Nuclear power experience

by J. Daglish*

The Nuclear Power Experience conference[+] organized by the IAEA highlighted technical and economic experience in nuclear power production over the past three decades. Planning and development of nuclear power programmes (especially in the developing countries), the nuclear fuel cycle, nuclear safety experience, international safeguards, and a number of other topics were discussed during a week of meetings and panel discussions.

In a sense, this conference blazed the trail for another – the United Nations Conference for the Promotion of International Co-operation in the Peaceful Uses of Nuclear Energy for Economic and Social Development (to be held 29 August – 9 September 1983 in Geneva). The UN conference is being organized in recognition of the need to support nuclear programmes worldwide with appropriate non-proliferation guarantees, and will depend on knowledge of past experience in order to look to the future.

At the Nuclear Power Experience conference, Dr Hans Blix, Director General of the IAEA, noted that the year 1982 marks both the 25th anniversary of the Agency, and the 50th anniversary of Chadwick's discovery of the neutron. Within ten years of that fundamental discovery, the fission process had not only been recognized but had been put to work in the Fermi pile at Stagg Field, Chicago in December 1942[‡]. "Ten years, I think, is a remarkably short period for the progress from a fundamental discovery to an application which showed a very great potential," said Dr Blix. "It is true that part of that potential was military and that this was the one which received priority. Yet, within 10 to 15 years after that first man-made chain reaction pile we had nuclear power electricity production demonstration plants in three countries. Again, this was remarkably fast.

"In another ten years, in 1962, the first larger-scale demonstration nuclear power plants were in operation and the contract for the first commercially competitive light-water reactor was being negotiated. This, in itself, had a fundamental influence on the development of the international market, in which the light-water reactor soon dominated with some competition from other systems. The result – as we all know – was a tremendous increase in orders for nuclear power plants.

"Ten years ago, in 1972–73, when the first oil price shock came, it was believed not only that nuclear power was firmly on the way to taking over a main part of electricity production, but also that it would set a new standard for energy costs. As it turned out, it was the beginning of a troubled decade for nuclear power, marked by concerns on technical and economic issues and by a shaken confidence among the public in many countries in the benefits of this source of energy."

Michel Pecqueur, head of the French Commissariat à l'Energie Atomique, underlined this point in a keynote address. During the past 30 years there has been an unprecedented increase in energy consumption which has gone hand in hand with unprecedented industrial expansion. Since 1973 the energy problem has been a priority in world economics; growth recovery, which alone can put an end to unemployment, necessitates the free availability of sufficient energy resources at acceptable prices and guaranteed security of supply. It is absolutely necessary to achieve the regular development of the various energy resources, diverse in nature and geographical origin, to reinstate balance in the world economy. Developing countries must in future have greater access to imported oil – the most flexible and easiest-to-use form of energy. In an interdependent world the development of these countries will nurture the growth of the industrialized nations which, in turn, must control their needs and limit their oil imports as far as possible. "Nuclear energy has an important role to play," said M. Pecqueur. "Along with coal, and for large-scale uses, it is by far the best substitute for oil. It can be counted upon, it is safe, it is economical. . . . To sum it up, this form of energy has reached full maturity."

Why, then, was it so difficult actually to use nuclear energy even in the developed countries? M. Pecqueur sketched the outlines of the discussions which were to take place during the rest of the week. Setting up a nuclear industry in any country is a complex undertaking, and with supporting research and development activities it represents an expense which only the bigger industrialized countries can bear. If other countries want to have access to nuclear energy, they must first finance the purchase of reactors. However, nuclear units

* Mr Daglish was at the time of the Nuclear Power Experience conference editor of *ATOM* United Kingdom Atomic Energy Authority, 11 Charles II Street, London SW1Y 4QP, England.

+ Held from 13–17 September 1982 in Vienna, the Nuclear Power Experience conference was attended by more than a thousand participants from 61 countries. Two hundred and eighty-eight papers from 32 countries and nine international organizations were read and discussed at the conference. Proceedings of the conference will be published by the IAEA at a later date.

