PROSPECTS FOR SMALL AND MEDIUM POWER REACTORS

A searching examination of the present status of nuclear power technology and economics was made in 64 papers presented to the Conference on Small and Medium Power Reactors held by the IAEA in Vienna during the week 5 - 9 September 1960. Over 250 representatives from 40 countries attended the Conference.

This was the first large-scale international conference to deal with the subject of nuclear power since the second (1958) United Nations Conference on Peaceful Uses of Atomic Energy in Geneva. That conference had reversed the general optimism about the future of nuclear power expressed at the first (1955) Geneva Conference. The IAEA's Vienna conference came at a time when recent technical developments were once more giving rise to a moderate degree of confidence. This was attested to by Sterling Cole, IAEA's Director General, who in his opening remarks pointed to "remarkable progress" made during the last six years to make nuclear power dependable, safe and economic. Mr. Cole further stated that "today we stand on the verge of important developments in atomic energy. Indications are that by the end of this decade nuclear power will become competitive in those areas where fuel costs are somewhat above average. In places where the fuel costs are high, nuclear power may achieve competitive status by the mid-sixties."

The IAEA's Conference concentrated on small and medium power reactors because these are the sizes of primary interest to less-developed countries around the world. The Conference fell within the scope of a program which the Agency has initiated to encourage the development of nuclear power in such countries. The program provides for surveys of the nuclear power needs of the less-developed countries, continuing studies on the technology and economics of power reactors suited to their needs, dissemination of the information thus obtained and assistance in training personnel.

While the Conference was thus focused on small- and medium-sized power reactors, it included also information on development of larger reactors, since the technology is largely interchangeable among sizes and since more information, particularly economic information, is available on large reactors than on the other sizes.

The Conference brought forward information on a wide range of subjects related to power reactors, including power costs, summaries of national programs, applications in less-developed countries, process heat reactors, reactor safety, results of experience in the actual construction and operation of power reactors and technical appraisals of various reactor types.

Nuclear Power Costs

Optimism was expressed that large size nuclear power plants would soon be able to compete economically with fossil fueled plants. U. Staebler of the United States referred to estimates "that in some situations in the United States nuclear power may become competitive . . . within the present decade, and, in fact, that some large plants that could be built now might prove to be economically competitive over their useful plant lifetime."

On the rostrom at the opening session of the Conference on Small and Medium Power Reactors, left to right: Munir Khan, Scientific Secretary, IAEA; Hubert de Laboulaye, Deputy Director General, IAEA; Sterling Cole, Director General, IAEA; G.C. Laurence (Canada), Chairman of the session; Arkadij Rylov; Deputy Director General, IAEA; and George Petretic, Scientific Secretary, IAEA

The 200 electrical megawatt (MW(e)) "CANDU" plant being built in Canada was stated by J. Melvin to be a direct forerunner of units which would produce power costing 5 mills/kWh, and which would therefore be "competitive generally" in Canada.

A paper by K. Kubushiro, Y. Togo and K. Mochizuki estimated that nuclear plants would, under certain conditions, supply competitive electric power in Japan in five to 15 years.

This early achievement of economic nuclear power was predicted notwithstanding general agreement that the investment costs of nuclear plants were substantially higher than those of conventional plants. A study reported by F. McCloska (USA) indicated that a large reactor tended to cost at least 50 per cent more than a coal-fired boiler.

Mr. McCloska enumerated some of the factors which cause the discrepancy in capital costs. Because of the early stage of the nuclear industry, design, purchasing and project administration are more costly. Legal requirements, such as for exclusion areas, detailed hazards investigation, accountability for fissionable material and testing, add to nuclear plant costs. A study had found that safety provisions, such as for containment, shielding and electrical systems, add $17.50 per kilowatt to the cost of nuclear plants. A longer construction period makes for higher financing costs. While he did not feel that the capital cost gap could be entirely closed, Mr. McCloska believed that it could be reduced, perhaps to half, by factors such as technological innovations, greater experience, standardization, less severe safety provisions and faster construction.

Maintenance costs for nuclear plants will also be greater than for conventional ones. This was the view of R. Guard (UK). "A nuclear power reactor has twice as many auxiliaries as a conventional boiler, and many of these auxiliaries are novel and lacking in extensive operating experience", Mr. Guard stated.

