15	297	54	18
				253	31	12	293	49	17	330	70	21
Eastern Europe	459	35.6	7.8	535	61	12	631	84	13	725	108	15
				556	61	11	682	111	16	806	150	19
Asia	243	11.6	4.8	310	14	4.6	403	19	4.7	499	27	5.4
				324	14	4.4	451	20	4.4	604	33	5.4
Latin America	136	1.6	1.1	175	2.2	1.3	230	5.6	2.4	289	7.5	2.6
				181	2.2	1.2	252	5.6	2.2	341	9.1	2.7
Africa and Middle East	112	1.8	1.6	144	1.8	1.3	184	1.8	1.0	223	1.8	0.8
				150	1.8	1.2	209	3.0	1.5	279	3.9	1.4
World total	2497	273.7	11.0	2834	350	12	3288	407	12	3760	482	13
				2996	350	12	3621	481	13	4269	604	14
Industrialized countries	1904	254.3	13.4	2086	322	15	2332	366	16	2595	423	16
				2218	322	15	2561	434	17	2873	527	18
Developing countries												
• In CPE-Europe**	88	5.7	6.4	104	11	10	124	16	13	140	24	17
				107	11	10	132	18	14	156	28	18
• Others	505	13.8	2.7	644	17	2.6	833	25	3.0	1025	36	3.5
				670	17	2.5	927	28	3.1	1238	48	3.9
• Total	593	19.4	3.3	749	27	3.7	956	41	4.3	1165	60	5.1
				777	27	3.5	1059	47	4.4	1395	76	5.5

* Nuclear programme in Austria has been interrupted, and the reactor is not included.

** Developing countries in the Centrally Planned Economies (CPE) in Europe: Albania, Bulgaria, Czechoslovakia, Hungary.

Note: High figures were estimated by taking the total capacity of all plants in operation plus those under construction with announced grid connection dates not later than December 1990. Low figures were estimated by IAEA using the following procedure. An average construction time for plants already in operation was computed for each country (Source: IAEA PRIS). For every plant under construction, the average construction time was added to the actual construction start date to obtain estimated completion date. Plants for which the estimated completion date, obtained by this procedure, is later than December 1990 were not included in the low capacity estimates for 1990.

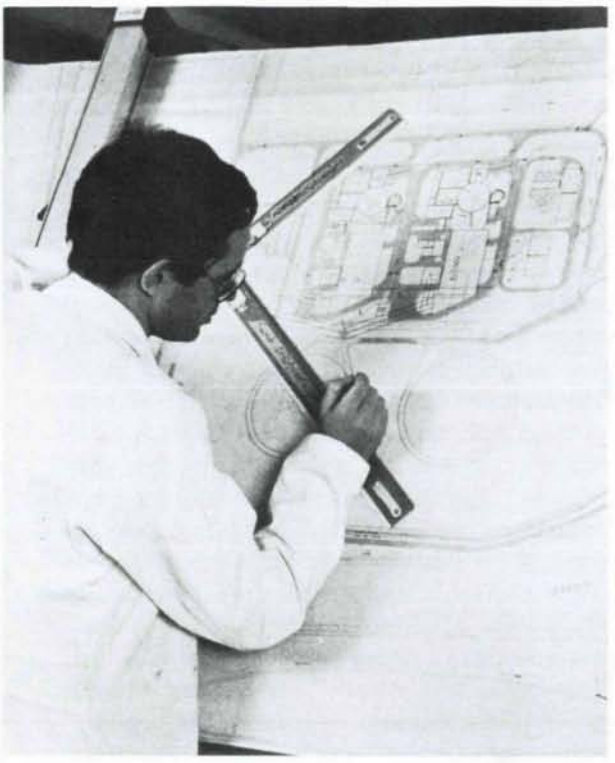
with some of them at an advanced stage of negotiating the acquisition of their first units.

