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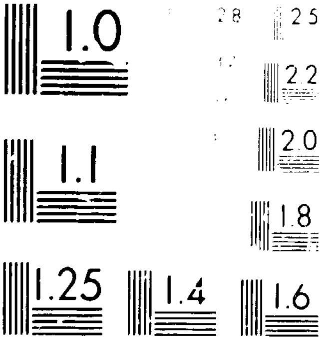
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NUCLEAR ENERGY FOR DEVELOPING COUNTRIES.

H.J. Laue

This paper was prepared by Dr. H.J. Laue, Director, Division of Nuclear Power, IAEA.

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NUCLEAR ENERGY FOR DEVELOPING COUNTRIES

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Consumption of electricity has been growing more rapidly than the demand for primary energy, especially in developing countries. As shown in Figure 1, in 1981 about 27% of the world primary energy consumption was used to produce electricity; by 2000, this figure is expected to increase to about 35%. In the developing countries only 17% of primary energy was used for electricity production in 1981, but this will increase to the present world average of 27% by the year 2000. Considering that demand for primary energy in the developing countries may double during the period from 1981 to 2000 (Figure 2), electricity consumption might increase by up to a factor of 4 in this period.

This trend of electricity penetration into the market is reinforced by the fast growing urbanization in the developing countries, e.g. Mexico City is expected to have 30 million inhabitants towards the end of the century or Calcutta and Sao Paulo, with some 25 million in the same year.

These are only some examples of the many expanding big cities which we now see growing in the developing world, which will have at least 12-15 cities of more than 10 million people in the late 1990s. These will certainly require highly centralized supply systems not only for energy but also for water, goods, sanitation, etc. The growth of these cities is only a symptom of the migration from the rural areas towards the cities where only industrialization would help to provide a reasonable way of living. As a result, in the year 2000 approximately 50% of the world population will live in highly urbanized areas. This will require large energy supplies and it would seem that nuclear energy, primarily suitable for centralized electricity supply, would be an evident solution within the framework of an optimized supply system which uses all available options.

Nuclear energy is commercially ripe for an immediate and expanding contribution based on a technology in which the anticipation of failures, their analysis and their limitation by effective safety devices have been considered from the early beginning of the peaceful use of nuclear energy around 30 years ago.

How about the nuclear situation in developing countries? As shown in Figure 3, at the end of 1982 only seven developing countries, namely Argentina, Brazil, India, Republic of Korea, Pakistan, Taiwan and Yugoslavia had 14 nuclear power plants in operation with a total capacity of around 6830 MWe, providing only 1.6% of the total electricity generation in developing countries. By comparison, for the total world, nuclear energy contributes about 10% of total electricity generation. Referring to Figure 4 as of 1 January 1983, 21 plants with about 15 000 MWe capacity were under construction or on order in these seven countries plus Cuba, Mexico and the Philippines. At least three other countries (Egypt, Peoples Republic of China, Libya) have plants in the planning stage. Some other countries, including Indonesia, Thailand, Turkey, Greece and Tunisia have stated their intention to introduce nuclear power, but have not yet made definite commitments to nuclear power plant construction. As shown in Figure 5, which is based on project information, the nuclear share of the total electricity generation in developing countries in 1985 might be 4.4% compared to 19% in industrialized countries. In the year 2000 the nuclear electricity generation in developing countries might be around 7% of the total electricity generation and around 2% of the primary energy requirements. The corresponding figures for the industrialized countries will be around 30% and 12%, respectively (Fig. 6).

Finally, Figure 7 shows the projected growth in the number of countries having nuclear power plants in operation. As shown, it is expected that out of a total of 31 countries only 10 developing countries, not including the European CMEA countries, will have 36 nuclear units (with a total capacity of 22 GWe) in operation by 1990. Details are provided in Tables 1 and 2.

As a result, several so-called threshold countries such as Brazil, Argentina, India, Republic of Korea and Taiwan are vigorously pursuing nuclear activities, whereas for the majority of the developing countries nuclear energy will have rather limited applications up to the end of the century.

What are the reasons which are limiting the growth of nuclear power in developing countries and which measures are needed to further increase the peaceful use of nuclear energy in these countries?

In response to the special needs of our developing Member States which are planning or intend to introduce nuclear power, the IAEA has published a "Guidebook on the Introduction of Nuclear Power" (Ref. 1) to provide up-to-date information and guidance to decision makers, planners, managers and professional staff on the work that has to be undertaken in the preparation for and introduction of nuclear power in a developing country.

First of all, the introduction of nuclear power technology in a developing country entails problems and considerations which are specific to nuclear power and which make experience with technology transfer in other areas of industrial development only partly relevant.

The technical complexities and unique safety requirements of nuclear power programmes, as well as the economic consequences of unreliable operation, make it imperative that highly qualified manpower be available from the very beginning of the programme, which requires a lead time of at least ten years or more. Experience has shown that the most serious manpower deficiencies to date have not been in the category of academically trained nuclear scientists and engineers but rather in engineers with training and practical experience in large projects as well as technicians and skilled craft labour.

To indicate the order of magnitude of manpower requirements, more details are given in the 1980 IAEA Guidebook on Manpower Development for Nuclear Power (Ref. 2). The following figures indicate the order of magnitude of the manpower requirements:

The construction of a 600 - 1200 MWe light-water reactor requires about 11-15 million hours of labour, most of which must be obtained locally.

The operation of a nuclear power project requires a minimum of about 150-200 trained staff members in such functions as station management and operation, maintenance, technical services, health physics and quality assurance and control.

An effective regulatory organization requires a minimum staff of 15 for the first nuclear power plant; and for a programme of 5-10 plants, a staff of about 50 managers, engineers and experts on siting and environment, mechanical systems, instrumentation, radiation protection, fuel management, operations and other special areas.

It is therefore a major task of the IAEA to assist its Member States on request in all aspects of manpower requirements, development and training, through special missions, planning studies, training courses and practical training within a general frame of the overall social and economic development.

In 1975, the IAEA started a training course programme aimed at transfer of experience from nuclear power planning, project execution and plant operation. They have been very valuable in providing the participants with an insight into the scope, complexity and requirements of a nuclear power project and programme.

Since 1975, nearly 1000 participants from about 45 developing countries have been trained in the Agency's Training Courses.

Another important part of the IAEA technical co-operation and assistance programme for developing countries are IAEA fellowships for on-the-job training in on-going nuclear projects and related areas. In 1982, the IAEA awarded 65 fellowships in fields related directly to nuclear power programmes.

In addition to the training courses and fellowship programmes, the IAEA also arranges scientific visits, provides experts and executes and administers United Nations Development Programme (UNDP) projects for nuclear manpower development. A major UNDP project has had the objective of establishing a nuclear power plant operator training center in Brazil, another the establishment of a school of nuclear engineering at an advanced level at Bariloche in Argentina.

In addition, the IAEA increasingly arranges missions to Member States to advise and assist on planning and implementing co-ordinated manpower development and training for the national nuclear power programmes.