‡ See article by Mr Goldschmidt on page 3 of this issue of the *IAEA Bulletin*.

sold on today's market usually are suited only to countries with large electricity distribution networks. Since nuclear power stations require highly competent personnel, training requirements act as a bottleneck and delay the introduction of nuclear energy in some countries.

M. Pecqueur noted that the problem of developing nuclear energy is particularly acute in the industrialized countries, where "there should be a harmonious and methodical development of nuclear energy adapted to the national needs. Unfortunately, all the orders made in the 1970–75 period, which should be bearing fruit today, were crushed against and by psychological barriers." The nuclear industry is still something 'new'. "If the present situation is what it is, then we are partly responsible for it," he said. "We developed nuclear energy, and I think we did it the right way. On the other hand, for a long time we have not published our findings to the general public. It isn't an easy matter, as the subject is so technical it is difficult to grasp. But we must do our utmost so that a wider group of people is aware of our work and so that we can cast off the mysterious aura that lies around the subject of nuclear energy .... A democratic exchange of views and information paves the way to a better understanding and later to conviction.

"But this also necessitates greater political determination at a national level. We have our role to play, for sure, but political responsibility in the fullest sense of the word has an even more important role to play, and this especially as psychological phenomena have become preponderant."

No other industry has studied the problems of security and safety with such care, he said – again underlining a common theme in the presentations which were to follow. "However, we have never consented to say that our power stations were 100% safe. Even if the possibility of a serious accident occurring is extremely slight, we do recognize the fact, at least in theory, that one could occur. This attitude, despite the fact that it is based on scientific knowledge, is often exploited and people try to impose more and more strict regulations and try to find proof of absolute safety. The result of this kind of attitude is to delay considerably construction work on power stations, to increase their costs a great deal and yet to change the level of security only nominally and very slightly, because often the real problems are not considered. It can even have the opposite effect, that is to make the working of a power station more difficult because it is more complex.

"The same holds true for the end of the cycle. It is very easy to demand information on the power station, its fuel and the future developments in the fuel field the minute the decision to build a power station is taken. Technical progress in this field is very great and we can even say today that solutions do exist safely to condition waste from spent fuel reprocessing or the fuel itself, although the latter does not seem to be a very satisfactory solution, technically speaking. But it is dangerous to want to fix technical options several years in advance, especially as better solutions may be found in time, particularly in the case of final-storage techniques. Therefore, scientists and technicians must be allowed to have as much time as possible to find the best solutions possible."

M. Pecqueur closed with an appeal to 'man's reasonable nature'. "It is practically certain that in the next 20 years our planet will be faced with acute energy crises, and the vulnerable nature of our energy supplies will have a great impact on our economies," he said. "On the other hand, the prospects we have of the 21st century mean that we have to add a new dimension to the world's energy resources. Is mankind, either through heedlessness or through indifference, going to let an essential, economic, safe and available product slip through its fingers – especially as it can ensure mankind's medium-term and long-term survival in energy? Being a firm optimist myself I cannot believe this possible, and I persist in thinking that the complex world of nuclear programmes will once again slowly start to breathe and to live."

Limits to growth

Professor Ivan Morozov, deputy chairman of the USSR State Committee on the Utilization of Atomic Energy, argued in a second keynote address that world reserves of coal, uranium, thorium, and especially thermonuclear fuels, could meet man's need for energy for centuries at practically any rate of growth in demand. The limits to growth would be determined by other factors, particularly those of an ecological nature.

Prof. Morozov singled out the main factors – technical, economic and also social and political – likely to influence nuclear power growth rates to the end of this century and in the beginning of the next. First, advances made in technology and in the creation of capacity at the back-end of the fuel cycle – reprocessing, and the storage and disposal of radioactive wastes – would be important. In principle, the main technical and technological aspects of reprocessing and waste management problems had been solved already. In Prof. Morozov's view, there was no reasonable alternative to reprocessing if nuclear power was to be developed on a large scale.

"We should always bear in mind certain factors which are constantly at work," he said, "the increase in population; the mastery of a vast economic explosion, which also embraces energy production in both developed and developing countries; the increase in energy consumption by industry; environmental protection; the need to solve social problems, and various other such issues."