The assessment of national plans and intentions to either proceed with ongoing nuclear power programmes or to go nuclear provides grounds for an optimistic view of the future of nuclear power. However, it must also be taken into account that during 1986 construction was started on only one plant (Japan, Ikata-3). Also, it seems that though 10 construction starts were scheduled for 1987, some of them might be delayed. Experience has shown that programmes have been slowed down, that projects tend to be delayed, and that some countries find it very difficult to effectively launch their nuclear power programmes even though their firm intention to do so is maintained unchanged year after year.

Forecasters of nuclear power development have become very cautious during the last years as reality obstinately refused to follow their predictions. Currently, the IAEA's forecast for the year 2000 is 480 000 to 600 000 MWe of installed nuclear capacity (low and high estimates). This means 90 000 to 120 000 MWe of new construction starts during the next 5 to 7 years in some 35 to 40 countries. An average of 20 000 to 30 000 MWe to start construction each year does not seem to be excessive; this figure is based on individual country programmes and plans, and there certainly is adequate manufacturing capability available to handle the number of projects involved.

The forecast does imply faith in the gradual recuperation of the nuclear industry from the negative effects of the recent past, and a reversal of the trend of diminishing new construction starts. This faith in nuclear power is not an expression of what one would like to happen, it is based on the objective assessment of a series of factors.

Experience also has shown that the aftereffects of accidents do not last forever; reasonable and responsible attitudes tend to prevail. Energy and electricity demand keeps growing, as does the recognition that conservation measures and "new and renewable" energy sources have only a limited role to play. Nuclear power has retained its economically competitive status, and plant performance is steadily improving all over the world.



To help meet projected electricity demand, many countries intend to pursue the nuclear power option. (Credit: French Nuclear Newsletter)

Nuclear power has been called a "mature" technology in the past, perhaps somewhat prematurely, but now it does seem to merit this adjective. It does constitute a viable alternative energy source and the efforts that are being expended on national levels and through international co-operation do provide reasonable assurance that nuclear power will retain its viability.

The Agency constitutes a channel through which international co-operation has been promoted and effectively implemented during three decades. This channel is open and will continue to remain so in the future.

Services for safety evaluation

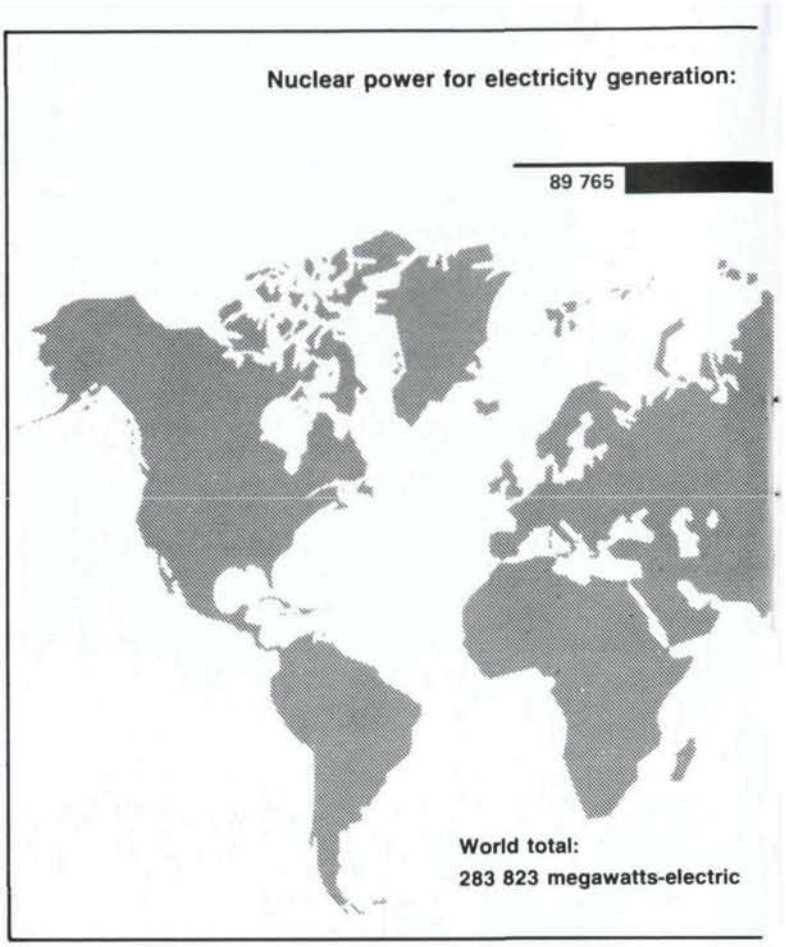
As the only worldwide intergovernmental nuclear energy organization, the IAEA is in a unique position to examine and advise on current and evolving safety issues that could have an international impact. From the very beginning, strict safety standards have provided a basis for the overall good safety record of nuclear power plants. The IAEA's Basic Safety Standards (BSS) for radiation protection and the Nuclear Safety Standards (NUSS) for nuclear power plants have been adopted entirely or in part by many Member States as the basis for national regulations. They are also mandatory for projects receiving Agency assistance. The Agency's authority is also recognized in the area of radioactive waste transportation. Its *Regulations for the Safe Transport of Radioactive Materials* have served as standards contributing to a strong safety record in this field. They have been adopted not only by national governments, but also by international organizations concerned with transports, such as the International Civil Aviation Organization (ICAO) and International Maritime Organization (IMO).