Reactor 2 at Chapelcross, UK, under construction

While pointing out that variations exist, depending on the type, size, location and method of operating the reactor, he felt that a "reasonable guess" of maintenance costs would be 1 per cent of the cost of the station per year.

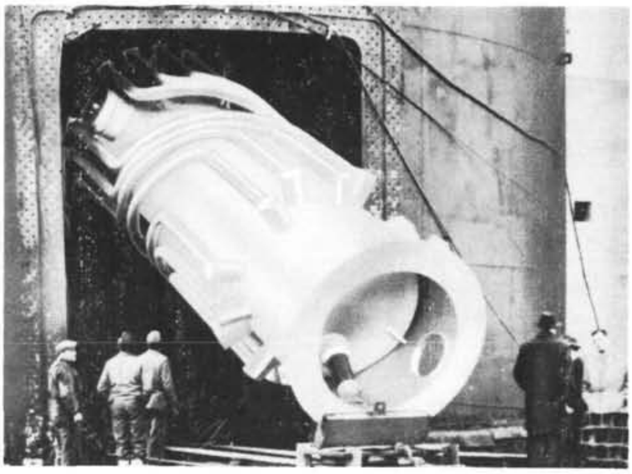
Under these circumstances, as Mr. McCloska's paper expressed it, the main burden of achieving competitive nuclear power is placed "on developing and attaining an overall fuel cycle cost sufficiently lower than conventional fuel costs to offset the inherently higher capital cost of a nuclear plant". As indicated earlier, there was widespread belief that this could be accomplished for large reactors at a relatively early date.

When it came to the costs of power from reactors in other than large sizes, however, the situation appeared less promising. Many figures were cited to show that power from small reactors cost considerably more than power from large reactors. The disadvantage was found to exist in all the major cost categories, that is, in capital, fuel and operating costs.

The paper by U. Staebler (USA) attributed the capital cost disadvantage to the fact that certain facilities and services associated with reactors have minimum practical sizes and thus "do not decrease proportionately with plant capacity". Mr. Staebler cited as illustrations fuel handling equipment, shielding, containment shells, facilities for decontamination and handling of radioactive wastes, and reactor control equipment. Similarly, he said, "operating costs for small plants tend to be higher per unit of energy output than for large plants . . . because of the need for a minimum number of operating personnel for a plant regardless of size." On the fuel cost side, Mr. Staebler attributed an increase with decreasing size primarily to the fact that "increased neutron leakage increases the required fuel enrichment and shortens the lifetime permitted by reactivity". This effect he thought "could be minimized by design choice and by various schemes of zone loading and fuel management."

While it is well known that conventional power costs also rise with increase in plant size, it was generally felt that this effect of size is greater in nuclear than in conventional plants. Consequently the gap between conventional and nuclear power costs tends to become greater with decreases in size. Thus, J. Lane presented results of a study of three highly developed reactor types, which showed that 10 MW(e) coal-fired plants in the United States could produce power for from 9 to 18 mills/kWh less than nuclear plants of equivalent size, whereas in 100 MW(e) sizes the disadvantage of nuclear plants was only 2 to 6 mills/kWh.

A recently completed study by the US AEC, presented in a paper by J. Kaufmann, M. Wiener and J. Roberts, showed further that power from 40 MW(e) nuclear stations will, in 1970, cost from 13 to 16 mills/kWh, as compared to a current cost of approximately 11 mills/kWh from similar sized conventional



Assembly of pressure vessel in containment building of 15 MW(e) nuclear power station at Kahl/Main, Federal Republic of Germany

stations. A parallel study on the prospects for large plants had indicated the likelihood of achieving competitive status before 1970.

Questions were raised concerning methods currently employed for estimating nuclear power costs. A. Lévai (Hungary) emphasized the importance of analyzing the effects which adding a nuclear station to an inter-connected power system would have on costs of power to all consumers in the system, not merely to those directly served by the individual plant. G. Petretic and R. Krymm of the IAEA staff showed how different methods of calculating nuclear power costs yield widely varying results. They described an IAEA program aimed at achieving some degree of standardization in the calculation and presentation of basic power reactor cost data.

