Growth projections and development trends for nuclear power

The "new generation" of reactor designs reflects the influence of past experience and today's demands

by B. Semenov, P. Dastidar, J. Kupitz, and A. Goodjohn

The world's population continues to increase, having nearly doubled during the past third of a century. World energy consumption has increased even more rapidly, having more than quadrupled over the same period. This increase in energy consumption as compared to population growth has been taking place proportionately faster in the developing countries over the past 15 years than in those that are already industrialized. *(See accompanying figure.)* It clearly indicates that initial development requires energy in increasing *per capita* quantities as efforts are made to make quantum improvements in the welfare of a country and its people.

For the industrialized countries, the same proportionately larger demand for energy was evident until the "oil crisis" of the early 1970s. Since that time, and particularly in countries which depend to a large extent on imported oil, an energy conservation/efficiency ethic has become a way of life and relatively smaller increases, and in some countries even decreases, in the year-to-year consumption of energy occurred. On the whole, however, the trend is still positive and it is expected to remain so.

Other interesting facts have been revealed. The rates of increase of total electrical consumption in both industrialized countries and the developing countries have been clearly positive, irrespective of any energy crisis and, in magnitude, always greater than just the increase in energy consumption itself. In the developing countries this rate of increase over the past 15 years has been almost 7% per year and 3% per year in the industrialized countries. The latter rates were also of the order of 7% per year until the oil crisis period of the early 1970s. If these trends of increasing electrical consumption on an overall worldwide basis continue as expected, conventional energy resources used to generate electricity, i.e., hydro and fossil fuels, will be rapidly depleted. Moreover, fossil fuels — coal, oil, and natural gas — whose burning now provides almost two-thirds of the world's electrical energy and contribute significantly to the increasing concerns regarding environmental pollution, have a myriad of other more unique uses.

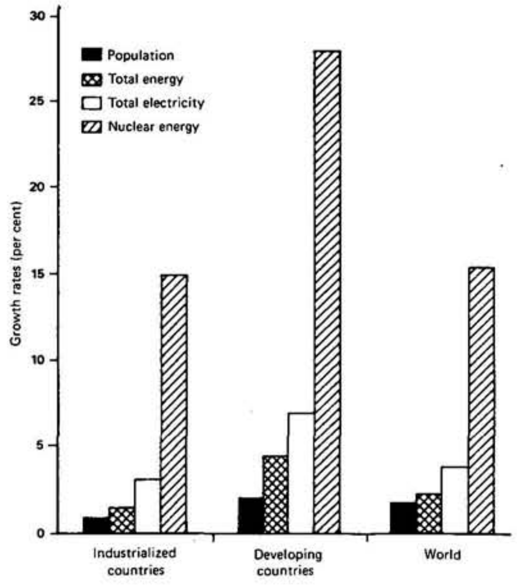
Energy resources other than fossil are needed and nuclear systems offer an effective option. Indeed, for the immediate future, pending some breakthroughs in the so-called soft technologies, i.e., in cost-effective photovoltaics, or in the ultimate promise of fusion systems, nuclear fission and fossil fuel (primarily coal) are the only really viable alternatives that can be considered.

Status of nuclear power

Despite the concerns presently identified, nuclear power continued to make great strides in 1988 in meeting the world's increasing demand for electricity. This is reflected

Mr Semenov is Deputy Director General, IAEA Department of Nuclear Energy and Safety; Mr Dastidar is Director of the IAEA Division of Nuclear Power; Mr Kupitz is a senior staff member in the Division of Nuclear Power; and Mr Goodjohn is a consultant to the Division.

Average annual growth rates, 1974–87



NUCLEAR POWER STATUS AROUND THE WORLD (as of 31 December 1988)