Since the early 1980s, the IAEA has strengthened its safety evaluation services for nuclear plant operations, radiological protection, and radioactive waste management in response to the needs of Member States and international developments. Five specific programmes have been launched:

- ***IAEA-IRS:*** This Incident Reporting System provides an exchange of nuclear plant operations experience in Member States on safety-related issues, to draw out the lessons learned, and to disseminate information among participants. Regular meetings for in-depth discussions of particular events are held involving participation from the Council for Mutual Economic Assistance (CMEA), Nuclear Energy Agency of the Organization for Economic Co-operation and Development (NEA/OECD), and developing countries.

- ***OSART:*** These Operational Safety Review Teams conduct on-site missions to a nuclear plant upon the request of the Member State. Typically, about 10 specialists visit a plant for 3 weeks to review various aspects of plant operation and to assist the national authorities in assessing the plant's safety practices against other successful ones.

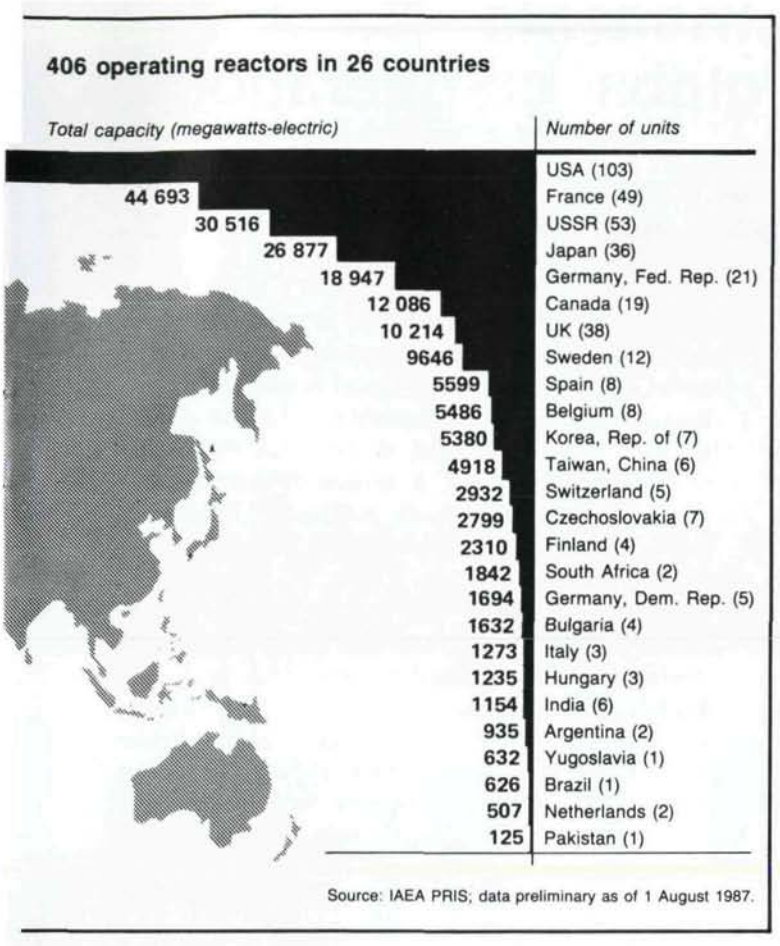
- ***ASSET:*** IAEA recently initiated this new service — Assessment of Safety Significant Events Teams — to provide plant operators and regulators with independent analysis and guidance regarding specific events that have occurred, their causes and safety implications, and corrective actions that were taken for operational safety.