Development of the necessary industrial infrastructure is another important prerequisite for a country embarking on a nuclear power programme, which, however, should be directly inter-related to the industrial development programme and the general energy supply and demand situation. The entirely domestic development of highly complex technologies would not be feasible in most developing countries on a reasonable time schedule. Acquisition from abroad is the commonly used manner to obtain new technologies, which requires governmental involvement in the assurance of continuity of technology transfer normally provided through bilateral co-operation agreements, today by far the most important channel for the transfer of nuclear technologies. Bilateral inter-governmental agreements are stimulated in conjunction with the transactions of nuclear power plants or nuclear facilities which require intimate technical and managerial co-operations between the purchaser and the vendor. Generally, it is simpler to make these complex arrangements directly rather than through a third party.

Because of the high investment requirements, financing may prove a limiting factor for nuclear power programmes in developing countries. However, the long-term savings in fuel costs should provide an incentive to solve the investment capital availability problem.

In this context the economic situation of nuclear power should be briefly summarized, considering that the costs of constructing nuclear power plants have risen very rapidly during the past decade, leading many critics of nuclear power to charge that nuclear power plants are uneconomic. However, studies carried out by AIF in the USA, by UNIPEDE in Europe and by the IAEA (Figure 8) all reach the conclusion that, in spite of their rising costs, electricity generation costs of nuclear power plants in all countries are very much lower than those of oil-fired plants and, in many situations, in the size range of 600 - 1200 MWe also substantially below generation costs of coal-fired plants. The comparison is not uniform within all countries, or even within a given country, as for example, in the USA where in some locations coal-fired plants can produce electricity at costs competitive with or lower than the costs of electricity from nuclear power reactors. In France and the Federal Republic of Germany, on the other hand, nuclear-produced electricity costs only 50% to 60% as much as electricity produced by coal-fired stations. In developing countries in the size range of 600-1200 MWe the economy of nuclear power seems to be very similar to that in the industrialized countries.

One of the important factors affecting nuclear plant investment costs, and thereby the generation costs, is the total nuclear project time, from commitment to commercial operation of a nuclear plant. This time presently is around 6 years in France, 11 years in the Federal Republic of Germany, and about 13 years in the USA. If the project times in all countries could be reduced to those in France, the plant investment costs would be significantly reduced.

For developing countries, however, the investment related to the gross domestic product seems to be even more important. According to studies by the World Bank, power expansion investment requirements have remained at about 7-8% of the gross fixed capital formation of developing countries. It is estimated, however, that a shift to higher capital cost plants (including nuclear and hydro) would force developing countries to raise this proportion to about 10 - 12%. This would correspond to about 1 - 1.5% of GDP for these countries. (By comparison, the Aswan Dam in Egypt would have consumed about 2% of Egypt's GDP during its construction period).

Thus, it is apparent that the financing of a nuclear power programme must be seen as a major national effort which may require suitable long-term financing arrangements. In this way, the impact on the domestic econonomy could be made acceptable during the long lead times before the benefits from the low fuelling costs begin to provide economic benefits.

Without going into details, the total investment for a 600 MWe nuclear power plant will be between 1.0 and 1.5 billion US$, considering capital investment costs between 1500 and 2500 US$/kWe installed capacity, depending on the available infrastructure, the transition to a higher voltage level and the expansion of the transmission and distribution system.

It must, however, again be recognized that the nuclear power programme is only one of the several development programmes which will compete for the available investment funds and that the development of nuclear power should not exclude the possibility of other options and technologies more appropriate to a specific country.

Another important factor which has limited the introduction of nuclear power in developing countries has been the unavailability of small and medium size power reactors (SMPRS) with the exception of the USSR 440 MWe PWR-type which is still built and exported. Such plants, between 200 and 400 MWe, if available, could help meet electricity needs in some developing countries with small and relatively weakly interconnected electrical power grids.

A generally-used rule-of-thumb is that a single power generating unit should not exceed 10% of the total generating capacity of all plants on the transmission grid, for reasons of voltage and frequency stability of the electricity supply. If one applies this rule to Member States of the IAEA, using current values and projections of the national electrical generating capacities, the result gives in Fig. 9 the number of countries which would be able to use power plants in various size ranges. In this approach, it has been assumed optimistically, that the total national electricity production is used in one ideally inter-connected grid; however, pessimistically, that there are no grid connections across national borders. In spite of such limiting assumptions, the results nonetheless allow certain qualitative conclusions to be drawn:

- At present, the power grids in as many as 50 IAEA Member States could accept nuclear units of 200 MWe and larger, whereas only 24 actually have operating power plants;

- At any one time during this period, about 15 countries represent a potential market for SMPRs (200-600 MWe);

- Typically, the availability of SMPRs would allow a country to utilize nuclear power about 15 years earlier than with present plants (600-1200 MWe).

Current studies indicate that, with the present high price of oil, nuclear power plants might be economically competitive with oil-fired plants in sizes as small as about 200 MWe (see Figure 8), although the capital costs of the nuclear units are still quite uncertain. Furthermore, there is a re-emerging interest on the part of the suppliers, leading to some new design developments in the 200 to 400 MWe range and up-dated designs for 600 MWe plants. This growing interest by both potential purchasers and suppliers of SMPRs could lead to an expansion in the number of developing countries able to use nuclear power as a part of their energy supply system.

It should, however, be recognized that going nuclear with a small reactor will requi. nearly the same commitments to a high technology as in the large reactor case, namely in respect of manpower, infrastructure and transfer of technology.

Undoubtedly the safety of nuclear power plants is crucial to the issue of public acceptability of nuclear energy. First of all, it should be remembered that the potentially serious consequences of big accidents were recognized from the very beginning in the case of nuclear power, unlike the case of other industries. It led to the international adoption of the important principle of the "strict liability" of the plant operator for any environmental health consequences. The theoretical calculations of some extreme cases are indeed now being used as arguments against nuclear power. Up to end 1982, almost 3000 reactor years of operating experience had been accumulated by around 300 nuclear power plants operating in 25 countries. This means that the average plant has been in operation for 10 years, and some have been in operation for 25 years. From this experience one can learn several things. First and most qualifying, nuclear power plants have been operating safely. There have been no accidents which resulted in fatalities directly caused by radiation. Secondly, even in very serious accidents such as the one at Three Mile Island, the nuclear safety system worked. Even with a combination of human and mechanical failures, the radioactive releases were essentially contained.

The general conclusion of the International Conference on Current Nuclear Power Plant Safety Issues in October 1980 in Stockholm was that there are no technical factors related to safety that should limit the use and development of nuclear power. It was, however, clear that safety could be further improved by giving more attention to certain identified areas, e.g. man-machine interface, development of equipment and training of personnel, to assure that small incidents do not turn into more serious ones.

For developing countries it is especially important to build up their own safety infrastructure based on internationally developed standards and codes. The extensive international effort which produced the IAEA Nuclear Safety Standards (NUSS) should provide a sound basis for guidance on nuclear power plant safety, particularly in cases where more than one country is involved. The world-wide acceptance and utilization of the NUSS documents can be an important step assuring that nuclear power plants in developing countries have an adequate degree of safety.

Finally, a few remarks should be made concerning the fuel cycle, as nuclear power plants and their fuel cycle must be considered together.

Supplies of nuclear fuel and nuclear fuel cycle services always have been and will continue to be subject to non-proliferation constraints which have affected assurance of fuel supply and transfer of technology. We need to work towards greater stability in supply policies which would give assurance of both supply and non-proliferation, as well as some long-term predictability of the functioning of markets and institutional measures. In other words, we should work towards a regime in which irrevocable safeguards has a counterpart in irrevocable assurances of supply of fuel. It is gratifying, considering the basically complementary nature of supply and non-proliferation assurance, that the IAEA Board of Governors, as one of the most important follow-ups of the International Nuclear Fuel Cycle Evaluation (INFCE), has established the Committee on Assurances of Supply for a discussion of these fundamental issues.

