The Outlook for Nuclear Power after Chernobyl

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Abstract
In light of the accident at the Chernobyl nuclear power station, 1986 represents a critical year for nuclear power programmes. The leaders of a large number of countries have declared their continued intention to rely on nuclear power, but some countries have decided to defer any decision on expansion of their nuclear power programmes (e.g. Finland and the Netherlands), or have reaffirmed earlier decisions to stop (e.g. Austria) or phase out (e.g. Sweden) nuclear power altogether. This paper reviews the nuclear power programmes in a number of countries, and gives an overview of the current status and future prospects of nuclear power for electricity generation in the world, with particular emphasis to developing countries. The paper also presents economic comparisons of nuclear and coal-fired stations, since the competitiveness of nuclear power is an important factor in nuclear power development. As reported by a recent NEA study, nuclear power has an economic advantage over coal for base-load electricity generation in many countries, except in situations where low-cost coal is readily available close to load centers. Conditions for nuclear power could be less favorable in countries with extensive infrastructure and technology transfer requirements if those additional investments are charged against the nuclear electricity generation costs. Finally, the paper presents projections of future nuclear electrical generating capacity. In the developing countries some 600–800 GW(e) of generating capacity will need to be added up to the year 2000. However, the IAEA estimates that only some 5% of these capacity additions would likely be with nuclear power plants. It is expected that by the year 2000 nuclear energy may supply about 20% of the world's electricity requirements (25% of requirements in industrialized countries; 10% of requirements in developing countries).

Résumé
Du fait de l'accident survenu à la centrale nucléaire de Tchernobyl, 1986 a été une année critique pour les programmes électronucléaires. Les dirigeants de nombreux pays ont fait part de leur intention de continuer à recourir à l'énergie d'origine nucléaire, mais certains Etats ont décidé de reporter toute décision relative à l'extension de leurs programmes électronucléaires (cas de la Finlande et des Pays-Bas) ou ont confirmé celle qu'ils avaient prise antérieurement de ne pas recourir au nucléaire (comme l'Autriche), ou d'y renoncer progressivement (comme la Suède). Le présent mémoire passe en revue les programmes électronucléaires mis en oeuvre dans un certain nombre de pays et donne un aperçu de la situation actuelle et des perspectives d'avenir de l'électronucléaire dans le monde, et notamment dans les pays en développement. Il établit en outre des comparaisons d'ordre économique entre les centrales nucléaires et les centrales au charbon, étant donné que la compétitivité de l'électronucléaire est un facteur important de son développement. Ainsi qu'il est indiqué dans une récente étude de l'AEN, le nucléaire est plus avantageux du point de vue économique que le charbon pour produire l'électricité servant à assurer la charge de base dans de nombreux pays, sauf dans les cas où l'on peut facilement obtenir du charbon bon marché à proximité des centres de base. La situation pourrait être moins favorable au nucléaire dans les pays ayant d'importants besoins en matière d'infrastructures et de transfert de technologie si les investissements supplémentaires requis sont englobés dans les coûts de production de l'électricité d'origine nucléaire. Enfin, le mémoire contient des projections concernant la capacité de production électronucléaire. Les pays en développement devront se doter de quelque 600 à 800 GWe supplémentaires de puissance installée d'ici à l'an 2000. Cependant, l'AIEA estime que les centrales nucléaires ne représenteront probablement qu'environ 5% de ces capacités. On prévoit que d'ici à l'an 2000 l'énergie électronucléaire couvrira environ 20% de la demande mondiale d'électricité (25% dans les pays industrialisés et 10% dans les pays en développement).

Current Status

The most significant event in nuclear power during 1986 was the Chernobyl accident. The overall effects of this accident on the nuclear power programmes of member states have yet to be seen, but it has not caused the cancellation of any nuclear power programme. The accident produced an immediate upsurge

Keywords: nuclear power, nuclear forecasts, energy demand, economics, costs, risks, Chernobyl.

Table 1: Connections to Grids during 1986

Country	*Number of units*	*Net capacity (MW(e))*
France	6	7,215
USA	6	7,034
Germany, Fed. Rep. of	2	2,534
Japan	2	2,182
Korea, Rep. of	2	1,800
Canada	2	1,353
Czechoslovakia	2	776
Hungary	1	410
Totals	23	23,304

in public and political concerns about nuclear power in many countries. However, a more accurate image of the accident is now becoming visible, and shows an accident comparable to some other grave industrial accidents, rather than an accident of unprecedented magnitude, as it was generally portrayed in media accounts in the period immediately after the accident.

