*Journal of the Korean Nuclear Society*
*Volume, 11, Number 1, March, 1979*

# Global Nuclear Power as an Alternate Source of Energy Prospects and Issues

Sigvard Eklund

Director General, International Atomic Energy Agency

World energy needs will rapidly grow over the next decade although there may be some legitimate question about the rates and extent of this growth. What is certain, however, is that the present world consumption of about 280 Exajoules[1] or 6.7 billions tons of oil equivalent will increase to more than twice this level by the year 2000 and therefore range between 12 to 15 billions tons of oil equivalent by that time.

Table 1 which is essentially based on the conservative projectionts of the World Energy Conference illustrates this process of growth for the main groups of countries and for the world as a whole.

This growth will take place-even if the maximum efforts at conserving energy are applied by industrial countries, as indeed they should be, and the most efficient methods for energy conversion and final utilization are developed throughout the world.

The population of the world which is of the order of four billion people today will grow to six billions by the year 2000. Most of this increase will take place in developing countries who, by then, will account for more than two thirds of the total. If the glaring gap between their standards of living and those of industrial nations is to be even modestly reduced a substantial expansion of the energy supply is unavoidable.

1) 1 Exajoule=$10^{18}$ Joules

Between 1950 and 1975 the world has increased its consumption from 1.7 to 6 billions of tons of oil equivalent. Its cumulative consumption has exceeded 100 billion tons during what is generally described as a period of incredible expansion. In comparison, the estimated 15 billion tons for the annual requirements of 2000 implies a cumulative consumption for the next 22 years of the order of 250 billion tons of oil equivalent that is two and half times that of the past two and half decades.

If oil which at present accounts for close to 50% of our total supplies were to maintain its relative share in the future a cumulative production of 125 billion tons would be required

**Table 1. Actual and Estimated Total World Primary Energy Consumption** ($10^{18}$ Joules)[1]

| | 1977 | 1985 | 2000 |
|---|---|---|---|
| North America | 85 | 102-112 | 120-140 |
| Western Europ | 53 | 63-75 | 90-110 |
| Japan, Australia, New Zealand | 19 | 26-33 | 34-46 |
| U.S.S.R and Estern Europe | 66 | 85-95 | 120-140 |
| Developing Countries (including China) | 57 | 84-95 | 136-174 |
| World Total | 280 | 360-410 | 500-610 |

1) $10^{18}$ Joules=$31.74\times10^6$ Kilowatt year thermal
=$23.90\times10^6$ Metric tons of oil equivalent

while present proven reserves are of the order of 90 billion tons. Of course, more reserves are likely to be found at ever increasing costs but these new discoveries could postpone by a few decades the unavoidable ultimate exhaustion. A similar situation prevails for natural gas. While resources of coal represent a substantially larger amount than those of oil, not only are these resources highly unequally distributed between nations but their increased exploitation gives rise to major social and environmental problems. Thus they can only partialy fill the increasing gap which the progressive depletion of hydrocarbon reserves will leave open.

Consequently, mankind has to turn to new sources of energy. Among them only nuclear power appears both technologically and commercially ripe for an immediate and major contribution.

In order to assess realistically the prospects of this contribution, four categories of questions should be briefly surveyed: the present status of nuclear power, its economic competitiveness, the obstacles its expansion encounters and the present and future role of international organizations in coping with these obstacles.

## 1. Present Status of Nuclear Power in the World

At the end of 1978 there were, throughout the world, 227 nuclear power plants in operation whose total capacity exceeded 110,000 MW(e) with 23 units with a capacity of more than 18,000 MW(e) coming on line during the year. A detailed breakdown by countries is contained in Table 2.

The significant role of nuclear electricity in the total electricity supply of some countries is clearly apparent from Table 3 which summarized nuclear electricity production for the period extending from mid 1977 to mid 1978.