It is clear that initiation of a nuclear power programme in a country could be a strong incentive for uranium exploration and production and vice versa. However, considering the decline in uranium price on the spot market, from around 112 US$/kg in 1978 to less than 60 US$/kg*/ today, and the slow-down of many nuclear power programmes in industrialized countries, developing countries may have little chance to attract capital for new uranium exploration and the establishment of uranium mines and mills.

Similarly, enrichment, reprocessing and waste management facilities require large capital investments. In addition, the economies of scale strongly favour large facilities, capable of providing service for tens of GWe of nuclear power capacity. At least during this decade, there is ample enrichment capacity available in several countries to meet the world's demand. There is, however, a severe shortage in reprocessing and radioactive waste storage capacity. Therefore, for the smaller nuclear power programmes in most developing countries, co-operative fuel cycle back-end ventures along the line of the multi-national fuel cycle centre concept would seem worth pursuing, from both economic and safeguards viewpoints. While the technical possibility of such centres seems to be assured, the necessary institutional arrangements seem to be far from a solution.

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*/ The price reached a low of about 40 US$/kg in the second half of 1982.

Conclusions

The problems briefly described are by no means the only causes of uncertainties which at present affect the prospects of nuclear energy in developing countries. There are a number of features of nuclear technology whose importance may have been underestimated in the past, for example, a much higher level of quality control and assurance than in other sectors of the industry.

Taking into consideration all factors mentioned above, by the year 2000 around 15 developing countries (excluding five European CMEA countries) may have a realistic chance to use nuclear energy to meet their increasing electricity demand. Even those few developing countries need extensive assistance from industrialized countries.

In this respect, the INFCE studies summarized the situation as follows: So far multilateral and international mechanisms have been of limited effectiveness in meeting the special needs of developing countries; bilateral arrangements, on the other hand, have been more important in the past. Experience would indicate that the developing countries need arrangements of broad scope, which will not only cover the supply of equipment and material but also give long-term assurance for the development of the needed trained manpower and of domestic participating industry, and for research co-operation and financing.

So far a solution of the energy problem of the Third World in general and the peaceful use of nuclear energy in particular can be achieved only through global co-operation and international and regional arrangements.

It is hoped that countries, the IAEA and other international organizations engaged in assistance to developing countries could co-operate more actively to remove some of the difficulties and limitations for the peaceful use of nuclear energy in developing countries. These international measures could be:

- to prepare more detailed and reliable future general energy demand analyses for developing countries;

- to increase the availability of co-ordinated training programmes for developing the required manpower, not only for nuclear energy;

- to assure supplies of nuclear fuel and materials within a universally accepted safeguards system;

- to establish specific multi-lateral fuel cycle activities, consistent with the non-proliferation commitment of the parties involved.

If we will have on the other side a continuing slow-down or even stop of nuclear programmes in some industrialized countries, there will be an even smaller chance to use the nuclear option in an increasing number of developing countries, as the transfer of practical experience and technology will remain one of the most important pre-requisites for the practical implementation of nuclear power in those countries which have only limited energy diversification options.

Finally, it should be stressed that the most important condition for the nuclear option is a clear decision to be taken by the Government, based upon an extensive analysis of the future energy supply and demand situation, in order to plan as early as possible all actions to be needed for the implementation of nuclear power, which requires a new dimension of qualified manpower, infrastructure and financing.

References:

(1) Guidebook on the Introduction of Nuclear Power; Technical Report Series No. 217, IAEA, Vienna 1982.

(2) Manpower Development for Nuclear Power, A Guidebook; Technical Report Series No. 200, IAEA, Vienna 1980.

Table 1

Power Reactor Programmes in Developing Countries (Dec. 1982)

Countries	Operating		Under construction		Planned	
	No. of Units	Total MWe	No. of Units	Total MWe	No. of Units	Total MWe
Developing Countries Outside CMEA-Europe						
Argentina	1	335	2	1 292	3	1 800
Brazil	1	626	2	2 490	6	7 470
Cuba	-	-	1	408	1	408
Egypt	-	-	-	-	8	8 400
India	4	809	4	880	6	1 320
Korea, Rep. of	2	1 193	7	6 227	4	3 456
Mexico	-	-	2	1 308	-	-
Pakistan	1	125	-	-	1	937
Philippines	-	-	1	620	-	-
Taiwan	4	3 110	2	1 814	4	4 120
Yugoslavia	1	632	-	-	1	1 000
Sub-total for DC's Outside CMEA-Europe	14	6 830	21	15 039	34	28 911
Developing Countries in CMEA-Europe						
Bulgaria	4	1 632	2	1 906	2	1 906
Czechoslovakia	2	762	6	2 520	13	9 316
Hungary	1	408	3	1 224	4	4 000
Poland	-	-	-	-	6	3 760
Romania	-	-	2	1 320	3	1 728
Sub-total for DC's in CMEA-Europe	7	2 802	13	6 970	28	20 710
Total for DC's	21	9 632	34	22 009	62	49 621
TOTAL FOR WORLD	297	173 039	216	204 780	142	134 070

Table 2

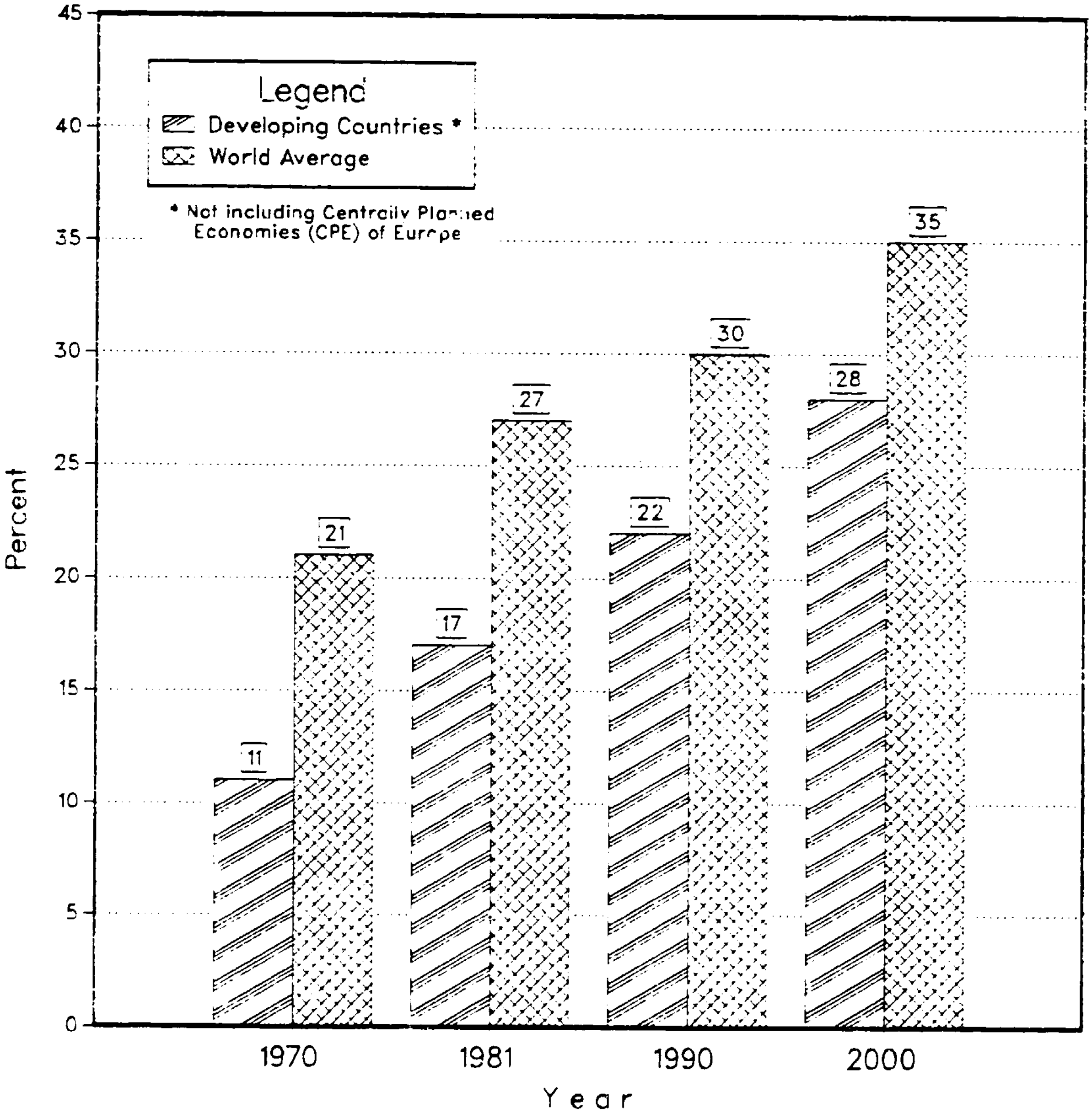
Power Reactors Operating in Developing Countries