With the significant exception of Chernobyl Unit 4, 1986 was another year of safe, reliable and economic operation for nuclear power plants.

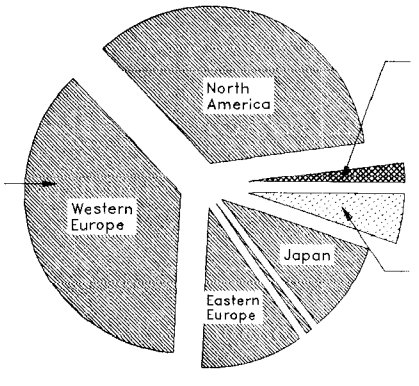
During 1986, total installed nuclear capacity increased by about 10%, with 23 new nuclear reactors, totalling more than 23,000 MW(e), connected to grids in eight countries (Table 1). The largest increase was in France, with 7,215 MW(e), followed by the United States, with 7,034 MW(e), the Federal Republic of Germany with 2,534 MW(e), Japan with 2,182 MW(e), the Republic of Korea with 1,800 MW(e), Canada with 1,353 MW(e), Czechoslovakia with 776 MW(e), and Hungary with 410 MW(e).

The only nuclear reactor which was shut down during 1986 was Unit 4 at Chernobyl. There were two cancellations in the US (MIDLAND-1, 491 MW(e) PWR, and MIDLAND-2, 816 MW(e) PWR) and one suspension in the Philippines (PNPP-1, 620 MW(e)PWR), of reactors under construction. By the end of 1986, there were a total of 31 shut-down nuclear reactors, with a total capacity of 4,328 MW(e). Most of these were reactors which began commercial operation in the 1960's, some even earlier, and which were shut down at the end of their economic life.

Table 2: Nuclear Power Reactors in Operation and Under Construction at the End of 1986

	Reactors in operation		*Reactors under construction*	
Country	*No. of units*	*Total MW(e)*	*No. of units*	*Total MW(e)*
Argentina	2	935	1	692
Belgium	8	5,486		
Brazil	1	626	1	1,245
Bulgaria	4	1,632	2	1,906
Canada	18	11,249	5	4,361
China			1	288
Cuba			2	816
Czechoslovakia	7	2,799	9	5,508
Finland	4	2,310		
France	49	44,693	14	17,809
German Dem. Rep.	5	1,694	6	3,432
Germany, Fed. Rep.	21	18,947	4	4,052
Hungary	3	1,235	1	410
India	6	1,154	4	880
Iran			2	2,400
Italy	3	1,273	3	1,999
Japan	35	25,821	10	8,431
Korea, Rep. of	7	5,380	2	1,800
Mexico			2	1,308
Netherlands	2	507		
Pakistan	1	125		
Poland			2	880
Romania			3	1,980
S. Africa	2	1,842		
Spain	8	5,599	2	1,920
Sweden	12	9,455		
Switzerland	5	2,932		
Taiwan (China)	6	4,918		
USSR	50	27,657	32	29,910
United Kingdom	38	10,222	4	2,520
USA	99	84,592	21	23,301
Yugoslavia	1	632		
Totals	397	273,715	133	117,848

At the end of 1986, worldwide, 26 countries were operating 397 nuclear power reactors (Table 2) with a total capacity of about 274 GW(e), accounting for about



Industrialized Countries	92.9%
USA	30.9%
France	16.3%
USSR	10.1%
Japan	9.4%
Germany, Fed. Rep. of	6.9%
Canada	4.1%
UK	3.7%
Sweden	3.5%
Spain	2.1%
Belgium	2.0%
Switzerland	1.1%
Finland	0.8%
South Africa*	0.7%
German Democratic Republic	0.6%
Italy	0.5%
Netherlands	0.2%

Developing Countries In CPE - Europe	2.1%
Czechoslovakia	1.0%
Bulgaria	0.6%
Hungary	0.5%
Developing Countries Outside CPE - Europe	5.0%
Korea, Rep. of	2.0%
Taiwan, China	1.8%
India	0.4%
Argentina	0.3%
Brazil	0.2%
Yugoslavia	0.2%
Pakistan	0.1%

Figure 1 Country distribution of installed nuclear generating capacity in the world, as of 31 December 1986. *Represented by the smallest slice. Source: IAEA Power Reactor Information System (IAEA-NENP-87-09).