**Table 2. Nuclear Power Reactors in Operation in IAEA Member States as of 11 December 1978**

| Country | No. of Reactors | Capacity (MWe net) |
|---|---|---|
| U.S.A. | 69 | 49,989 |
| Canada | 10 | 4,755 |
| Belgium | 4 | 1,676 |
| Finland | 2 | 1,080 |
| France | 14 | 6,353 |
| Germany, Federal Republic of | 15 | 8,174 |
| Italy | 4 | 1,382 |
| Netherlands | 2 | 499 |
| Spain | 3 | 1,073 |
| Sweden | 6 | 3,700 |
| Switzerland | 3 | 1,006 |
| U.K. | 33 | 6,982 |
| Japan | 21 | 12,279 |
| Argentina | 1 | 345 |
| India | 3 | 602 |
| Korea | 1 | 564 |
| Pakistan | 1 | 126 |
| U.S.S.R. | 27 | 7,616 |
| Bulgaria | 2 | 837 |
| Czechoslowakia | 2 | 491 |
| Germany, Democratic Republic of | 4 | 1,287 |
| 21 Member States | 227 | 110,814 |

In this connection, the excellent record of operation of nuclear stations during the harsh winter of 1977 is particularly worth remembering. For the period of the first three months of that year, the load factor of seven nuclear plants in New England, USA, averaged 86%, that of the four Pickering Units in Canada more than 90%, and that of five nuclear power plants in Sweden more than 75%.

While it is obviously too early to speak of operational statistics for advanced nuclear systems, it is worth noting that the operation of the three fast reactors in the world, BN-360 in the U.S.S.R., Phenix in France and PFR in

**Table 3. Total Electricity Production from NPRs for the Period 1 July 1977—30 June 1978**

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

the United Kingdom, have shown no insuperable technological or safety difficulties. In particular, the problems connected with the steam generators seem to be quite well understood. The firm belief in the future of these systems has been demonstrated not only by the three above-mentioned countries, where bigger commercial sized units are being built or designed, also through the prototypes in the Federal Repulic of Germany and Japan and the start of the construction of a demonstration reactor in the Federal Republic of Germany.

## 2. Economics

Without going into a complex comparative analyiss of electricity generating costs which depend on the ground rules chosen and will, therefore, vary from country to country, the following major points should be made:

In spite of the sharp increases in the investment costs of both nuclear and conventional stations which have occurred over the last, few years, mostly caused by increasingly numerous and stringent environmental standards, nuclear plants in the 1000 MW(e) range have, as a result of a quintupling of fuel oil prices, achieved a substantial competitive advantage over oil electric stations fueled with imported fuel oil.

With regared to coal fired plants, the situation may be more complex and depends on the production and transportation costs of coal. However, if coal is priced on the basis of adjusted thermal parity with oil, the above conclusion reached for oil fired plants would of course apply.

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

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

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

Naturally, in the longer run, increasingly costly uranium ores would have to be mined if today's power plants, which use less than 0.5% of the potential energy obtainable from a unit mass of uranium, were to remain the main basis of expanding nuclear power programmes, but the efforts at present applied to the development of commerical breeder reactors in major industrial countries provide a solid foundation for a nuclear economy whose fuel resources would become practically unlimited, both as a result of a hundredfold increase in the energy which would be derived from known uranium resources, and the economic possibility of mining much poorer uranium ores.

### 3. Obstacles and Issues

In spite of these highly positive elements, substantial reductions have occurred in the nuclear power programmes of most industrial and developing countries as compared to their 1773 objectives. What is particularly striking is that these reductions took place against the background of a fivefold rise of oil prices and we are unavoidably faced with the question: considering the technical reliability and the economic advantages of nuclear power, what are the reasons for its present difficulties?

The answer requires a brief analysis of a chain of events adding up to a genuine vicious circle. Certain aspects of nuclear power and of its fuel cycle have given rise to doubts and uncertainties, some of which are based on fact and many on imagination. As a result, nuclear opposition movements have grown among private citizens in some countries and restrictive laws and regulations have been enacted by some governments in others. The campaign unleashed by thess groups and the impacts of these regulations have brought about serious difficulties for the decisionmakers in the electric power sector, cancellations and cost overruns have occurred, which are then used in some quarters as arguments against the reliability of estimates of nuclear power performance and costs.