Apart from its use for electricity generation, we could expect a certain increase in the share of nuclear power in total energy production, starting in the 1990s, through

More than a thousand participants from 61 countries attended the Nuclear Power Experience Conference. The Press also were interested. Seen here are the speakers at the press conference at the end of the first day: (from left to right) Mr B.A. Semenov, Chairman of the Steering Committee of the Conference and IAEA Deputy Director-General, Head of the Department of Nuclear Energy and Safety; Professor I.G. Morozov of the USSR, who delivered on of the introductory lectures; IAEA Director General Hans Blix; Monsieur M. Pecqueur of France, who delivered the other introductory lecture; and the Deputy Chief Scientific Secretary of the Conference, Mr R. Skjoeldebrand.

the replacement of fossil fuels by nuclear power for heat production. Prof. Morozov noted that more than half of the Soviet Union's consumption of fossil fuels was for such purposes.

"The problem of the large-scale utilization of nuclear fuel for combined heat and power production is under consideration at present in a number of countries, and quite soon a large new specialized field will evidently emerge – nuclear heat and power engineering," he said. "The Soviet Union has developed and is implementing projects for nuclear heat and power stations where the production of heat is combined with that of electricity, and also for district-heating nuclear power plants producing only heat for domestic purposes."

Another use of nuclear energy would certainly be in the production of high-temperature heat for industrial purposes, using high-temperature helium-cooled graphite-moderated reactors; this would broaden the range of the direct application of nuclear sources in metallurgy and in chemical processes such as coal gasification. In principle, nuclear fuel could also be used efficiently in transport applications: prolonged navigation of nuclear-propelled ice-breakers in trans-arctic, high-latitude conditions had demonstrated convincingly that they were capable of performing tasks which were too difficult for ice-breakers burning fossil fuel. The Soviet Union also had some experience in using nuclear-powered ships for the carriage of freight. "Although the use of nuclear propulsion for ships does raise a number of complex and difficult problems, it is quite possible that in the not too distant future the construction of large capacity vessels, for example container ships, will be economically feasible."

Prof. Morozov urged that long before resources of uranium became depleted it would be necessary to implement measures designed to reduce the rate of consumption of uranium – by improving the economics of thermal reactor fuel cycles (increasing burnups attained, introducing reprocessing of spent fuel on a wide scale and other measures), and by introducing fast reactors. "The vital importance of this particular approach should be stressed because it alone will enable virtually all countries to bring about the energy develop-

ment they require on the basis of secondary fuel of indigenous fuel resources, since in such a case the price of uranium will no longer be a decisive factor," he said. The practical time-scale for the introduction of fast reactors depended however on many factors; according to the most optimistic forecasts a start would be made in the 1990s.

Session highlights

The conference was remarkable for the broad agreement of conclusions drawn in papers by authors from a wide variety of backgrounds, from industrialized and developing countries alike.

Important and obvious is the fact that the nuclear contribution to electricity supply is already significant, and is growing. In France, for instance, nuclear power plants accounted for almost 100 billion ($100 \cdot 10^9$) kWh electricity production in 1981 – about 40% of that country's total generation. In Sweden the share reported was 36%; in Belgium, 22%; in Japan, 17%; in the Federal Republic of Germany, 15%; and in the USA and UK about 12%. The importance of the contribution that nuclear power could make to electricity supply is recognized even in countries which have as yet only comparatively small programmes. From Spain, it was reported that nuclear energy "is an almost obligatory alternative if we wish to continue with economic, industrial and social development"; in India, a shortage of electricity has been "the single most important factor affecting . . . economic growth". Many developing countries are in fact being forced to turn to nuclear energy, despite the enormous national effort required, simply to conserve their limited conventional resources, whether these be hydro, coal and oil, or even fuel wood. The Indian experience highlights the problems a developing country may face: the need for an adequate industrial infra-structure; the long lead-times; the difficulty of operating relatively large nuclear units in small- or medium-sized distribution networks, and so on. However, "it is entirely possible for a developing country to derive the benefits of nuclear power technology".