Countries	Dec. 1982 Units	Dec. 1982 Mwe	1985 Units	1985 MWe	1990 Units	1990 Mwe
Developing Countries Outside CMEA-Europe						
Argentina	1	335	2	935	3	1 627
Brazil	1	626	1	626	3	3 116
Cuba	-	-	-	-	1	408
India	4	809	6	1 249	9	1 909
Korea, Rep. of	2	1 193	7	5 534	9	7 420
Mexico	-	-	1	654	2	1 308
Pakistan	1	125	1	125	1	125
Philippines	-	-	1	620	1	620
Taiwan	4	3 110	6	4 924	6	4 924
Yugoslavia	1	632	1	632	1	632
Total for DC's Outside CMEA-Europe	14	6 830	26	15 299	36	22 089
Developing Countries in CMEA-Europe						
Bulgaria	4	1 632	5	2 585	6	3 538
Czechoslovakia	2	762	8	3 282	8	3 282
Hungary	1	408	3	1 224	4	1 632
Poland	-	-	-	-	1	440
Romania	-	-	-	-	2	1 320
Total for DC's in CMEA-Europe	7	2 802	16	7 091	21	10 212
TOTAL FOR WORLD*	297	173 039	427	291 593	531	392 074

*China not included.

Figure 1

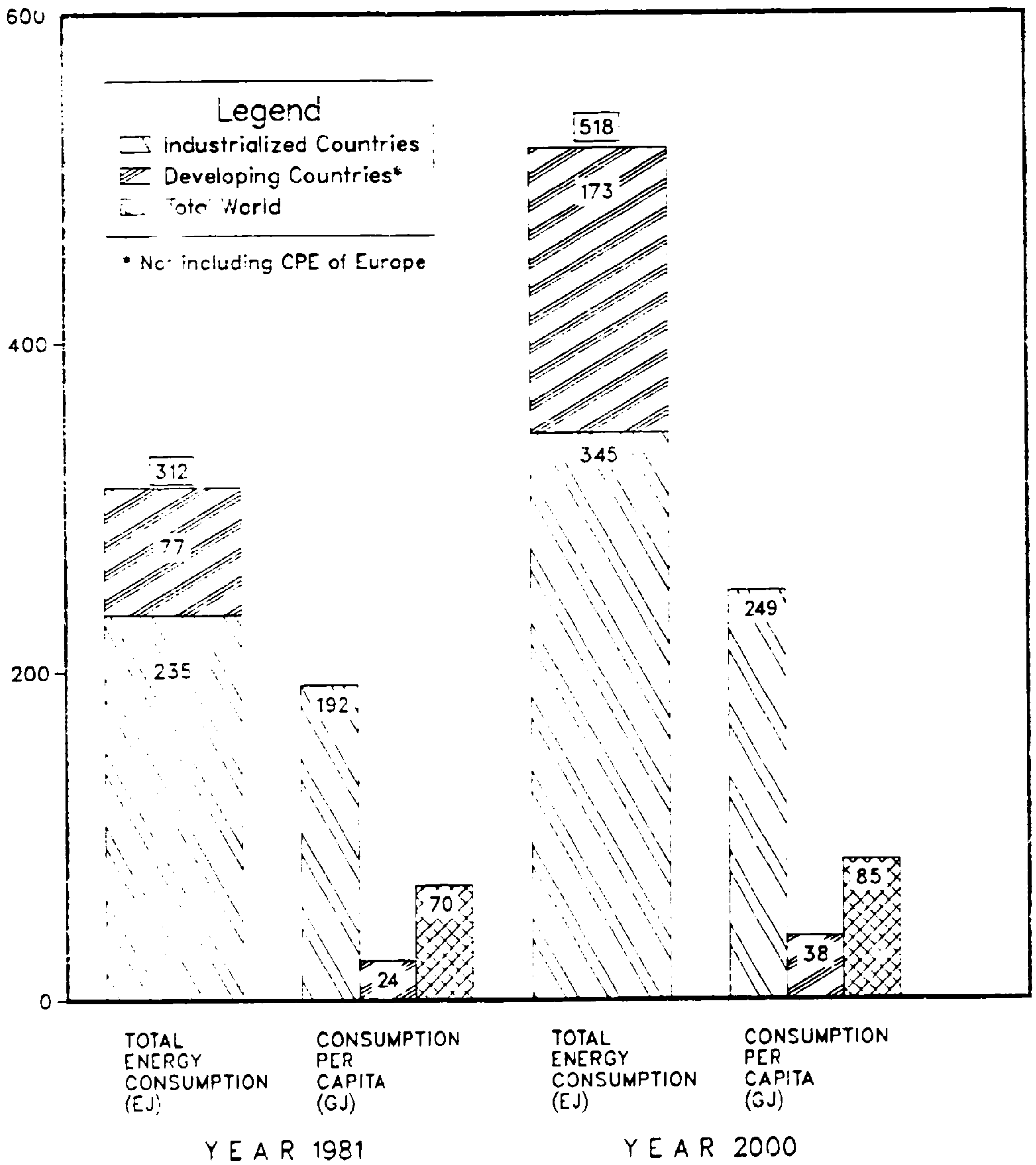
Percentage of Total Energy Consumption used for Electricity Generation