Table 3: Nuclear Power Reactors by Reactor Type in Operation at End of 1986

Reactor type	*No. of units in operation*	*Net capacity (MW(e))*
PWR	207	164,890
BWR	83	64,782
LWGR	26	14,564
PHWR	26	13,792
GCR	33	6,692
AGR	10	5,736
FBR	7	2,380
HTGR	3	639
Other	2	240
Totals	397	273,715

AGR Advanced Gas-Cooled, Graphite-Moderated Reactor
BWR Boiling Light-Water-Cooled and Moderated Reactor
FBR Fast Breeder Reactor
GCR Gas-Cooled, Graphite-Moderated Reactor
HTGR High-Temperature Gas-Cooled, Graphite-Moderated Reactor
LWGR Light-Water-Cooled, Graphite-Moderated Reactor
PHWR Pressurized Heavy-Water-Moderated and Cooled Reactor
PWR Pressurized Light-Water-Moderated and Cooled Reactor

4,210 reactor-years of accumulated operating experience. There were also 133 nuclear power reactors under construction, totalling nearly 118 GW(e), mostly in the USSR (29,910 MW(e)), the USA (23,301 MW(e)), France (17,809 MW(e)), Japan (8,431 MW(e)), Czechoslovakia (5,508 MW(e)), Canada (4,361 MW(e)), and the Federal Republic of Germany (4,052 MW(e)).

Figure 1 shows the percentage distribution by country of the world's installed nuclear generating capacity as of 31 December 1986. As shown, 92.9% was in the industrialized countries, with 37.1% in Western Europe, 35% in North America, 10.7% in Eastern Europe (USSR and the German Democratic Republic), and 9.4% in Japan. Developing countries outside the centrally planned economies of Europe (CPE-Europe) accounted for 5%, and those in CPE-Europe for 2.1%. The distribution by type of reactor is given in Table 3. PWR's and BWR's account for more than 80% of the installed nuclear capacity to date.

The number of nuclear power reactors in operation and under construction in the developing countries at the end of 1986 is shown in Table 4. There were 24 nuclear power reactors with a total capacity of 13,770 MW(e) in operation in seven developing countries outside CPE-Europe, and 14 nuclear power reactors with a total capacity of 5,666 MW(e) in developing countries in CPE-Europe.

China, Cuba, Iran, Mexico, Poland, and Romania have their first units under construction. It is expected that LAGUNA VERDE-1 (654 MW(e) BWR) in Mexico will be connected to the grid during 1987. Grid connection for QINSHAN (288 MW(e) PWR) in China is scheduled for 1989. In developing countries outside CPE-Europe there were 15 units under construction, with a total capacity of 9,429 MW(e); in developing countries in CPE-Europe there were 17 units under construction, totalling 10,684 MW(e).

In energy terms, nuclear power plants generated about 1,515 TW.h(e) of electricity during 1986, an increase of 8% over 1985, and accounted for about 15.5% of the world's electricity production in 1986. It

Table 4: Nuclear Power in Developing Countries (as of 31 December 1986)

	Reactors in operation		*Reactors under construction*	
Country	*No. of units*	*Total net capacity MW(e)*	*No. of units*	*Total net capacity MW(e)*
Developing countries outside CPE-Europe				
Argentina	2	935	1	692
Brazil	1	626	1	1,245
China	–	–	1	288
Cuba	–	–	2	816
India	6	1,154	4	880
Iran, Isl. Rep. of	–	–	2	2,400
Korea, Rep. of	7	5,380	2	1,800
Mexico	–	–	2	1,308
Pakistan	1	125	–	–
Taiwan (China)	6	4,918	–	–
Yugoslavia	1	632	–	–
Sub-totals	24	13,770	15	9,429
Developing countries in CPE-Europe				
Bulgaria	4	1,632	2	1,906
Czechoslovakia	7	2,799	9	5,508
Hungary	3	1,235	1	410
Poland	–	–	2	880
Romania	–	–	3	1,980
Sub-totals	14	5,666	17	10,684