Despite the abiding need for energy, a factor limiting the rate of growth of world nuclear programmes was seen to be the increasing cost of measures to obtain greater assurance of safety. A paper from Belgium, for example, noted that 30% of the cost of nuclear plant which entered service in 1975 was attributable to such measures. For plants now under construction, to enter service this year and in 1984, this proportion has risen to almost 50%. Simultaneously, plant construction times – currently around five to six years in most countries – have tended to lengthen with increasing attention given to plant design and quality assurance to meet ever more stringent regulatory requirements.

A statement from the World Energy Conference, presented at an early plenary session, noted that nuclear energy "has more than proved itself; but as the scale of use increases so it has come up against more difficult problems of social acceptance which, however, vary from country to country. During the last few years, the nuclear risks have been at the heart of so many discussions and perhaps too little consideration has been given to the even greater risks which loom if nuclear energy cannot assume in time the role which it is expected to play." Although energy forecasts might be regarded with 'healthy scepticism', they were nevertheless useful indicators of future trends. "Provided that reasonable conditions of growth are assumed and provided that catastrophe does not intervene, in our view the world will not be able to manage without nuclear energy by the year 2000 to 2020."

This statement was supported by a paper from the Holy See which argued that mankind should be able to assure the adequate availability of energy before or by about the turn of the century *if* the necessary actions are taken now and with sufficient vigour. The Holy See's paper acknowledged that some concern had been voiced over possible links between nuclear energy and the proliferation of nuclear weapons, but continued: "In this field, however, it is recognized that once a certain general level of knowledge and technical expertise has been acquired a country's development of nuclear weapons is primarily determined by political considerations. Thus, with adequate precautions, there is no reason to bar the development of nuclear energy for civil uses."

Current status

The conference heard that there are now 281 nuclear power plants in Member States of the IAEA, with a total capacity of more than 161 000 MWe, capable of accounting for 10% of world electricity generation in 1982. Nuclear plant is now being considered for not only base-load but also load-following applications; and the dual use of nuclear plant for both electricity and heat production is increasing especially in the USSR. Within the total of installed nuclear capacity pressurized-water reactors account for 55.5% (91 323 MWe); boiling-water reactors for 26% (42 050 MWe); light-water cooled, graphite-moderated reactors for 6.1% (9926 MWe); pressurized heavy-water reactors for 3.8% (6093 MWe); gas-cooled reactors for 4.5% (7484 MWe); and other reactor types for 3.1% (5000 MWe).

A joint paper from the World Energy Conference, UNIPEDE*, and the IAEA reviewed the performance of nuclear plants and compared this with that of fossil-fired units of comparable sizes, citing data collected in the Agency's Power Reactor Information System (PRIS). The report concluded that the availability of nuclear plants has not been significantly lower than that of fossil-fired plant in the same size ranges, although it would be desirable and still seems possible to improve the availability of nuclear plant – mainly through improved

* International Union of Producers and Distributors of Electrical Energy.

feedback of operating experience and through improved management practices. The non-nuclear, conventional parts of nuclear power plants were found to be major contributors to unavailability, and the report suggested that a careful and conservative approach to the standardization of major components and to size and performance extrapolations in design should help to avoid such problems in future.

The report noted that in comparison with the theoretical load factor of 80%, which is still what manufacturers quote as "attainable" for nuclear plants refuelled off-load, the 62.4% achieved in 1980 for plants included in PRIS represented a loss of power generation of 160 terawatt-hours (corresponding to the operation of generating capacity totalling 23 120 MWe at the theoretical 80% load factor). This "loss" could be considered to be a reserve which could be available in future without building new plants – *if* it were possible to improve the capacity of plant already installed.

The results of a joint IAEA/UNIPEDE study of investment costs are rising more rapidly than those of coal-fired plants, with the possible exception of plants built in Canada and in France. A major cause for the rapid rise which is being experienced was seen to be the drastic lengthening of project duration in most countries. France, again here as so often in other areas discussed at the conference, is a notable exception in that it has been able to maintain a stable and reasonably short project time.