	In operation		Under construction		Total operating experience (to 31 December 1988)	Electricity supplied by nuclear power reactors in 1988	
	No. of units	Total net MWe	No. of units	Total net MWe	Years — Months	TWe·h	% of total
Argentina	2	935	1	692	20–7	5.1	11.2
Belgium	7	5 480			86–7	40.6	65.5
Brazil	1	626	1	1 245	6–9	0.6	0.3
Bulgaria	5	2 585	2	1 906	43–8	16.0	35.6
Canada	18	12 185	4	3 524	206–0	78.2	16.0
China			3	2 148			
Cuba			2	816			
Czechoslovakia	8	3 264	8	5 120	44–1	21.7	26.7
Finland	4	2 310			39–4	18.4	36.0
France	55	52 588	9	12 245	488–1	260.2	69.9
German Dem. Rep.	5	1 694	6	3 432	72–5	10.9*	9.9
Germany, Fed. Rep. of	23	21 491	2	1 520	279–3	137.8	34.0
Hungary	4	1 645			14–2	12.6	48.9
India	6	1 154	8	1 760	72–8	5.4	3.0
Iran, Islamic Rep. of			2	2 392			
Italy	2	1 120			77–10		
Japan	38	28 253	12	10 931	394–0	167.8*	23.4
Korea, Republic of	8	6 270	1	900	36–4	38.0	46.9
Mexico			2	1 308			
Netherlands	2	508			35–9	3.5	5.3
Pakistan	1	125			17–3	0.2	0.6
Poland			2	880			
Romania			5	3 300			
South Africa	2	1 842			8–3	10.5	7.3
Spain	10	7 519			82–7	48.3	36.1
Sweden	12	9 693			135–2	66.3	46.9
Switzerland	5	2 952			68–10	21.5	37.4
Taiwan, China	6	4 924			44–1	29.3*	41.0*
United Kingdom	40	11 921	2	1 833	810–10	55.5	19.3
USA	108	95 273	7	7 689	1261–10	526.9	19.5
USSR	56	33 833	26	21 230	687–2	215.7	12.6
Yugoslavia	1	632			7–3	3.9	5.2
World total	429	310 812	105	84 871	5040–9	1794.4	

* Estimates. Source: IAEA PRIS.

in the world status of nuclear power plants, in operation and under construction as of the end of 1988, based on data available to the IAEA's Power Reactor Information System (PRIS). *(See accompanying table.)*

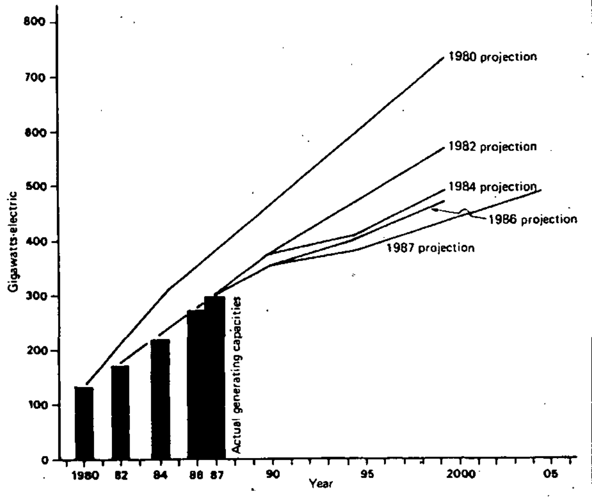
In 1988, fourteen new nuclear power reactors in eight countries were commissioned, bringing the world's total number of operating nuclear electricity plants to 429. As of the end of 1988, 26 countries now have nuclear power plants for electricity generation. Total worldwide electrical generating capacity of nuclear plants grew by about 12 gigawatts-electric (GWe) in 1988, and now surpasses 310 GWe.

Countries that brought new nuclear power reactors on line in 1988 were France (2), Japan (2), Federal Republic of Germany (2), Republic of Korea (1), Spain (1), United Kingdom (3), United States (2), and USSR (1). In 11 of the 26 countries, more than one-third of the total electricity produced was supplied by nuclear power. In total, with the generation of just under 1800 TWh, almost 17%, or one-sixth, of the electricity generated in the world in 1988 was produced by the 429 nuclear power reactors. For comparison, this is about equal to the total electricity generation in the world in 1957 from all sources.

Over the past 15 years the growth in the use of nuclear power has been phenomenal. Whereas the growth rate in electrical consumption in the industrialized countries has been 3% per year during this period, the growth rate in the fraction of electricity produced by nuclear has been 15%. In the developing countries where electrical consumption has been growing at an even faster rate of 6.9% per year during this period, the fraction supplied by nuclear has undergone growth rates of 28% per year. Of interest, of course, are all the countries of the world in this second category where electrification and all of its associated conveniencies is being increasingly recognized, leading to growth rates in electrical consumption which exceed growth rates in energy consumption as a whole and where nuclear power is yet to be implemented.