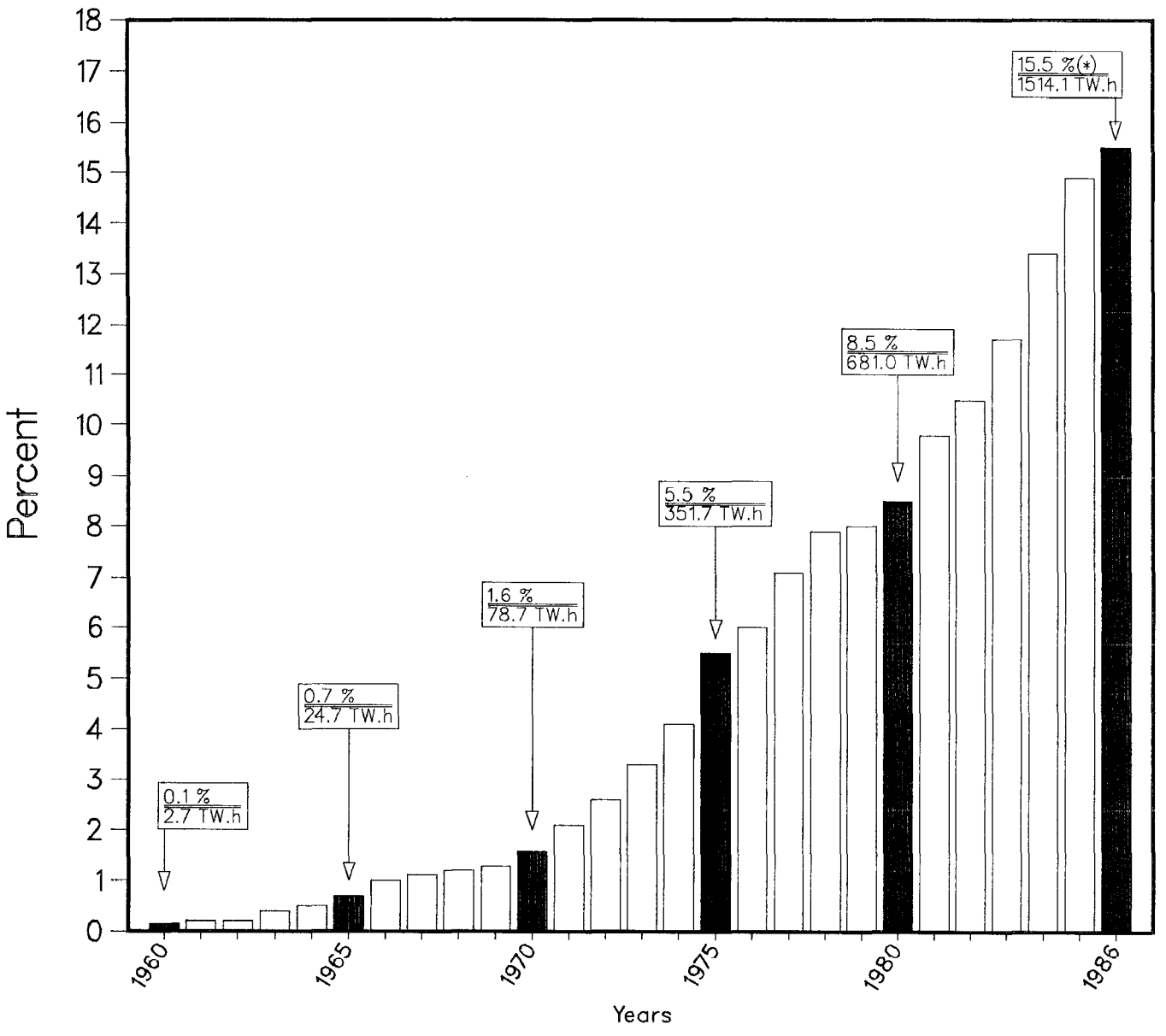


Figure 2 Nuclear electricity generation and share of total electrical energy for the period 1960 to 1986. *Total world electricity production in 1986 has been estimated. Source: IAEA Energy and Economic Data Bank (IAEA-NENP-87-18).

would take additional coal production equivalent to the current US production, or additional oil production equivalent to Saudi Arabia's production in 1982, to generate this amount of electricity by coal or oil, respectively. It is clear that if these additional amounts of fossil fuels were being required for electricity generation, the upward pressures on coal and oil prices could have a significant economic impact, particularly on developing countries.

The world's operating reactors represent a cumulative investment of well over US $200 billion, with an estimated $60 billion spent annually in building new plants and operating existing ones.

Figure 2 shows the growth of nuclear electricity generation and its contribution to total electricity production, since 1960. After more than 30 years of development, nuclear power is today providing a sizeable portion of the world's electricity. In the decade 1975–1985, nuclear-based electricity production quadrupled. Nuclear power plants in 1986 produced 10% or more of total electricity in 19 countries, and 25% or more in 12 of these countries (Figure 3). Three countries now produce more than 50% of their electricity from nuclear power plants (France – 70%; Belgium – 67%; Sweden – 50%). In the United States, where about 17% of total electrical energy was produced by nuclear power plants, the states of Vermont and North Carolina produced 65.4% and 63.2%, respectively, of their electricity from nuclear power plants; three other states, Connecticut, Maine, and