The joint report concluded, however, that despite the rapid rise in investment costs, nuclear electricity generation has an economic advantage over coal-fired generation in Europe and in Canada, and is competitive with coal in the east and north-central states of the USA. (In the western USA the availability of abundant low-cost coal gives coal-fired generation an advantage.) A UNIPEDE study of generation costs in Belgium, France, the Fed. Rep. of Germany, Italy, the Netherlands, and the UK – given assumptions specific to each country – showed that at a discount rate of 5% annually, the cost of generation from nuclear plants ranges from 53% (in the Fed. Rep. of Germany) to 76% (in the UK) of the cost of generation from coal-fired plant in the same country. At a discount rate of 10% annually – which the report's authors felt to be unrealistically high – nuclear-generated electricity would remain competitive, ranging from 67% (in France) to 93% (in the UK) of the cost from coal-fired plants.

The keynote to analyses of the technical performance of nuclear plant was perhaps set in a paper from the Fed. Rep. of Germany, which concluded that operators cannot content themselves with establishing that operating experience so far could be termed 'good'. The collection of operating experience must act as the impulse toward continuous improvement.. A common theme in papers presented was that the goal of continued safe and economic operation could be achieved by standardization

The head of the French Commissariat à l'Energie Atomique, M. Pecqueur, pointed out in his keynote address that since 1973, the energy problem has been a priority in world economics; growth recovery, which alone can put an end to unemployment, requires sufficient energy – at acceptable prices and at guaranteed supply.

of design, the use of standardized materials and manufacturing processes, the building of series of plants to the same design and with the same technical characteristics (as in France), the application of strict and effective quality analysis and quality control procedures, and the improvement of plant operational practices through the exchange of practical operating experience and information about methods of generic problem solving.

Fuel cycle factors

It was evident, to quote one paper, that despite the change in the economic climate since 1973 which has led to reduced expectations of growth in energy demand, the general line of development necessary to ensure a sustained and worthwhile nuclear contribution to energy supply remains the same. Uranium supply capacity at present exceeds demand and could continue to do so until the 1990s if the uranium market develops in an orderly way. At first sight this may seem to reduce the urgency of spent fuel reprocessing, but authors from the UK stressed that a number of points must be borne in mind:

- In the long term the balance of environmental advantage favours reprocessing and the use of extracted plutonium;
- Reprocessing thermal reactor fuel will provide the initial plutonium inventory for fast reactors, which will then produce their own replacement fuel;
- Perceptions differ as to when fast reactors will be needed, but most informed observers judge that commercial introduction during the first quarter of the next century would be reasonable; and
- A commercial system covering both the fast reactor and its associated fuel cycle needs to be proved some ten years before its deployment.

These and other considerations point to the need to prove the reprocessing option at an early date, using large plants to derive the maximum benefit from economies of scale. By concentrating reprocessing at a limited number of centres, large plants would also facilitate the application of improved safeguards procedures and reduce concerns about proliferation.

A paper from the Uranium Institute noted that market fluctuations could create serous problems for the uranium supply industry, which will always remain vulnerable to sudden and unexpected government interventions in the market. The Institute has developed a series of recommendations to help governments, consumers and producers of uranium alike to establish a consistent market and assurance of supply.

The odd state of the present uranium market was illustrated at one of the technical sessions. A large exploration effort in the 1970s in response to *rising* uranium prices resulted in over-production and a consequence *drop* in prices. Current prices are too low even to sustain many producers. Thus mines and mills are closing and production plans are being deferred, especially in the United States. This reduction in production is expected to result in a *rise* in prices later in this decade to a level approaching that of the 1970s – about US $160 per kg of uranium (US $60 per pound of uranium oxide, U_3O_8) in 1982 dollars – in order to be sure that production capacity will again be available when it is needed to meet demand.