In some countries, governments, although elected in democratic ways, are prevented through the activity of pressure groups from introducing major technological innovations in the society. Just how widely these new ideas are shared is not exactly known, but those who espouse them are very adament and vociferous, they have access to news media and they exercise considerable political influence. Although referenda had sometimes in the recent past shown a remarkable consistency of two to one in favour of nuclear energy, the latest cases of Austria and of some states of the U.S.A. show an alarming trend towards rejection or at any rate postponement of nuclear power.

It should perhaps at this stage also be said that this is a phenomenon particularly evident in the highly industrialized affluent countries with market economies. The developing countries with more than 2/3 of the world's population are still primarily concerned with how to gain access to modern technologies on the best term and how to use technology to further their economic development and self-reliance. The countries with centrally planned economies also continue to regard science and technology as benevolent forces.

The present attitude of some sectors of the public against nuclear power in affluent societies is only one aspect of the changed attitude toward science and technology in general. Although everybody wishes to benefit from all the convenience which electric energy makes available, further development is considered unneccessary by some groups. Very little thought is given to the means which must be provided to maintain the standard of living in the developed countries, not to mention what is needed to raise the standard of living in the developing countries. Very little thought is given to the question of how to secure food and water for a population which will probably reach the 6000 million level at the end of the century. Hiding behind terms like "appropriate, soft or intermediate" technologies, these wishful thinkers would have a world where the developing countries can make do with windmills while the developed would content itself with zero growth. Let there be no mistake: small non-conventional energy sources might be the best solution to energy supply in small rural communities, but they cannot turn the wheels of industrialization of a country.

In this turmoil of unclear thinking, nuclear energy has become the symbol of the hard technology which non-believers in technical development are now so vigorously critizing. I can see two explanations for this.

One is that the consequences of a slow-down or halt in the planning and construction of nuclear power stations are not immediately felt. The difficulties will only show up six to ten years from now in the form of lack of electrical energy for which the utilities and electricity boards will then be held responsible. Part of the difficulty lies in the difference in the time-frame in which the scientist or engineer, as opposed to the politician, must operate. It is clear, for instance, that advocates for a decision to stop using artificial fertilizers, the greatest polluting agent of our surroundings, would never get much support because the consequences would be felt within a year's time and their responsibility for such a decision would still be fresh in the public mind.

Another reason why nuclear energy has become a scapegoat lies in the conscious or unconscious association in most people's minds between the peaceful uses of nuclear energy and nuclear weapons. If asked to which one of the two arguments I attach the greater significance, I would very definitely consider it to be the first one: the changed attitude towards science and technology, and the underestimation of the importance of a secured energy supply for the whole economy.

What are some of the real issues which condition the future development of nuclear energy?

With regard to the impact of nuclear power on the environment, it has, in many respects, become a victim of its own thoroughness. No other source of energy, indeed no industrial technology, has even been the subject of such comprehensive and detailed analyses of its environmental effects. The results of these studies have led to two major conclusions:

> Under normal operating conditions, the release of radioactivity to the environment caused by operating reactors and their fuel cycle infrastructure within the scope of the largest programmes contemplated for the year 2000 would represent a very small fraction of the natural radiation burden.
>
> The mathematical expectation of human and property damages which may result from nuclear accidents within these programmes is only a small fraction of the overall risks involved in the life style of an industrial society.

However, these generally favourable conclusions do not in any way imply than no work remains to be done on the ecological effects of nuclear power.

Among the major areas which call for additional investigation and action are: further improvements of nuclear safety, decommissioning of nuclear installations and, above all, the closing of the nuclear fuel cycle, especially with regard to the storage and ultimate disposal of radioactive waste. At the same time, more the rough analyses of comparative environmental impacts of different energy sources are essential to achieve a reasonable perspective on the consequences of alternative energy strategies.

The other category of problems stems from a very legitimate concern over the possible proliferation of nuclear weapons. However valid this preoccupation may be, it has sometimes been coupled with a quite invalid argument according to which the expansion of nuclear civilian power programmes is unavoidably linked with an increased probability of military applications.

Although the history of nuclear energy offers not a single example of such correlation, there still remain lingering doubts which only a comprehensive system of controls and safeguards, freely accepted by all parties, can finnaly dispel.