National Nuclear Power Programs

Several of the papers presented to the Conference shed light on the factors which have shaped the national nuclear power programs of some of the more industrialized nations.

U. Staebler of the United States stated that his country's program planning has emphasized the desirability of carrying out development of a variety of reactor concepts "in order to give greater assurance of having the most favorable plant designs for the wide variety of nuclear power applications and situations which are conceivable". He stated further that the program is oriented toward the expectation that nuclear power is likely to be competitive in the United States first in areas with relatively high fossil fuel costs which can use large plants, but that small plants were not being neglected.

Two Canadian papers, by G. Laurence and J. Melvin, made it clear that power reactors being built or designed in Canada are virtually all based on the use of natural uranium as fuel and heavy water as moderator. Dr. Laurence stated that Canada will continue to prefer such reactors as long as uranium remains a cheap and abundant fuel.

The Japanese paper mentioned above explained why Japan had elected to install at this time both a small boiling water reactor and a larger natural uranium gas-cooled type. The expected differences in power costs for the two are not over 10 per cent. The natural uranium plant represents a more proven technology and experience with it would be essential "if the fast breeder reactor would be used as one of the commercial power reactors in future". The boiling water type, on the other hand, has high potentialities if fuel elements problems are solved. The need to proceed now with a nuclear power program in Japan has its basis in the fact that hydroelectric development has reached its "upper limit", while coal and oil are costly.

H. Brüchner stated that the utility company installing the 15 MW(e) boiling water reactor plant at Kahl on Main, Federal Republic of Germany, made a wise decision in constructing this relatively small pilot plant rather than a full-sized power station "because thus the risks to be borne by all participants for the first time could be reduced to a reasonable magnitude, and still have the benefit of getting full experience". He recommended this policy to "every country that is about to commit itself to plans for nuclear power generation". Dr. Brüchner stated that in building pilot plants primarily to gain experience, it is more important to keep capital investment as low as possible than to aim at a low cost of power.

This suggestion conformed to comments made by H. de Laboulaye, IAEA Deputy Director General for Technical Operations, in introductory remarks to the Conference. Mr. de Laboulaye indicated that manufacturers could improve power reactor technology more quickly and at less total investment cost by building a series of small units rather than a much smaller number of large stations. He suggested that they could "limit the unproductive side" by installing the reactors in areas "where electricity is dear, where it is still scarce, and where the benefits it can provide are eagerly awaited."

Later, in a paper presented at a technical session of the Conference, Mr. de Laboulaye analyzed the choices which nations in different economic circumstances might make to minimize the cost of constructing and operating experimental nuclear power stations. High load factors, low capital charges and a high sale price of electricity, he pointed out, would argue for a large experimental plant, whereas under the opposite conditions the country would be better advised to install a small plant.

Nuclear Power for Less-Developed Countries

Several papers examined closely the situation of less-developed countries with respect to nuclear power. J. Barnea and E. de Breuvery of the United Nations staff dealt with characteristic features of the electric power situation in such countries. While cautioning that wide variations exist from country to country, they stated that it is not uncommon to find scattered small generating stations each serving a small area; low plant utilization factors; frequent power shortages; a high rate of growth in power demand; high prices for electricity; a shortage of material resources; and high prices for fuel.

P. Teitelbaum and F. Pikler of the IAEA staff analyzed the benefits which introduction of nuclear energy might over the long run bring to the economies of under-developed countries. Besides the enlargement in national income which might result from greater availability and lower costs of energy, they found also that there might ensue changes in the location of economic activity, the introduction of processes previously not economical, savings in foreign exchange, and a general stimulus to scientific and technological development.

Basing their analysis on the economic history of Japan, Y. Kawashima and T. Suzuki traced the process by which nuclear power reactors could be introduced into developing countries. They noted that intensified use of electric power is an essential concomitant of industrialization. At the early stages of industrialization, when electric power supply is organized essentially on a local basis, small and medium power reactors, perhaps producing both electricity and process heat, might have an important role to play. Later, when power supply becomes integrated into regional, national, or even international networks, large sized nuclear power reactors might be more appropriate for incorporation into the networks.