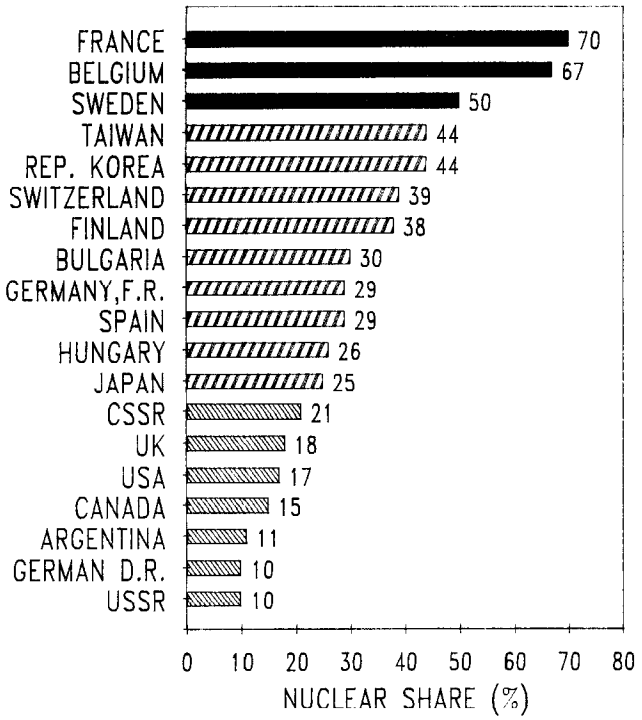


Figure 3 Countries with highest nuclear share of total electricity production in 1986.

New Jersey, produced over 50% of their electricity requirements from nuclear power plants. Similarly, in the province of Ontario in Canada, the nuclear share of electricity production was almost 50% in 1986.

Economic Viability

A study [1] published in 1986 by the OECD Nuclear Energy Agency shows that, in most countries, electricity generation with nuclear power plants is cheaper than with coal-fired plants. In some exceptional cases, such as in parts of the USA and Canada, coal-fired power plants located near the coal mines have lower generation costs than nuclear plants.

Some key results from the OECD (NEA) study are summarized in Table 5, showing the relative costs of nuclear and coal-fired generation in different European countries and in Japan. The comparison is expressed as a ratio of coal-fired to nuclear generation costs in each country, as it is judged not meaningful to compare the absolute values of generation costs in one country with those in another country.

It will be seen from Table 5 that nuclear electricity is expected to have a 20 to 80% economic advantage over coal-fired electricity, for stations commissioned in the mid-1990's in Europe and Japan.

It should be noted from Table 5 that a significant number of European countries expect the total costs for generation from nuclear plants to be less than the fuel costs alone for coal-fired plants operating in the post-1995 period. Under such circumstances it would be economic to construct new nuclear capacity to replace existing fossil-fuelled capacity, even when additional capacity is not needed to meet electricity demand.

Although no specific analysis has been made of the costs of base-load power generation using natural gas or oil fuels, it is expected that the latter will be significantly more expensive sources than coal in all the countries over the lifetime of the reference plant.

The situation in North America is less clear-cut. There are considerable regional variations in coal prices and this affects the coal / nuclear cost comparison considerably. In some regions of the United States with access to cheaper surface-mined coal, coal-fired generation could have a 21 per cent cost advantage over nuclear generation; in other regions more remote from coal fields, nuclear plants could have a nine per cent advantage. However, as explained in the NEA report, the situation would be generally more favourable for nuclear plants in the United States if construction times and costs could be brought into line with those experienced in, for example, Japan and France, or the best industry experience in the United States itself. While not considered achievable for a 1995-commissioned reactor, this is not unrealistic for the longer term.

Data for Canada also show strong regional effects, and bring out an additional aspect of plant type choice. Ontario Hydro has been able to build multiple reactor stations and gain considerable benefits from replication and scale. These advantages would not necessarily be available to smaller Canadian utilities, and the capital component of generation costs for such a small utility, building only one reactor at a time on a site, has a profound effect upon the unit production cost for nuclear electricity.

Clearly the significance of these two factors, namely coal price and the ability to capitalize on replication and scale of operations in the nuclear case, will differ between countries and within continents, so that the

Table 5: Nuclear vs. Coal Generation Costs* (1986 OECD–NEA study)

	Generating cost ratios	
Country	*Coal total / Nuclear total*	*Coal fuel / Nuclear total*
Belgium	1.62	1.03
Finland	1.33	0.84
France	1.80	1.30
Germany, F.R.	1.68	1.20
Italy	1.41	1.01
Japan	1.37	0.82
Netherlands	1.31	0.88
Spain	1.19	0.83
UK (1) / (2)	1.40 / 1.71	1.15(2)

*Reference case. Plants for commissioning in 1995.
(1) Sizewell "B" station.
(2) Later repeat PWR station.