Projections for the future. Projecting future nuclear power growth has become a most difficult task. The past does not portend the future, certainly not the immediate future. For reasons already cited, not only have the growth rates for electrical consumption in the industrialized countries been lower over the past decade or more, leading to either cancellation or delays in previously planned capacity additions, but the overall emotional

History of projections of nuclear generating capacity based on IAEA low estimates



Source: IAEA Energy and Economic Data Bank.

concerns regarding nuclear power have even more seriously affected the corresponding nuclear power growth rates. On a worldwide basis, actual growth has also consistently been lower than repeated forecasts. *(See accompanying figure.)* The steady reduction in nuclear capacity forecasts for the year 2000 is quite evident, although the discrepancy in recent forecasts has been reduced. The result has been a reduction of about 300 GWe in nuclear capacity additions for the year 2000 between forecasts made in 1980 and in 1987. Due to the continuing long period for nuclear implementation, including planning, licensing, construction and startup, nuclear generating capacity additions in the short term (up to about the turn of the century) will largely be determined by past decisions, although construction or licensing delays or policy changes could still have an effect. In contrast, the situation after the year 2000 is less predictable.

On the basis of the IAEA low estimates made in 1987, the projected growth of installed nuclear generating capacity and percentage of nuclear contribution to the total installed electrical generating capacity in industrialized and developing countries up to the year 2005 has been estimated. *(See accompanying figure.)* The total increase in nuclear generating capacity from 298 GWe in 1987 to 503 GWe in 2005 corresponds to an average annual growth rate of 3% and an increase of 205 GWe during this period.

Of this increase, the nuclear generating capacity in the industrialized countries is forecast to increase by 153 GWe, corresponding to an annual average growth rate of about 2.5% or just about the same growth rate as forecast for electrical consumption. In other words, the concerns regarding nuclear, coupled admittedly with overly optimistic projections of electrical consumption growth during the early 1970s, have now brought the projected nuclear participation in future electrical growth to be just about equal to overall electrical generating capacity growth. Indeed, starting in 1995, nuclear is forecast to levelize at 15% of the generating capacity in industrialized countries and remain at this level for the remainder of the forecast period. Due to their utilization in more of a base-loaded capacity, the nuclear plants are expected to produce, however, about 23% of the total electrical consumption between 1995 and 2005.

During this same period nuclear generating capacity in developing countries is expected to reach 72 GWe by the year 2005, corresponding to 51 GWe of nuclear capacity additions and to an average annual growth rate of 7.1%. In contrast to the industrialized countries, nuclear power in the developing countries is expected to continue to gain an increasing share of the expansion in electrical generating capacity, rising to a 5.3% share by the year 2005. Thus, as indicated, 25% of all new nuclear generating capacity to be placed in commercial operation in the world by the year 2005 is expected to be in developing countries.

By the year 2005, the share of nuclear power worldwide is forecast to be about 12% of the total electrical generating capacity, significantly below expectations of a decade ago, but reasonable based on the current situation and trends. Disturbingly, to meet the current projections of total electricity demand, electricity generation by fossil fuels, mainly coal, will have to increase by a factor of about 1.8 by the year 2005, not a desirable trend from the point of view of the effects on environment. The urging of the Toronto Conference of 1988 to reduce CO_2 emissions to 20% below the present emissions is therefore not likely to be met.

Lessons learned from past experience. For nuclear power to again regain a position of providing an increasing fraction of new generating capacity in industrialized countries as a whole, to sustain and, hopefully, to increase the rate of growth in the developing countries and, indeed, to open the doors for the introduction of nuclear power to several new countries, critical attention must be paid to the lessons learned from past experience.

Of particular significance in this regard were the nuclear power accidents at Three Mile Island and Chernobyl. Both led to careful reexaminations by all countries with operating nuclear power plants of the basic safety characteristics of their own plants. The former accident, although relatively insignificant in terms of consequences to the public, led to several improvements to further enhance technological safety and reliability. This accident also revealed that the available instrumentation could lead to a misinterpretation of the status of the reactor system. The operator training was also insufficient to interpret unusual events as they evolved. Improved simulators and more rigorous operator training, including training on simulated unusual happenings, resulted. In addition, the instrumentation itself improved and operators were presented with better formulated information. This subject matter, often called man-machine interface, is still undergoing development. The Chernobyl accident did have a severe impact on the public and was of much greater international significance. The accident at Chernobyl has led to a very thorough reevaluation by the Soviet Union of their nuclear programme and the type of plants they will build in the future.