PNEDCO' Source: IAEA Economic and Energy Databank

Figure 2

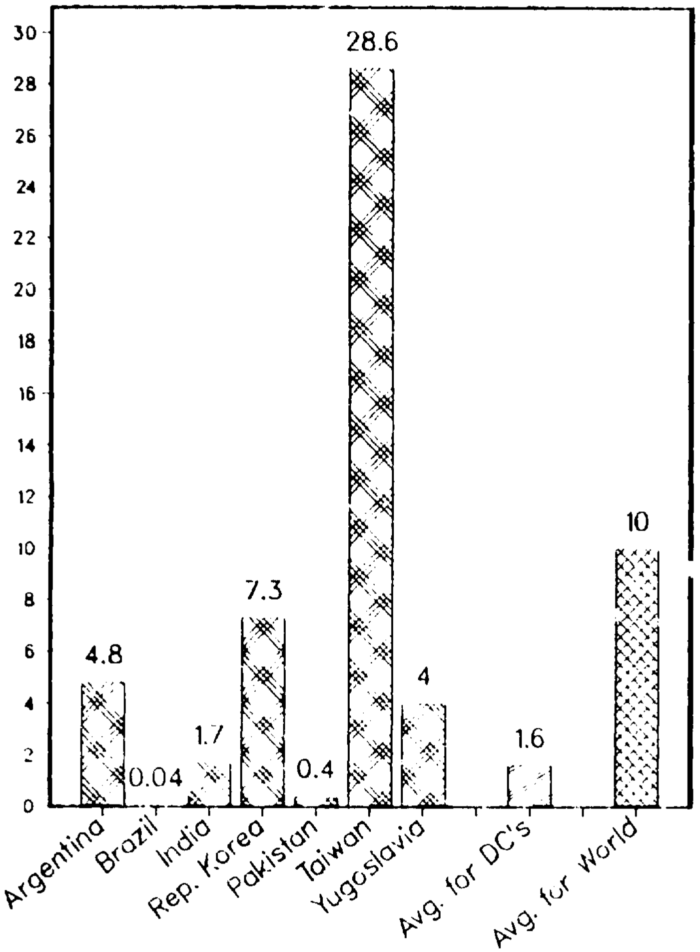
Total and Per Capita Consumption of Energy



IPNEDC02 Source: IAEA Economic and Energy Databank

Figure 3.(a)

Nuclear Share of Total Electricity Generation in Developing Countries during 1982 (Percent of Total)



PNEDC03 Source: IAEA Economic and Energy Databank

Figure 3.(b)

Power Reactors in Oper. .n During 1982

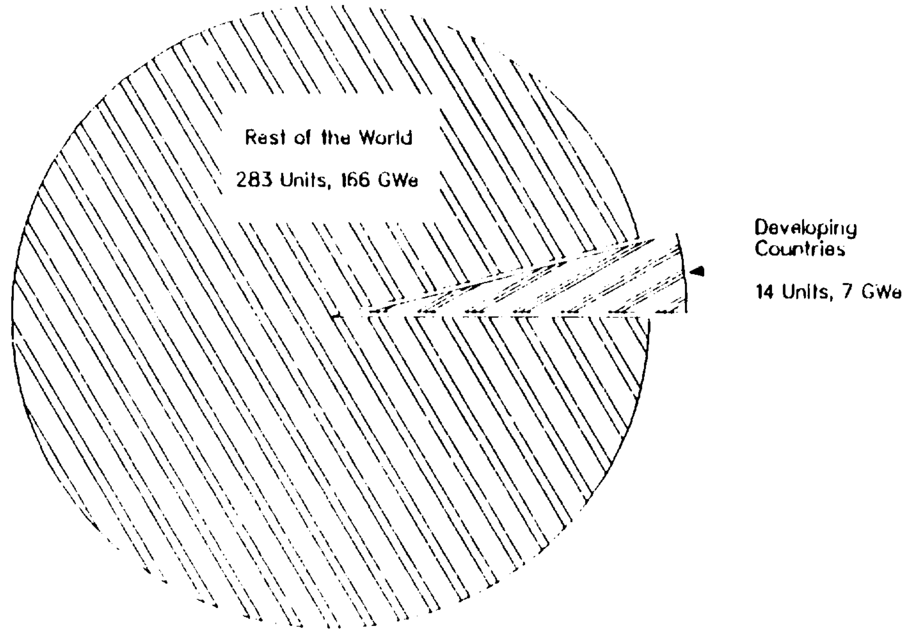
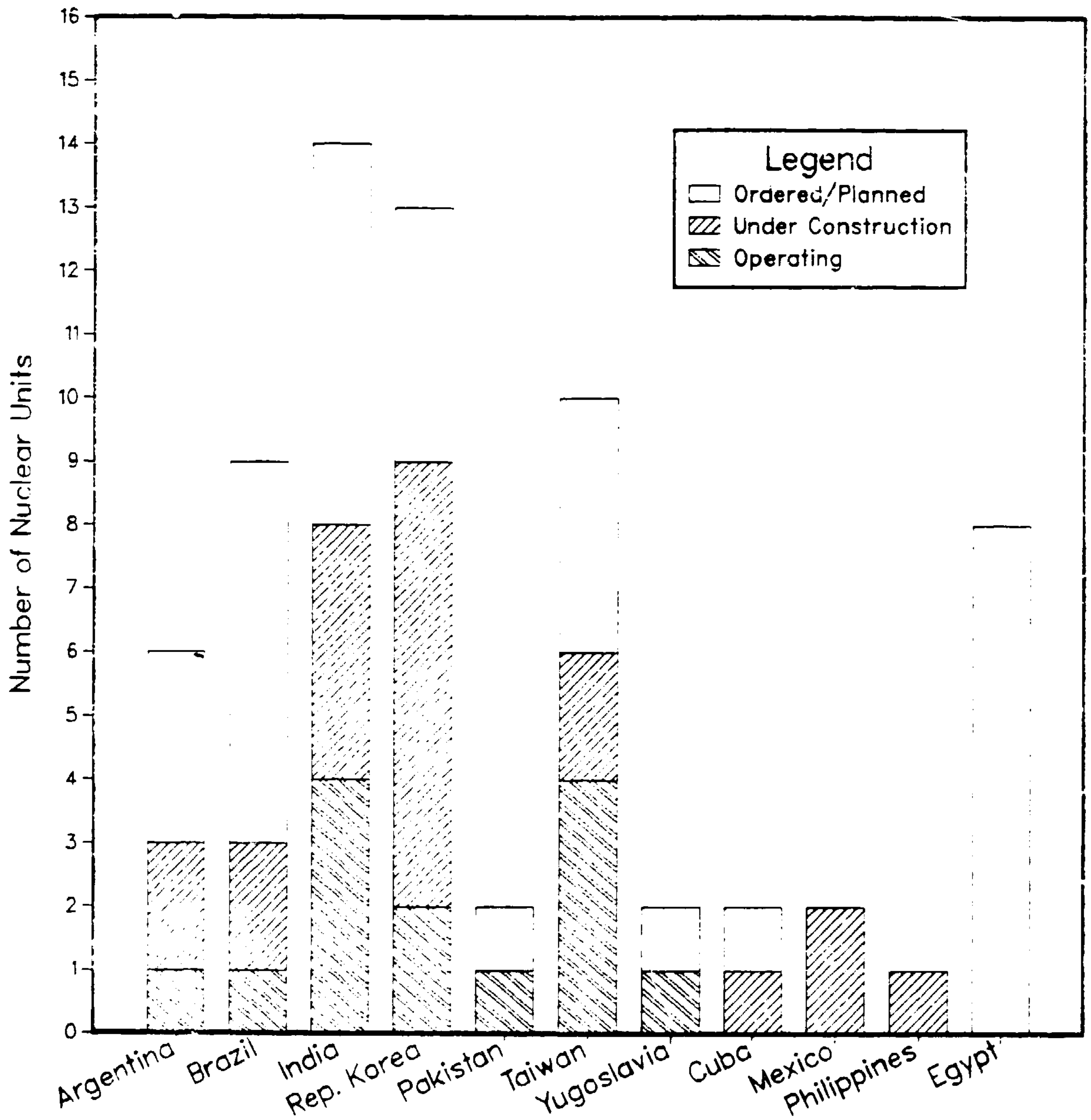