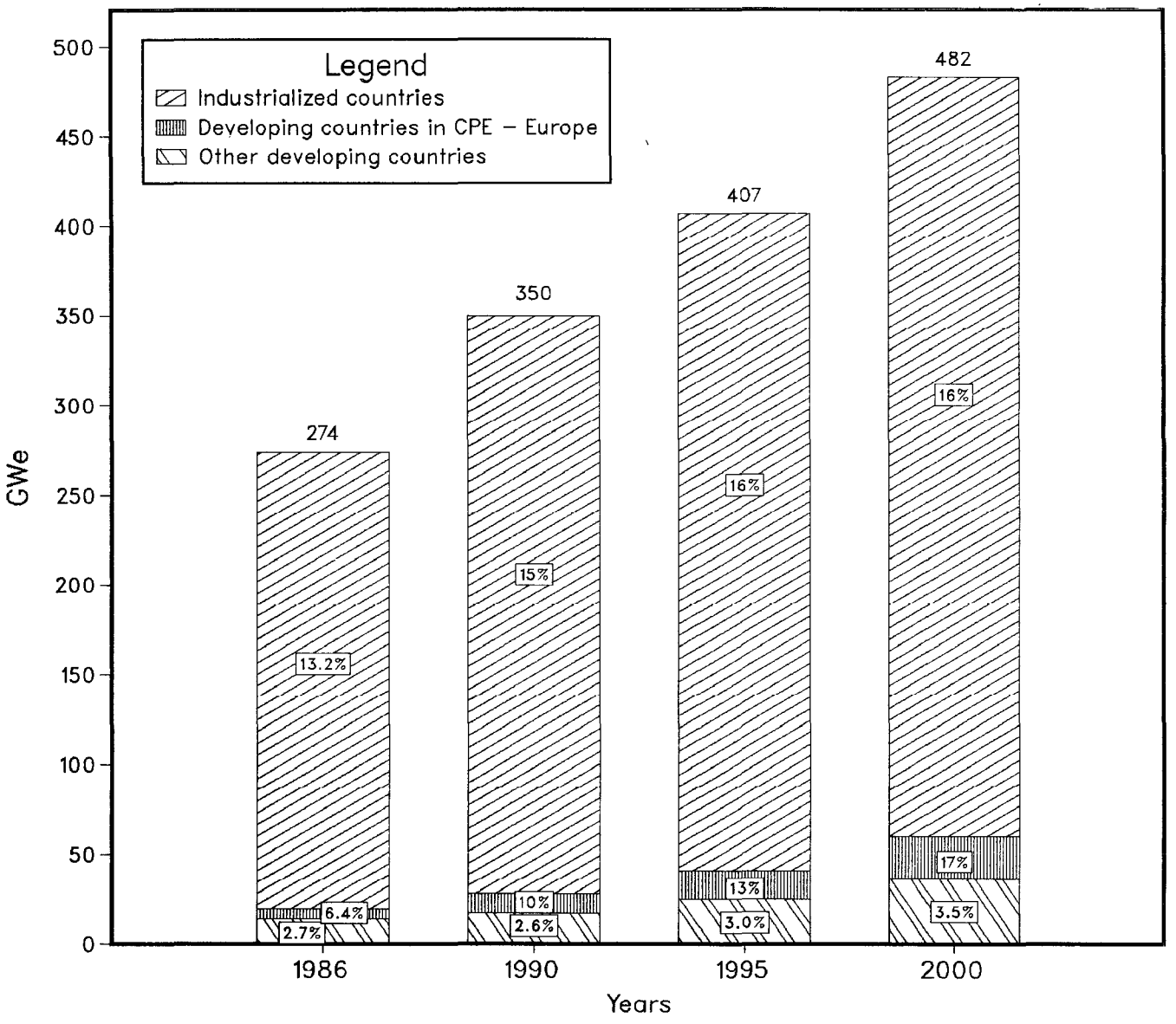


Figure 4 Growth in nuclear capacity up to 2000 (based on IAEA low estimates) and percentage nuclear contribution to total installed electrical capacity. Source: IAEA Energy and Economic Data Bank (IAEA-NENP-87-08).

relative attractiveness of nuclear and coal-based electricity has to be judged in relation to the local circumstances affecting the utility.

Outlook for the Future

Obviously, the Chernobyl accident will affect, to varying degrees, the outlook for nuclear power programmes in different countries. Following the political debates that were precipitated by Chernobyl, some countries will postpone decisions and delay their plans, as well as lower their expectations, for nuclear power development. Indeed, a few governments have felt compelled to present policies promising the dismantling, freezing, or phasing out of nuclear power.