IAEA advisory missions in nuclear plant safety, radiation

	OSART	RAPAT	ASSET	WAMAP
Brazil	1985			
Bulgaria				1987
Canada	1987			
Chile		1985		
China		1984		
Colombia		1987		
Dominican Republic		1986		
Ecuador		1986		
Egypt		1986		
Finland	1986			
France	1985			
Germany, Fed. Rep. of	1986, 1987			
Greece		*1987*		
Hungary	*1988*			1987
Iceland		1986		
Iraq		1984		
Italy	1987			
Jordan		*1987*		

Notes: Missions are done at the request of the Member State. Years in italic denote planned or proposed missions. The missions listed here under these programmes are in addition to other ongoing IAEA activities in these fields.



protection, and radioactive waste management

	OSART	RAPAT	ASSET	WAMAP
Kenya		1986		
Korea, Rep. of	1983, 1986	1987		
Malaysia		1985		
Mexico	1986, 1987	1986		
Netherlands	1986, 1987			
Nicaragua		1985		
Pakistan	1985			
Panama		1986		
Peru		1987		
Philippines	1985	1987		
Poland				*1987*
Portugal		1986		*1987*
Spain	*1987*			
Sudan		1987		
Sweden	1986			
Syrian Arab Republic		*1987*		
Tanzania		1987		
Turkey		1985		*1987*
United States	1987			
Venezuela		1986		
Yugoslavia	1984		1986	
Zaire		1986		
Zambia		1986		

● ***RAPAT:*** The need in developing countries for stronger radiation protection programmes led to the creation of Radiation Protection Advisory Teams in 1984. Teams visit a Member State upon request to assess radiation protection programmes and activities relative to all uses of radioactive material, identify specific needs and priorities, and to suggest practical long-term actions in training and other areas. Team expertise includes IAEA staff and participants from the World Health Organization (WHO) and the International Commission on Radiological Protection (ICRP).

● ***WAMAP:*** To complement its ongoing activities in the field and to extend the range of its technical assistance and services, the IAEA initiated a Waste Management Advisory Programme in 1987. These teams of three to four highly qualified experts from the Agency and its Member States visit developing countries on request to review and evaluate national activities. Their emphasis is on promoting practical approaches to the integrated development of safe radioactive waste management systems.

Requests from Member States for many of these services have increased markedly since the accident of Chernobyl in 1986. More complete reports on nuclear power and safety will be featured in the forthcoming edition of the ***IAEA Bulletin*** (Vol. 29, No. 4). The edition will include a special report on the IAEA's International Conference on Nuclear Power Performance and Safety, scheduled for 28 September to 3 October 1987 in Vienna. More than 600 participants are expected.

Nuclear plant incident reporting system (IAEA-IRS)

Participants:	*Since:*
Argentina	May 1983
Brazil	November 1983
Bulgaria	February 1983
Czechoslovakia	January 1985
Finland	May 1983
German Dem. Rep.	January 1984
Hungary	October 1984
India	June 1984
Korea, Rep. of	February 1983
Netherlands	June 1983
Pakistan	August 1984
Spain	January 1983
United Kingdom	March 1986
USSR	September 1984
Yugoslavia	May 1986
Participants through the NEA/OECD:	
Belgium	February 1983
France	June 1983
Germany, Fed. Rep.	July 1983
Italy	March 1985
Sweden	October 1983
United States	August 1985
Canada	July 1986
Reporting and meeting participants:	
Japan	
Switzerland	