Figure 4

Status of Nuclear Power Programmes
in Developing Countries
as of Dec. 1982



PNEDC04 Source: IAEA Power Reactors Information System

Figure 5.(a)

Estimates of Nuclear Power Share in Total Electricity Generation

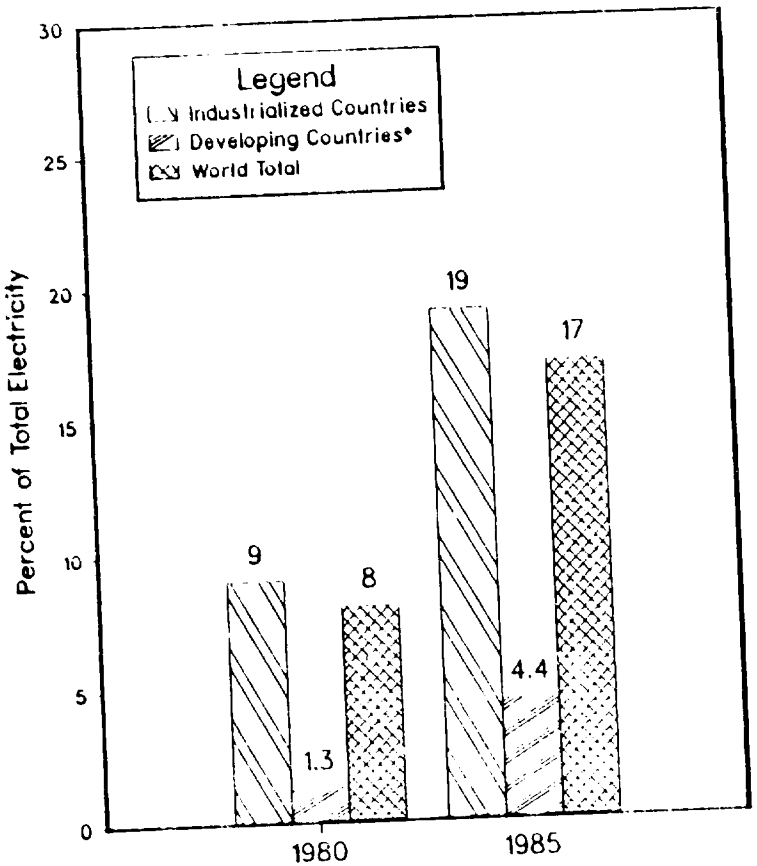
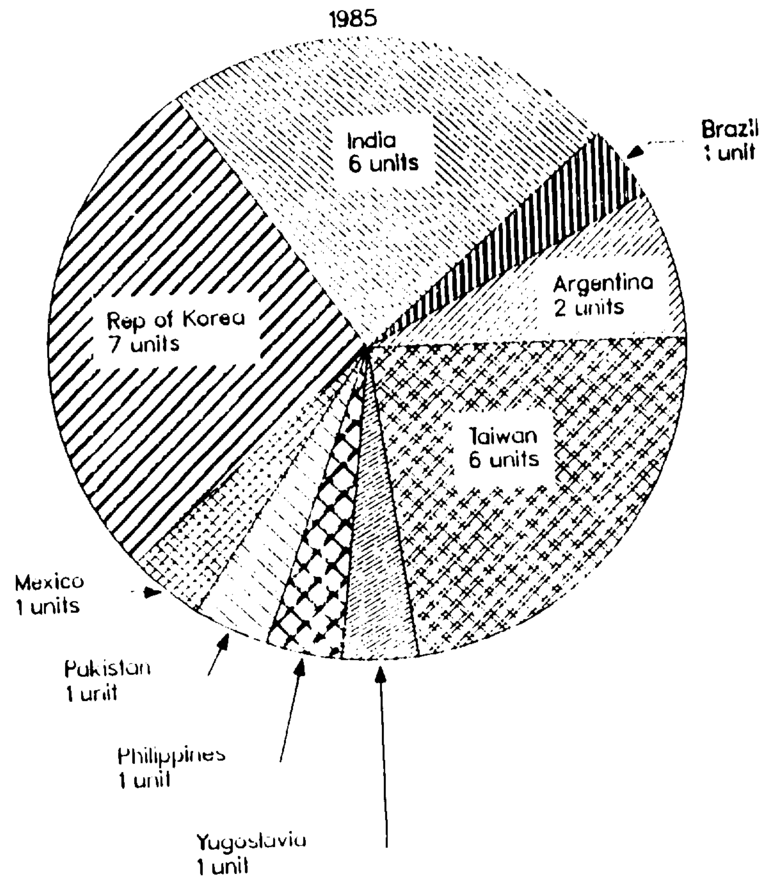


Figure 5.(b)