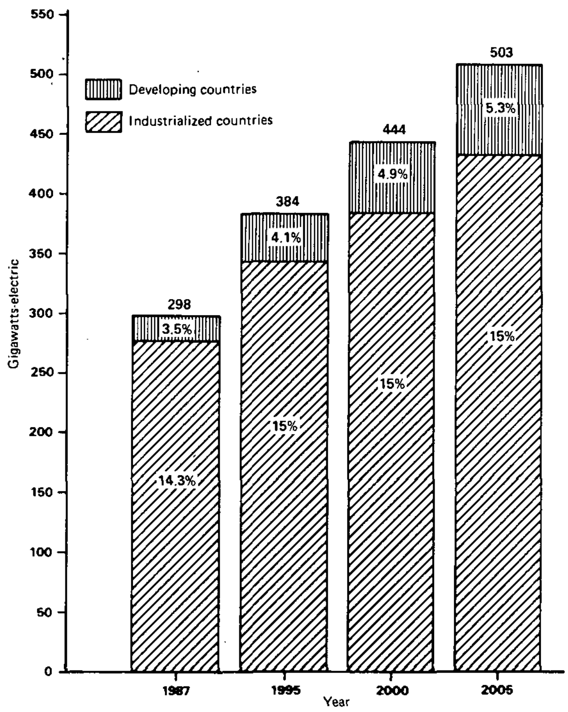
Irrespective of the different consequences to the public, both accidents did result in an enormous investment and economic loss and large expenditures for cleanup, a lesson learned which clearly demands that greater attention be paid to investment and economic risk protection in future nuclear plants.

Nuclear plant reliability and the closely associated plant availability — which indicates the percentage of time per year that a plant is capable of supplying power — are also key factors requiring future consideration. Actually, the improvements in availability over the last decade have been significant. In 1977, the average availability factor for the 137 nuclear power reactor units reported to the IAEA's Power Reactor Information System was only 64.7%; in 1982, the number of nuclear reactor units had increased to 200, but the average availability factor remained around 65% — a figure which gave cause for concern. By 1987, this figure had improved to 71.4% for 346 nuclear power reactor units. It is even more significant that 42% of these nuclear power units operated with an energy availability of 80% or more in 1987. Efforts to continue this improvement trend are clearly required.

Correspondingly, through studies of probabilistic safety — where the probabilities of failure of components and systems are used to estimate the overall probability of a sequence of failures — the weak links in the safety chains have been identified and measures taken to improve overall safety. Human failures have also been analysed using similar techniques. The result has been large reductions in the number of challenges to a plant's safety systems.

Another factor which has become predominant in terms of past experience as a key element in guiding future developments is the matter of size. In recognizing the capital-intensive nature of a nuclear power plant, design development by the highly industrialized countries has led, for the most part, to larger and larger sizes for the sake of promised reductions in investment cost per unit power output. Such extrapolations have led not only to greater complexity in terms of number of components and instrumentation and control required, but has placed greater demands on operation and maintenance capabilities. Simplifying the systems could not only reduce human failures at the operation and maintenance level, thereby improving safety, but could also reduce investment costs. Some designers believe that simplification, built-in high quality, more recourse to natural processes for safety, and good economics can be effectively achieved in power units of smaller sizes. It is becoming increasingly clear both in terms of future application in many developing countries and in terms of flexibility to meet apparent lower load growth patterns in some industrialized countries that there is a market for smaller nuclear power plants. The IAEA's investigations, initiated in 1983, of such small- and medium-sized power plants (SMPRs) provided such evidence.

Projected growth in nuclear generating capacity up to the year 2005 (based on IAEA low estimates) and percentage of nuclear contribution to total installed electrical generating capacity



Source: IAEA Energy and Economic Data Bank.

Another size-related factor which also gives impetus to the future development of SMPRs is the potential future application of nuclear power for heat only, either as low temperature district heating for commercial and residential applications or for higher temperature process steam and heat. Concerns about the release of greenhouse gases in such applications if fossil fuel continues to be used may accelerate the need for nuclear heat generation in the not too distant future. The market for such systems demands smaller sizes associated with more localized distribution networks.