A suggestion consistent with this analysis was made in a paper by J. van der Spek of Belgium who suggested that thought be given to the design of small, portable nuclear plants which could be moved to another location when increased power demand warranted their replacement by larger units.

That portable nuclear plants are already being designed was made clear by J. Bratton of the United States in a paper describing a US program for development of small reactors suitable for use at remote installations. Features of these plants, in addition to portability, which make them technically suitable for use in remote areas, are their simplicity, reliability and compactness. Mr. Bratton's analysis showed that while the initial cost of the plants was in every case higher than that of a conventional alternative, they could compete favorably in areas where the cost of conventional fuel was sufficiently high. Thus a 5 MW(e) nuclear plant to be built in Antarctica will be economic, as would a 40 MW(e) plant and a 20 MW(e) plant proposed for Okinawa and Guam, respectively.

Process Heat Reactors

While the primary emphasis of the Conference was on the use of nuclear reactors to produce electricity, attention was also given to their potentialities for producing industrial process heat. L. Forgo, J. Halzl and M. Torma of Hungary presented a paper pointing out that for small countries having a fairly developed industry, such as Hungary, small process heat reactors might prove a more economic introduction to nuclear energy than electricity-producing reactors. For such countries, large electric power reactors would be too expensive, while it would not be practical to add small ones to the interconnected power networks. Process heat plants, on the other hand, are generally required in small sizes, are less likely to become obsolete, can operate at very high load factors, and would help to train staff for future large nuclear power plants.

A nuclear power application of the future under consideration in the USA

Characteristics which make an industry particularly ripe for nuclear heat supply were considered by the authors to include a high utilization factor, requirements for steam in certain temperature ranges, and a location considerably removed from a fossil fuel supply. The alumina, paper, plastics, textile, leather, petrochemical, nitrogen, pharmaceutical and rubber industries were noted as promising candidates.

A paper by B. Baines and J. Conway-Jones pointed out that there were 50 chemical factories in the United Kingdom with steam consumption in excess of 150 000 lb/hr, the amount the authors assumed to be desirable for effective utilization of nuclear heat. They described an organic moderated reactor system capable of producing steam of a quality suitable to meet the wide range of requirements for heat and power found in the chemical industry. Under certain conditions of joint demand for power and steam and allocation of costs between the two, the authors found that such a system might be economically competitive.

Reactor Safety

The necessity for developing firm safety criteria and standards with respect to reactor location, design integrity of construction, and competence of operation was emphasized in a paper by M. Biles and

C. Beck (USA). Preliminary criteria under consideration in the US were presented. The authors concluded, however, that lack of operating data and uncertainties as to the proper approach prevent establishment of firm standards at present so that "safety evaluation of reactors is largely a matter of judgments based on general principles".

E. Jantsch (Switzerland) pointed out that placing reactors underground adds to their safety because rocks provide both additional shielding to protect the environment from the effects of a reactor accident and a reliable protection against destruction of the reactor from outside causes. He presented an evaluation of the "worst conceivable accident" to an underground plant and showed that the consequences would be relatively mild.

On the other hand, a paper by C. Vélez (Mexico) indicated that for reactors located above ground consequences of an accidental release of fission products decrease as the height of the source of release increases. Mr. Vélez accordingly recommended that reactors should be so located and designed as to maximize the elevation of any potential fission product source.

Experience in Operation and Construction

Although nuclear power is relatively young, the first atomic power plant having begun operation only six years ago, there is already available a wealth of experience in the construction and operation of nuclear plants which can be a useful guide to the future. Several papers were devoted to a description and evaluation of such experience.

The operation since 1954 of the USSR's first atomic power station was described in a paper presented by M. Minashin. The paper emphasized the high dependability of the plant's standard fuel elements, none of which has failed. In tests some of the fuel elements exceeded considerably their design lives. The paper described various other experimental tests carried out in the plant, including "the world's first nuclear superheating of steam". The experience gained through operation of this pioneer plant has provided a basis for the design and construction of the large-scale I. V. Kurchatov Atomic Power Station at Beloyarsk.