At another technical session the remarkable diversity of commercially viable enrichment processes was well illustrated. The Eurodif gaseous diffusion plant at Tricastin, in the Rhone valley, was reported to have achieved its planned capacity of 10.8 million separative work units (swu) per year, positioning Eurodif as a major enrichment supplier and rendering Europe substantially independent in this field. The Urenco tripartite project was also reported to have progressed well, with two centrifuge plants in operation (in the UK, at Capenhurst, and in the Netherlands, at Almelo) and a third planned in the Fed. Rep. of Germany. Urenco has sales contracts which will be the basis for expansion to a capacity of 2 million swu per year in the late 1980s. In the USA, gaseous diffusion plants – although currently operating at only about 35% of capacity – continue to act as base-load plants for most of the world. Plant improvement and uprating projects expected to be completed in 1983 will increase plant capacity to 27.3 million swu per year; and power requirements per swu have been reduced by about 23%. France reported considerable progress in the development of the *Chemex* process unveiled at the Salzburg conference*; and the Fed. Rep. of Germany also reported progress in development of the Becker separation nozzle process. A pilot plant using this process is being built in Brazil.

Waste management

The need for more work on options for the long-term management of high-level wastes was underlined in a number of papers. French experience supports the conclusion that processes are available both for the conditioning and disposal of low- and intermediate-level wastes, and also for the primary conditioning and intermediate storage of alpha-bearing and high-level wastes, although the authors of one paper acknowledged that improvement is always possible. In the long term, it is expected that solidified high-level wastes may be placed in deep geological formations, and research into this option is under way in a number of countries. French authors noted that the wastes in question are of small volume and that the "more than satisfactory safety of their intermediate storage may seem to make their long-term disposal less than urgent". On the contrary, however, they warned that "this is a fallacy. The highest standard of safety at the lowest cost – i.e. optimization – will only be attained through pursuing the effort to the end, which is the commissioning and running of a disposal site."

A Swedish paper urged that generic criteria for the management of the back-end of the fuel cycle and a quantitative performance analysis system, acceptable worldwide, are required. Intergovernmental organizations such as the IAEA and the Nuclear Energy Agency (NEA) of the OECD** should undertake the task of attaining a consensus. Secondly, "we need proper demonstrations of the system for the final storage of high-active and long-lived radioactive products . . .". Achievement of these two inter-related goals is of great importance to future world nuclear prospects.

Safety and safeguards

The safety of operations within the nuclear fuel cycle was an underlying theme of the conference to which a plenary session was devoted. Sir Walter Marshall, chairman of the UK Central Electricity Generating Board, presented a closely-argued paper concerning the way in which we *talk* about the consequences of big accidents. Sir Walter noted that much of the debate about the

* International Conference on Nuclear Power and its Fuel Cycle, held in Salzburg, Austria, 2–13 May 1977. Proceedings were published by the IAEA in 8 volumes in 1977.

** Organisation for Economic Co-operation and Development.

safety of nuclear power focuses on the large number of fatalities that could, in theory, be caused by extremely unlikely but imaginable reactor accidents. This, along with the nuclear industry's inappropriate choice of vocabulary in public debate, has given the public a distorted impression of the safety of nuclear power.

Sir Walter suggested that the consequences of imaginable big accidents should be presented in terms of reduction in life expectancy, the increased chance of fatal cancer, and the equivalent pattern of *compulsory* cigarette smoking. He took as an example a "gigantic" accident as a result of which 10 million people living in London each receive a radiation-dose of 1 rem (0.01 sievert). The potential long-term death toll from such an accident would be 1250 people, as calculated using the recommendations of the International Commission on Radiological Protection (ICRP). Sir Walter's punch-line was that the very same long-term detriment would be incurred if everyone in London were compelled to smoke a twentieth of a cigarette every Sunday – and that the fatalities from the reactor accident would occur only *if* the accident were to happen.

In another paper, authors from the ICRP discussed the impact of their publication No.26 on the administration of radiation protection. ICRP publication No.26 appeared five years ago. The authors noted that concepts and terms which had at first been received with hesitation and scepticism – such as "effective dose-equivalent", "collective dose", "dose commitment" and "optimization of protection" – have gradually become recognized and accepted. It became apparent from related papers that it is now impossible to conceive of a design philosophy which is not firmly grounded in experience, since the goal is to enhance the reliability of measures for accident prevention (including specific features of plant design, and also the responses of operators in emergency situations).