Framework for future success. Past experience with nuclear power has established a framework upon which the future structure of nuclear power will be built. The structure should have many facets:

- large-sized plants for those industrialized countries whose load, load growth, and distribution systems justify such application;
- small- and medium-sized plants where the converse is true and for applications beyond solely electrical generation;

- greater attention to the nature of safety irrespective of the size of the plant, with more emphasis on longer grace periods for safety actions, passive characteristics and the ability of man, if needed at all, to control and manage the situation particularly during upset conditions; in addition, the plant has to be designed with good operational margins so that the safety systems are rarely challenged; increased aversion to investment risk may be considered a subset of this facet;
- greater standardization and simpler plants, enabling improved schedules, better economics, higher reliability, simpler operation, better man-machine interface, centralized services, enhanced international exchange and overall improved understanding; in addition, there should be a streamlined regulatory mechanism which would be promptly responsive but without losing effectiveness;
- improvements in resource utilization, effective fuel cycle closure, and efficient waste handling.

So that the framework itself does not crumble, the "strive for excellence" in every plant and in every activity, which has become a key phrase relating man's effort to revive the nuclear growth pattern, must remain inherent to the whole process.

Nuclear power development trends

Increased attention to this new framework is being given by not only the governments and industrial entities in nations with an already well-developed nuclear power infrastructure, but also by those nations seriously considering an expansion or entering into nuclear power implementation. The development trends for all reactor concepts are clearly reflecting the influence of past experience and the revised framework for the future.

Light-water reactors. The current light-water reactor (LWR) technology has proven to be economic, safe, and reliable. Most industrialized countries continue to develop large units, with power outputs above 900 MWe, as advanced LWRs (ALWR) for the 1990s. These ALWR designs result from a continuous upgrading and evolutionary improvement of current models. The N4 model (1400 MWe) for example, which is now under construction in France, derives directly from the standardized P4 series (1300 MWe), while achieving a reduction of 5% in cost per installed kilowatt compared with the P4 series. In the Federal Republic of Germany the "Convoy" plants are a group of three pressurized water reactors of the standard 1300-MWe size. The advanced features of the "Convoy" plants are mainly in the engineering and project management associated with nuclear power plant construction. The design of the VVER-1800 has been started in the USSR as an upgraded version of the VVER-1000 with improvements in safety and economics. The Westinghouse-Mitsubishi advanced pressurized water reactor (APWR-1350 MWe), the British "Sizewell-B" PWRs (1250 MWe), the Combustion Engineering "System 80 Plus" (3800 MWth) and the General Electric-Hitachi-Toshiba advanced boiling-water reactor (ABWR-1360 MWe) are further examples of the large size ALWRs. All of these advanced systems incorporate technological and operational procedure improvements, better fuel performance and burnup, better man–machine interface using computers and improved information displays, greater plant standardization, better operator qualification and simulator training. The result has been manifested in the gradual availability factor improvements and the lower number of challenges to the safety systems.

The United States programme, being conducted by the Electric Power Research Institute jointly with the Department of Energy, is an example of a different approach to evolutionary development. A comprehensive set of user requirements has been compiled and the conceptual design of ALWRs to meet these requirements is scheduled to be carried out over a 3-year period with industry participation. Both large reactors and smaller reactors (outputs of 600 MWe or less) are being considered, with the smaller units emphasizing the use of passive safety features. Design certification from the licensing authorities is a key feature of this programme and it is contemplated that these units could be commercially offered in the 1990s without the need for prior demonstration. The AP-600 (advanced passive 600 MWe) pressurized-water reactor, the SBWR (simplified boiling-water reactor) and the SIR (safe integral reactor) pressurized-water reactor are all small ALWRs emphasizing enhanced passive safety. The SIR has been developed jointly by Combustion Engineering and Stone and Webster in the US together with Rolls-Royce and the Atomic Energy Authority in the United Kingdom.

A more radical approach is being taken by the developers of the PIUS reactor (ABB-Atom) and the ISER (University of Tokyo). These reactors are based on the principle that the ability to shut down the reactor and provide continuing core cooling to remove decay heat after accidents should be entirely passive. Several unique plant design features whose operation is entirely passive and, hence, requires no operator action and whose performance is based on irrefutable physical principles are incorporated in these designs. The designs, covering both boiling and pressurized water reactor concepts and mostly in the small size range are, in many cases, at an early stage in concept design and proof of principle will probably require a demonstration plant. Thus, these concepts would appear to be farther away from commercialization.