As was already mentioned, these primary uncertainties have given rise to a series of actions which have in turn brought about secondary uncertainties in such fields as, for instance, nuclear power plants licensing and construction times, assurances of nuclear fuel supply, ultimate fate of irradiated fuel, which sometimes outweigh the clear economic advantages. While a good part of the efforts required for the solution of these problems will have to be borne by national governments, many of them have international implications with which only an international approach can successfully cope.

The question thus arises: what international action can be taken to diminish these uncertainties?

## 4. International Action

There are still uncertainties, at least in the public mind, on some technical questions, particularly on certain aspects of nuclear safety and waste management. The IAEA and the Nuclear Energy Agency in Paris have been working for many years to establish internationally acceptable standards, guidelines and procedures that will not only help to ensure the safe design, construction, operation and siting of nuclear plants but will also give the necessary reassurance to the public. The limited resources at our disposal mean that all major Research and Development activities in the field of nuclear safety must be based on national efforts. International work must concentrate on harmonizing these efforts, on distilling a consensus and on giving this consensus a truly international authority which should at least carry more weight in the public mind than the efforts of national nuclear bodies. For these reasons too, the IAEA has brought safety and environment oriented organizations, such as the World Health Organization, the United Nations Environmental Progamme, the International Labour Organization and others, fully into its work.

As a result, it may be truly said that international nuclear safety standards today have the full endorsement of the world's health and safety authorities, as well as its nuclear regulatory authorities. It must be frankly recognized, however, that this has not made these standards immune from attack and criticism.

It is gratifying that in the beginning of December 1978, the following five codes of practice were issued:

1. Safety in nuclear power plant siting
2. Safety in nuclear power plant operation, including commissioning and decommissioning
3. Design for safety of nuclear power plants
4. Quality assurance for safety in nuclear power plants
5. Governmental Organization for the regulation of nuclear power plants

The IAEA shall, of course, continue to complete the comprehensive nuclear safety programme which, year by year, is extending its coverage to every aspect of the safety and the current generation of nuclear power reactors.

While this work is very valuable, one major element is still missing. There has still not been any national or international demonstration of the viability of final geological disposal of high-level waste on an industrial scale. This must become a top priority. The focus of environmental criticism has shifted with time from reactor operation to the risks of reactor accidents and now chiefly concentrates on what it considers to be the main chink in the armour of the nuclear industry, namely, final high-level waste disposal.

This is an important technological "uncertainty", not in the sense that it is insoluble, far from it, but in the sense that the solution has not yet been demonstrated for the world to see.

The Swedish Government has approved building of a spent fuel storage centre 25 meters underground and about 600 meters from the Oskarshamn nuclear station on the south-east Swedish coast. The facility, with four 750-metric-ton capacity pools, is to be started in autumn 1979 and the first half is to be completed and ready for storage in early 1984. The facility is intended for 10~30 year storage.

However, it must be repeated again that the major uncertainty which nuclear energy must overcome is not technological but political and lies in the changing policies of government.

At the root of this uncertainty is concern about the further proliferation of nuclear weapons, a concern which made a quantum jump in 1974 and which deepened again last year with reports that nuclear weapons might be spreading to other areas of acute political concern. This is a problem on which the IAEA has been working from the start of its activities, since it is perhaps the major raison d'être of its existence.

The history of the last thirty years has demonstrated that even the most strenuous efforts at control will not prevent the slow but steady spread of the technology needed to produce highly enriched uranium or to separate plutonium. There is little prospect that the next thirty years will show us the way of creating technological or legal barriers against dissemination of industrial technologies-and it is really not our goal. A policy of denial would be neither realistic nor effective. What is, however, necessary now is to strengthen the existing international framework aiming at the non-proliferation of nuclear weapons. In this context the IAEA can make a major contribution to diminishing the political uncertainty by applying safeguards, full-scope safeguards, effectively and universally in the non-nuclear-weapon States and by being instrumental in other non-proliferation measures complementary to safeguards. Whether this universality of safeguards can be achieved, or other measures agreed upon, is up to the statesmen of the world.

Since 1974, there has been a growing apprehension that even effective safeguards may not be adequate to prevent proliferation if a country already has within its reach the means of producing nuclear explosive material. Debate has focused on the question of detection times of the "timely warning" needed to give diplomacy enough time to act upon the would-be diverter after he has begun the process of diversion but before the explosion takes place.