However, it now appears that most countries with well-established nuclear power programmes will continue with the planned further development of nuclear power, with only minor perturbations due to the Chernobyl accident.

Based on data collected by the IAEA, a 'low-case' projection of nuclear capacity up to the year 2000 is shown in Figure 4. Nuclear capacity is expected to increase by 28% in the period 1986–1990; in the period 1990–1995 the increase is projected to be only 16%, reflecting the generally low ordering rate. The situation after 1995 is less predictable, particularly after the Chernobyl accident, but under the IAEA low-case estimate, an increase of 18%, from 407 GW(e) in 1995 to 482 GW(e) in 2000, may be expected.

In the industrialized countries, the percentage share of nuclear capacity in the total installed electrical capacity is expected to increase from 13.2% in 1986 to

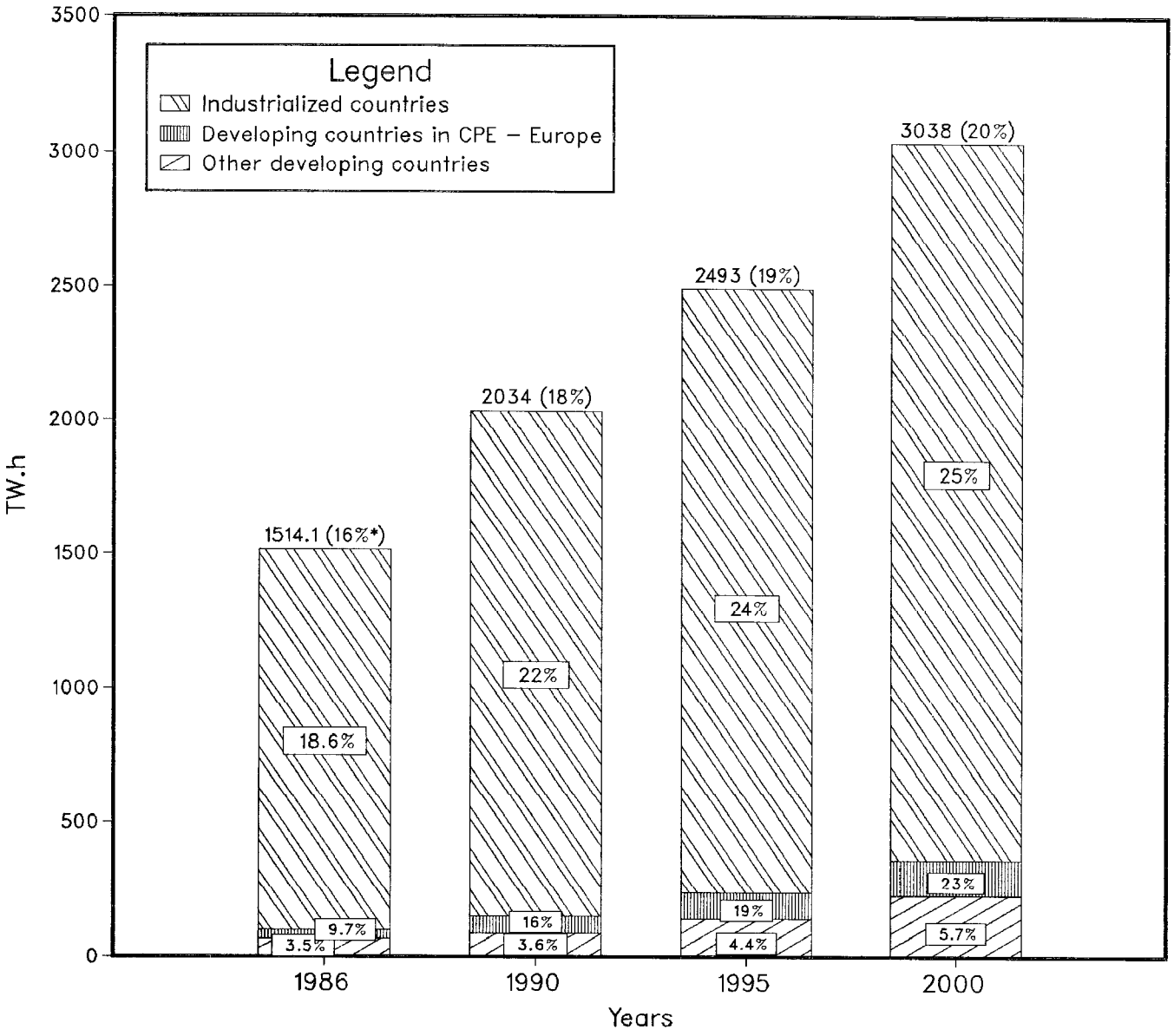


Figure 5 Growth in nuclear electricity generation up to 2000 (based on IAEA low estimates) and its corresponding shares in satisfying total electricity requirements. *Total world electricity production in 1986 has been estimated. Source: IAEA Energy and Economic Data Bank (IAEA-NENP-87-07).