With delays apparent in the large-scale deployment of breeder reactors, mostly from cost considerations, improvement in uranium resource utilization has become another element in the evolutionary development of LWRs. Relatively limited changes in existing water reactors could provide attractive alternatives for such improved utilization strategies. These changes could range from plutonium recycling to new core designs specifically aimed at significant improvements in fuel utilization. Some of these approaches would have low economic risks and could be incorporated easily and rapidly. Confirmation of technical and economic feasibility and safety is expected shortly from validation studies and development work in progress in several countries, including the US, Japan, Federal Republic of Germany and, in particular, France. Many of these modifications, if proven satisfactory, could be applied to existing reactors within the next 3–5 years.

Heavy-water reactors. Two types of commercial pressurized heavy-water cooled reactors (HWR) have been developed. Both the pressure tube and pressure vessel variants have been fully proven in commercial application in several countries. Sizes in the output range of a few hundred MWe up to 900 MWe are available. Lifetime capacity factors of most of them have been among the top of all commercial reactor types. Safety performance has also proven very good. The promise of low fuelling costs arising from the inherent neutron economy of heavy water moderation has been demonstrated. This inherent neutron economy offers prospects for a wide range of fuel cycles including low-enriched uranium, use of reprocessed uranium from LWRs (offering a synergism between LWRs and HWRs), plutonium recycle, and thorium high conversion cycles; most of which are being investigated, particularly in Canada, as part of a continuing development programme.

The continuing design development programmes for HWRs are primarily aimed at reduction of plant costs and evolutionary-type enhancement of plant performance and safety. These designs include the 500-MWe reactors in India, several designs in Canada, including the 480-MWe Candu-3 and the 800-MWe Candu-6 MK2 and the 380-MWe Argos under joint development by an engineering firm in Argentina and Siemens in the Federal Republic of Germany.

Gas-cooled reactors. With the completion of the Heysham-2 and Torness Stations in the United Kingdom, the advanced gas-cooled reactor (AGR) programme, pioneered by the UK, appears to have come to an end. Further development work on this carbon dioxide-cooled system will be concentrated on improvements in plant performance and life extension studies of existing plants.

The development of the higher temperature, helium-cooled gas-cooled reactor (HTGR) is proceeding in the US, Federal Republic of Germany, USSR, and Japan. Most of the effort is concentrated on small modular designs with an individual power output capability of 80 MWe up to about 150 MWe with only a limited effort, at this time, on larger designs based on the Fort St. Vrain (330 MWe in the US) and the THTR (300 MWe in the Federal Republic of Germany). The motivation for the present effort comes entirely from a critical examination of the requirements evolving from the new framework for future nuclear plants. Emphasis has been placed on the modular nature of the designs with a maximum use of factory fabrication, as opposed to field construction, for better quality control, and schedule and cost savings. The power output of the individual modules and the reactor core configurations have been deliberately determined on the basis of satisfying safety and investment risk protection criteria (which are more stringent than previously implemented for any reactor system) by means of completely passive systems closely coupled to the reactor core. Separation of these fewer nuclear systems, constructed according to nuclear standards, from the majority of the plant, which could be constructed according to more conventional construction standards, is intended to yield significant cost savings.

The key features of the HTGR which permit these characteristics are the benign helium coolant, the large mass of graphite moderator (hence, low power density) closely coupled to the fuel, the always negative power coefficient and, particularly, the fuel itself, which is in the form of small particles individually coated with multiple layers of ceramic material. This fuel is capable, along with the graphite moderator, of withstanding very high temperatures without losing integrity. These plants are capable of withstanding a complete loss-of coolant accident, which is a unique feature associated with no other reactor system.

After almost 30 years of design and operating experience, the basic characteristics and technical performance of HTGRs are already well known. However, it is recognized that the unique features and characteristics of the modular HTGRs will likely require demonstration prior to design certification and commercialization and hence programmes in the US, Federal Republic of Germany, and USSR are proceeding accordingly. With the relatively small size of each module, it is possible to contemplate such a demonstration with just one module with a later expansion into a multi-module plant at the same site for commercial purposes. Indeed, one of the advantages claimed for the modular concept is the ability to progressively expand on a single site by adding modules to meet load growth demands. This feature, coupled with the benign nature of the concept, could perhaps make the modular HTGR a good candidate for export to countries with low electricity demand patterns and a less developed infrastructure for the implementation of nuclear power.