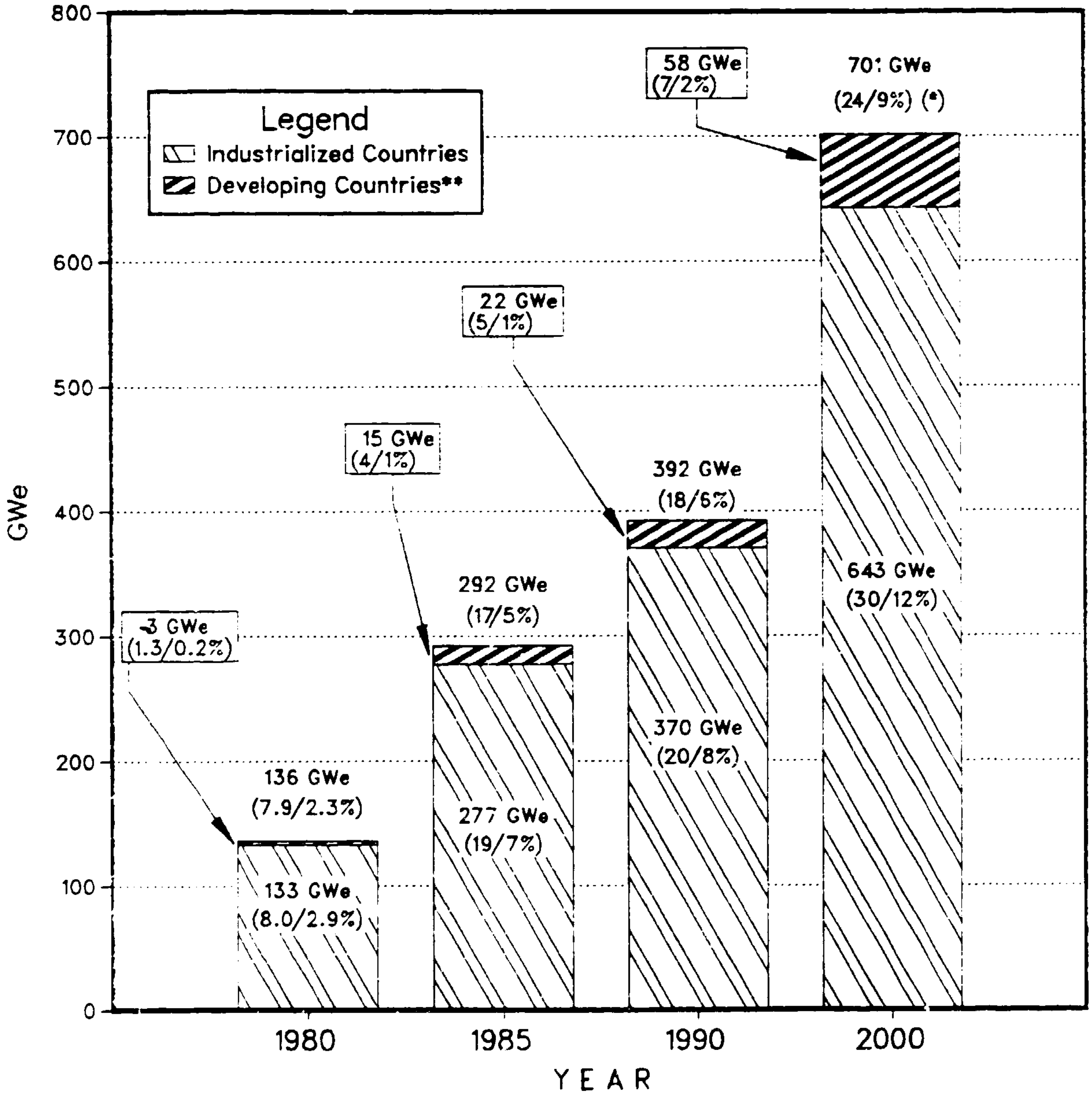
Estimated Nuclear Power Reactors in Developing Countries Number of Operational Units



PNEDC05 Source: IAEA Economic and Energy Databank

Figure 6

Estimates of Nuclear Electrical Generating Capacity and Contribution to Energy Supply

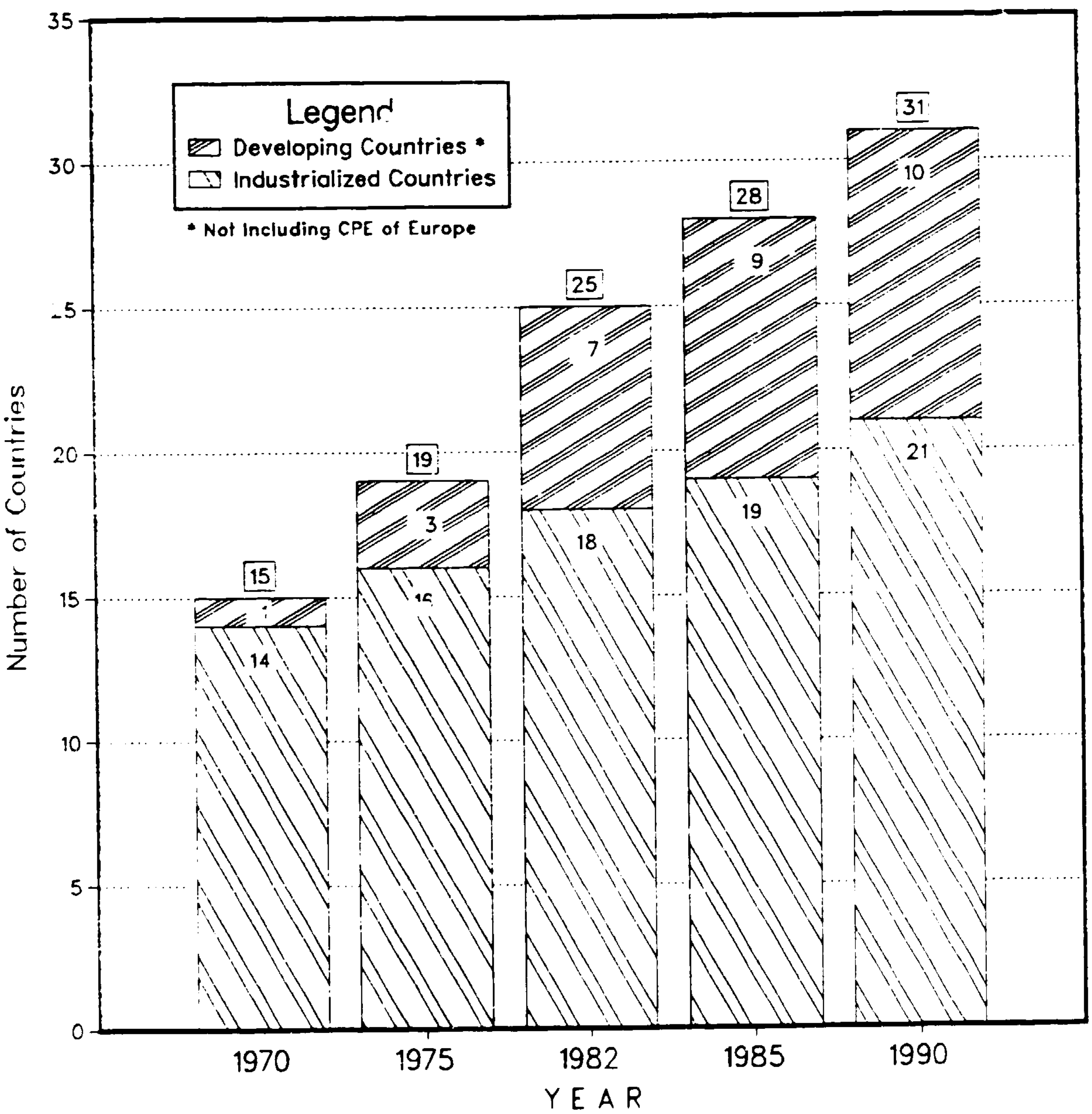


(*) Figures in brackets are percentages of total electrical capacity and primary energy requirements
Figures for 1985, 1990 & 2000 are averages of low and high estimates
(**) Not including centrally planned economies of Europe