Until now it has been the IAEA's view that the chief political value of safeguards was to give other countries the continuing assurance that the safeguards country was not diverting -to remove this particular uncertainty-rather than to give time for international diplomatic action after a decision to divert has already been made. It still seems to us in Vienna that the continuous assurance of non-diversion rather than the last-minute prevention of an intended diversion must remain the main objective of safeguards.

Nevertheless, there is no question that the world would be a better place if the production of enriched uranium and plutonium were concentrated in as few localities as possible and were preferably undertaken in large, truly commercial plants operated under international or regional auspices. It is also in the interests of all that the political uncertainties that have beset the supply of nuclear fuel and particularly enriched fuel in recent years could be diminished.

These are some of the questions which are the subject of intensive study in a major international forum-the International Nuclear Fuel Cycle Evaluation Programme-which was initiated by the United States and in which all nuclear oriented countries play an active part. The work is divided between eight groups. In group no. 8 (advanced concepts) Commissioner Byoung Whie Lee plays an important role as one of the two co-chairmen.

The resulting reports and recommendations are expected to be ready by the end of 1979. They will provide a mass of useful information and possibly new approaches to the problems which face us. While INFCE cannot by itself establish new international structures, it may provide foundations for future political action which would remove the major uncertainties at present clouding the future of nuclear power.

**Table 4. Latest Estimates of Nuclear Capacity in the World** ($10^3$ MWe)

| | 1978 | 1985 | 1990 | 1995 | 2000 |
|---|---|---|---|---|---|
| High Case | 111(101)* | 365(274)* | 700(462)* | 1100(770)* | 1650(1200)* |
| Low Case | 111(101)* | 300(245)* | 530(373)* | 785(550)* | 1060( 850)* |

*Table figures in brackets refer to the countries with market economies and are based on the replies received to the questionnaires sent out in 1978 in the course of the work performed by the International Nuclear Fuel Cycle Evaluation Programme. The totals for the countries having not replied to the questionnaire have been estimated on the basis of the best available data.
Beyond 1990 all figures are rounded off.

**Table 5. Estimated Future Nuclear Energy Production and share of Total Primary Energy**
($10^{18}$ Joules and % of Total in Brackets)

| | 1977 | 1985 | 2000 |
|---|---|---|---|
| North America | 3.22(3.8) | 7—8(7) | 18—28(15—20) |
| Western Europe | 1.67(3.2) | 5—8(8—10) | 19—33(21—30) |
| Japan, Australia, New Zealand | 0.35(1.8) | 1.6—2(6) | 6—9 (18—20) |
| U.S.S.R and Eastern Europe | 0.57(0.9) | 3.3—5(4—5) | 18—24(15—17) |
| Developing Countries (including China) | 0.05(0.1) | 1—1.5 | 9—16( 7— 9) |
| World Total | 5.86(2.1) | 18—23(5—6.6) | 70—110(14—18) |

Like most general summaries of vast and complex problems, this survey of the issues connected with nuclear power has been both brief and incomplete. It does, however, lead to some unchallengeable conclusions:

Over the short term, nuclear power offers a proven substitute for the oil and gas which might be used for electricity production and can provide for many countries deficient in fossil fuel resources a substantial alleviation of their dependance on foreign imports. As tables 4 and 5 show, even the present minimum nuclear objectives for the year 2000 would represent for the world savings of the order of 1. 5 to 2. 2 billion tons of oil which is more than half of the present global consumption.

Over the long term, nuclear power offers us a technologically mature solution for meeting increased energy needs. In addition, through the development of breeder reactors, which would extend by a factor of a hundred the present uranium resources, it would supply a powerful insurance for the future economic development of the world.

Since in its most advanced applications nuclear power depends more on human than on natural resources, it will, to large extent, remove the inequalities which characterize the di stribution of the latter.

The obstacles still existing and the uncertainties still prevailing are more of a social-political than of a technical nature. Man has proved his abilities to cope successfully with the infinitely complex scientific and technological problems involved in the successful development of nuclear power plants. It should not be too much to hope that he will not fail in solving the remaining human problems.