The HTGR programme in Japan, although recognizing the potential for higher quality steam production and higher efficiency electricity generation, is nevertheless aimed primarily in the direction of proving the capability for even higher core outlet temperatures for the helium coolant (up to 1000°C) with the view to a large number of industrial process heat applications. A small test reactor, the 30-MWe HTTR, is presently being constructed in Japan for tests related to this objective.

Liquid-metal reactors. The deployment of liquid metal fast reactors (LMFR) as breeder reactors as well as for electricity generation has not gained the momentum expected due to availability of adequate low-cost uranium resources to meet near and mid-term demands.

Nevertheless, there is an awareness in the industrialized countries that breeder reactors will be needed in the early decades of the next century particularly if nuclear power implementation regains momentum.

In the interim, experience continues to be gained from the more than 200 reactor-years of operating experience from experimental and mid-size LMFR power units. The design development of advanced versions is also continuing, with due recognition to the revised framework for the next generation of nuclear power plants. Work is also continuing on fuel cycle development with emphasis on extending fuel burnup and demonstrating fuel cycle closure. Most of the fuel cycle development is on mixed oxide, but recent developments in the US on the use of ternary metallic (U-Pu-Zr) fuel and the associated pyroprocessing of spent fuel is showing considerable promise. A notable feature of pyroprocessing is that the majority of the long-life actinide elements which accompany plutonium through the process are subsequently recycled and thereby removed from the waste stream.

Design development in Europe, Japan, USSR, and India is following the traditional path of considering large designs fuelled with mixed oxides. In Europe and in the USSR, 1500 to 1600-MWe units are being developed with component design, plant design, and fuel cycle following an evolutionary pattern from the successful operation of the Phénix and Superphénix in France, the PFR in the UK, and the BN-350 and BN-600 in the USSR. Major efforts are under way at this time to make better use of the philosophy of passive safety in these designs. The efforts in Japan and India are concentrated on smaller units as the next step in design evolution. With the 280-MWe Monju prototype reactor expected to go critical in 1992, Japan's next step is expected to be in the 800 to 1000 MWe range. India is proceeding from their fast breeder test reactor (FBTR) with the follow-on design of a 500-MWe pool-type prototype (PFBR).

With the demise of the Clinch River breeder reactor in the US in the early 1980s, the liquid metal reactor programme initially proceeded down many advanced design avenues. The main thrust of the programme is now on a modular-type concept (PRISM) evolved by the General Electric Company. Each power block of the proposed system is comprised of three 471-MWth reactor modules connected to a single 465-MWe turbine generator. The plant has many innovative characteristics including the use of the ternary metallic fuel cycle, inherent reactor shutdown by thermal and reactivity response, passive decay heat removal, and all of the other construction and operational type characteristics claimed for such small modular concepts. The programme is proceeding with the conceptual design, pre-licensing stage on this concept with the intent of obtaining design certification following extensive testing of a full scale prototype module.

Conclusions

The trend of increasing electrical consumption in the world leads to several conclusions:

- Electricity is clearly foreseen as the most suitable and most adaptable energy option for the future. The cleanliness, ease of transport and end use, efficiency and overall versatility of electricity are among the many reasons. Electricity growth rates that are higher than both population and total energy consumption growth rates are expected to continue.
- The demand for electricity will place ever increasing demands on the basic resources used to generate electricity. Rapid depletion of the world's natural resources is foreseen if such resources continue to be the primary means of generating electricity and the environmental impact of such use will definitely be significant. In the long term, other resources for electricity generation must be developed and deployed.
- Nuclear power, despite the past and present emotional controversy concerning its use, can generate electricity in a safe, reliable, and economic manner. Indeed, when viewed in a larger perspective, the increasing world need for electricity and the development of nuclear power, which does not emit carbon dioxide into the environment, would appear to have occurred concurrently as a matter of coincidence and absolute necessity.
- The continued development of nuclear power in the manner of small evolutionary changes to those types that are presently deployed and of larger incremental advancements in the technology, as being considered in several advanced reactor designs, are addressing several of the issues identified with nuclear power. These development programmes should be aggressively pursued.