15% by 1990, with a further increase to 16% by 1995, and to remain at 16% up to the turn of the century, when the installed nuclear capacity is projected to be 423 GW(e). In the developing countries in CPE-Europe, the percentage nuclear contribution to installed electrical capacity is expected to increase from 6.4% in 1986 to 10% in 1990, 13% in 1995, and to reach 17%, corresponding to a nuclear installed electrical capacity of 24 GW(e), by the year 2000. In developing countries outside CPE-Europe the nuclear contribution to installed electrical capacity is expected to rise from a present 2.7%, to 3.5% by the year 2000, when nuclear installed electrical capacity is projected to be 36 GW(e).

The limited growth of nuclear power in developing countries is not due to a ready availability of alternative sources of energy, but rather to other considerations, such as infrastructure requirements, economic viability, and acceptable financial arrangements. One can also note that a few technologically advanced developing countries are making excellent and extensive use of nuclear energy for electricity production and have developed a broad research capacity in the nuclear field.

However, the projections presented in Figure 4 lead to some important conclusions which are not dependent on numerical precision of the data:

- The share of world nuclear capacity located in developing countries is likely to remain at modest levels for the foreseeable future;
- The IAEA estimates that nuclear power plants will

provide only about 5% of the 600–800 GW(e) of total electrical capacity additions projected to be needed in developing countries up to the year 2000.

In terms of electrical energy, the projected growth of nuclear electricity generation up to the year 2000 is shown in Figure 5, for the IAEA low-growth estimates. In the 14-year period up to 2000, nuclear-based electricity generation is expected to more than double. The percentage share of nuclear electricity to the world's electricity generation is expected to increase from about 16% in 1986 to 18% in 1990, 19% by 1995, and 20% by the end of the century. In developing countries in CPE-Europe the growth of the share of nuclear electricity generation is more pronounced, from 9.7% in 1986 to 16% in 1990, 19% in 1995, and 23% in the year 2000. In the developing countries outside CPE-Europe, the share of nuclear electricity generation is expected to increase from 3.5% in 1986 to 5.7% by the turn of the century.

Challenges

As stated above, the nuclear power programmes in a number of countries are the subject of public and political debate. However, this was also the case before the Chernobyl accident.

The economic viability of nuclear power is certainly of great importance to industry and to the competitiveness of countries. However, public opinion on nuclear power reacts more to perceptions of accident risks and environmental impacts.

Public opinion was seen to react dramatically after the Three Mile Island accident and, again, even more strongly after the Chernobyl accident. However, there is already evidence in some countries that opinion is returning to the levels of acceptance that existed before Chernobyl. This trend needs to be reinforced by the dissemination of factual information on nuclear power.

In this regard, a sense of public and political reality needs to be promoted about the relative risks of nuclear power, alternative energy sources, and other industrial activities.

Reference is often made to environmentally benign, renewable sources like hydro, wind, and solar power. Of these, only hydro now makes a significant contribution (21%) to the world's electricity production. It is not without environmental consequences. Big hydro projects have major local impacts and we have learned through the years that they can also entail risks for major catastrophes. One dam accident in 1979 in Morvi in India caused an estimated 15,000 deaths. In Europe, the dam failure in Vaiont, Italy, in 1963, killed 3,000 people.

The chemical plant accident at Bhopal in India resulted in about 2,500 deaths and 150,000 injured, and also had long-term health effects.

This does not mean that one should draw comfort by comparing a disaster in the nuclear industry with disasters in other industries. Nonetheless, it must be made clear that while nuclear power has some unique features, the level of risk it poses to health and environment is not unique. Whether or not these risks are tolerable should be assessed in the same way for nuclear as for other energy sources, and for other industries.

It is a question of choice, and that choice should be made in full awareness of the possibilities for managing the risks for health and environment associated with the different energies. It would be paradoxical if nuclear power were rejected and phased out in some countries for environmental and security reasons, only to be replaced by an energy source that would jeopardize the health and lives of even more people, and that would subject the environment to much greater hazards.

Acknowledgements

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