Safeguards against the diversion of nuclear materials were the sole focus of one plenary and one technical session. Myron Kratzer – a man with a wealth of experience in the field, now with International Energy Associates Ltd in Washington – concluded in a keynote paper that "even though imperfect, safeguards can – when effectively implemented – subject would-be violators of non-proliferation undertakings to a high risk of detection, thus providing both an important deterrent to proliferation and verifying with a high degree of probability that nuclear activities declared to be peaceful are indeed so. Where this conclusion can no longer be reached, safeguards can sound the alarm, initiating appropriate responses. There is convincing evidence that safeguards are currently fulfilling these functions in a creditable manner . . . . Safeguards continue to merit the support and confidence which they have enjoyed so far as an important element in the non-proliferation regime."

An IAEA survey presented at the technical session stressed that much more r&d work is required: the total amount of nuclear material in peaceful nuclear programmes is increasing, and the material is being used in more sophisticated ways, so measurement and verification techniques will also continue to require improvement and refinement. The paper concluded that the task facing the Agency is "difficult but not impossible".

Professor I.G. Morozov, Deputy Chairman of the USSR State Committee on the Utilization of Atomic Energy, described, amongst other things, the USSR's development of nuclear reactors where the production of heat is combined with that of electricity, and of district-heating nuclear power plants producing only heat for domestic purposes.

Nuclear power in developing countries

This survey of a conference which explored virtually every nook and cranny of the world's accumulated experience would be incomplete without reference to the very great deal of work reported from developing countries. The keynote in nearly all the papers here was the gross imbalance which exists between the industrialized and the developing nations: 90% of the world's energy is being consumed by only 20% of the world's population. Not only is this inequitable, but developing countries will in the not too distant future be forced to turn to nuclear energy to conserve their limited resources.

To do so, however, they will have to make increasing use of technology transferred to them from more advanced

nations. The value of international co-operation in this field was well illustrated by ten papers presented at one of the last plenary sessions. One spelled out the far-reaching achievements of the IAEA itself, in fields as diverse as the safety of nuclear installations, radiological and environmental protection, the transport and physical protection of nuclear materials, nuclear data processing and information exchange, manpower development, planning and implementation of nuclear programmes, nuclear liability, emergency preparedness, fuel-cycle studies, and specialized publications.

Another paper underlined the role of the Council for Mutual Economic Assistance in increasing multilateral co-operation and integration, facilitating the development of nuclear power programmes including the development of fast reactors, studies on the fuel cycle, safety and quality assurance. A paper from the NEA noted that governments and intergovernmental organizations have been a driving force in the creation of joint projects in research and development, often in association with industry or with private research organizations. While still highly valuable, such projects now tend to be concentrated in a limited number of areas.

The common view was that the success of a programme of technology transfer will be determined by selection of a proven technique, supported by firm decisions and a long-term, government-backed programme. It is necessary that a state interested in nuclear power should make a realistic assessment of its own capabilities; that it select a proven concept of technology transfer, and a partner; and that it identify in sufficient time and ensure the motivation of all the categories of personnel involved.

Overview

The conference closed with an overview by Dr Eklund, former Director General of the IAEA. He noted that the number of jobless people in Western Europe is, or will soon be, of the order of 30 million. "Science and technology have not been able to rectify that situation as their achievements as regards industrial activities usually lead to a reduction in the number of jobs," he said. However, most authors of papers presented at the conference shared the opinion that nuclear power should play a major role in meeting future energy needs: by 2000–2020 the world would not be able to manage the energy supply-demand balance without it.

Dr Eklund remarked wryly that "I think we could recognize a certain saturation in the flow of really new nuclear information," but "the mind-searching and desk-cleaning at so many institutions for this conference have resulted in the presentation of a lot of useful information . . . which in the future will contribute to the economic viability of nuclear power and to the safety of different types of installation everywhere."

Dr. Eklund concluded: "In the last few years I have often raised the question about ways and means to assure that nuclear energy and nuclear industry can survive the present period. The answer can be given in a very simple way: nuclear power will survive if it is economically viable, which I understand to embrace safety, waste disposal questions and decommissioning. Please do recall the words of the late Dr Homi Bhabha, 'No energy is more expensive than no energy.' I am convinced that this conference, in spite of its somewhat dry and business-like manner, has contributed to make nuclear power more viable."