PNEDC06 Source: IAEA–Energy and Economic Databank

Figure 7

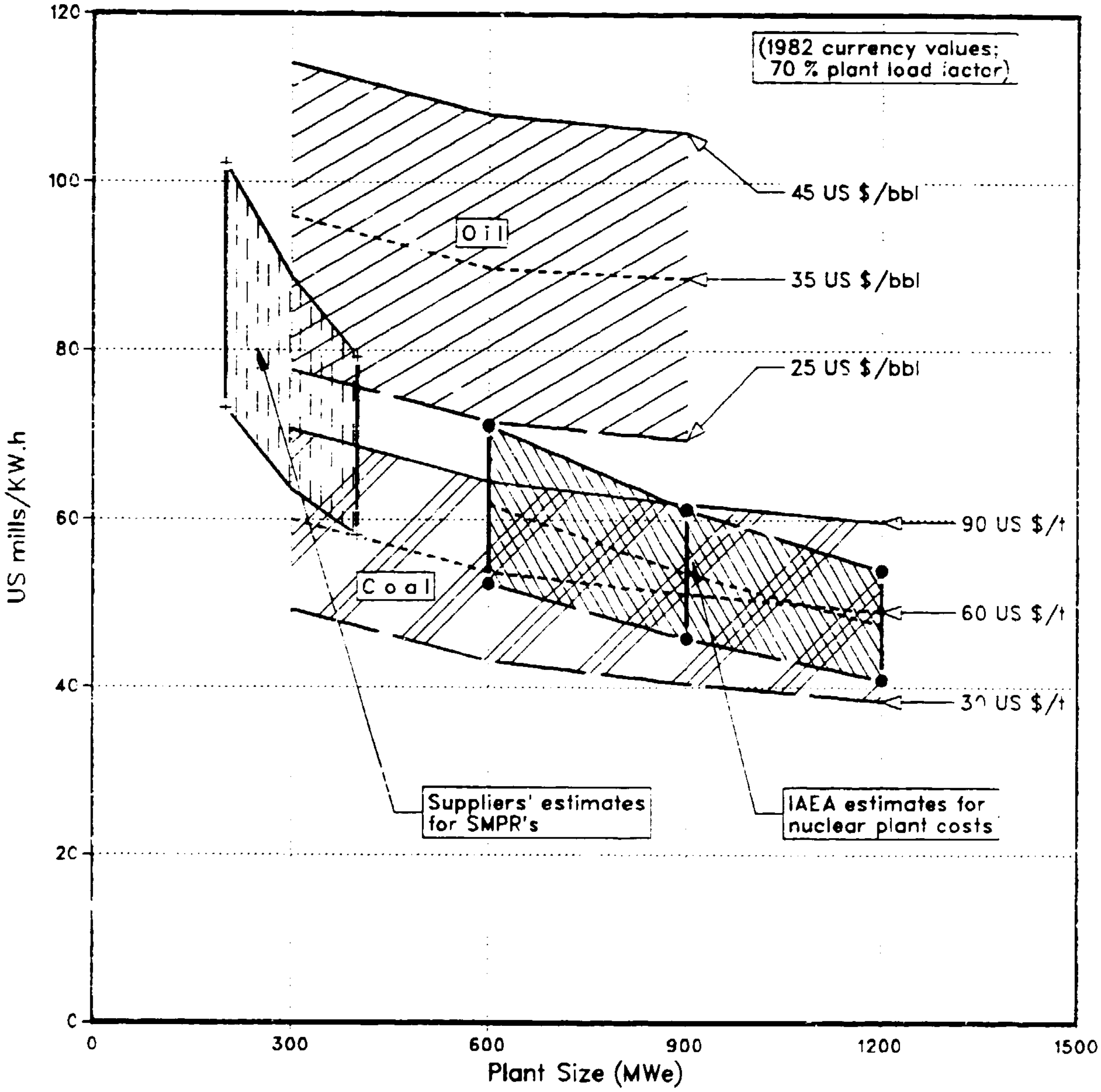
Countries with Operational Nuclear Power Reactors



PNEDC07 Source: AEA Power Reactors Information System

Figure 8

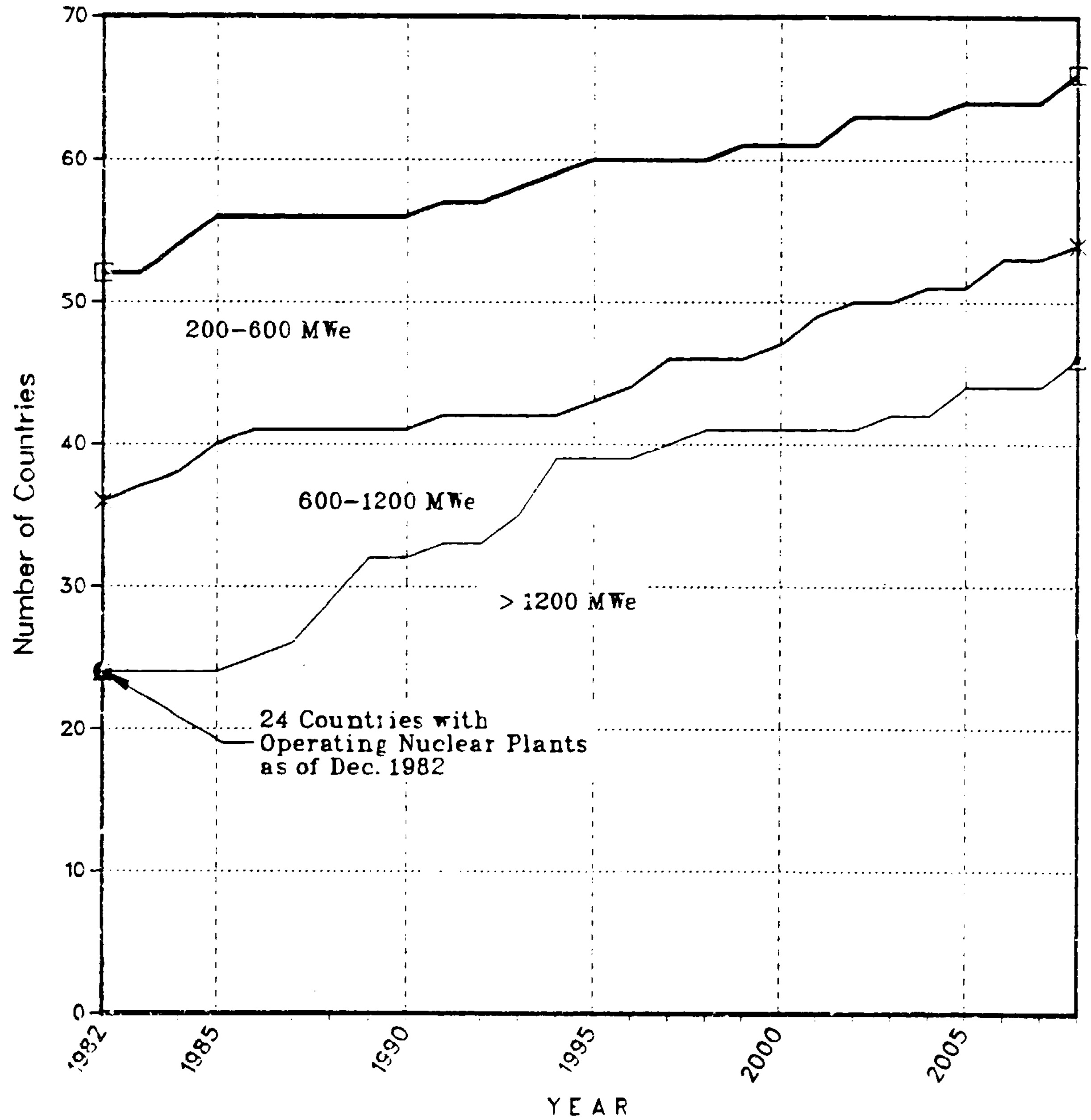
Estimated cost of electricity generated by nuclear, coal- and oil-fired plants starting operation in 1990



IPNEDC08 Source: as indicated

Figure 9

Number of IAEA Member States able to use Nuclear Power Plants as a function of Plant Size



Source: IAEA Economic and Energy Data ...