A paper by T. Tuohy and T. Marsham of the UK described experience in four years of operating the Calder Hall Nuclear Power Station. The authors stated that major malfunctions have arisen only in the electrical generation equipment "and in all cases the safety circuits have prevented any ill-effects being felt on the reactors". They reported that radiation levels in all operating areas "have proved quite acceptable".

Modifications to the pressure vessel of the Experimental Boiling Water Reactor at the Argonne National Laboratory (USA), undertaken as part of the increase in its design rating from 20 to 100 MW(th), were described in a paper by D. Roy and T. Kettles.

NPD-2, Canada's first power reactor, now nearing completion

The successful completion of this modification was considered support for the conclusion that maintenance of this type of reactor is remarkably easy.

Other United States papers summarized performance data obtained from three years' operation of a small pressurized water reactor and the operating and maintenance procedures employed for two boiling water reactor plants.

Several papers presented by United Kingdom representatives considered the manpower requirements for nuclear power plants. The paper by Tuohy and Marsham stated the staff requirements for operating all four Calder Hall reactors as 50 professional staff and about 80 supervisors controlling 280 semi-skilled operatives and 230 maintenance men. R. Guard concluded that well-designed nuclear power stations with a single reactor and turbine might require more than a "man per megawatt" in sizes much below 100 MW(e), but that above 150 MW(e) "this ratio should fall rapidly", and that a large two-reactor station "should not require much more than 0.5 man per megawatt." K. Frost emphasized that to have an efficient operating team in a nuclear plant requires "an appropriate marrying" of a group with reactor knowledge and one able to operate mechanical and electrical equipment.

Problems in the actual construction of nuclear plants were dealt with in a paper by Knowles and Leader (UK). They concluded that "the construction of a nuclear station differs from that of the conventional because of increased urgency, accuracy and attention to detail", as well as a greater need for coordination. These differences demand that the nuclear construction force have a supervisory staff greater than usual both in quantity and quality, and that there be a certain amount of formal staff training. In another paper, Mr. Knowles gave an account of the methods adopted in constructing the Chapelcross Nuclear Generating Station on a schedule requiring completion of the first reactor within 36 months and the remaining three reactors over the succeeding 12 months. A much larger staff was required than the constructing firm uses for conventional stations of equivalent capacity. A large part of the work was of the same sort as arises on conventional power stations, however, so that most of the staff could be drawn from those experienced in constructing such stations.

The manner in which difficulties experienced with a reactor experiment can provide a basis for design improvements in a large-scale reactor of the same type was described in a paper by R. Beeley and J. Mahlmeister (USA). The reactor involved was the Sodium Reactor Experiment in California which suffered fuel damage and other difficulties. Features to prevent such occurrences have now been installed in the SRE and incorporated in the design of the large-scale Hallam Nuclear Power Facility being built in Nebraska, for which the authors predict a high reliability and long plant life.

Technical Evaluations

Another feature of the Conference was the presentation of papers discussing the technical features and prospective economics of a variety of reactor types being developed in leading industrial nations and considered suitable for construction in small and medium sizes. Among the reactor types described were boiling water, with and without nuclear superheat; heavy water moderated; pressurized water; organic-cooled; and gas-cooled.

Conclusion

In bringing the Conference to a close, IAEA's Director General Sterling Cole stated that the review of the technical and economic status of nuclear power presented at the Conference had given "a realistic appraisal of the situation". Based on this appraisal, he found the outlook bright and encouraging, in spite of the fact that at present nuclear power generally costs more than conventional power. Deputy Director General de Laboulaye, in his concluding remarks, emphasized the usefulness of the discussions on reactor construction and operational experience and on reactor safety which indicated that power reactors had become technically very reliable. At a press conference held on the last afternoon of the Conference, Mr. de Laboulaye commented that the nuclear power cost picture, although not yet confirmed by experience, appears definitely brighter than the picture presented at the 1958 Geneva Conference on the Peaceful Uses of Atomic Energy. "This", he said, "indicates that we are on the right track."

The proceedings of the Conference will be published by the IAEA early in 1961.

REPORT ON VINCA DOSIMETRY MEASUREMENTS

The report by the scientific team from Oak Ridge National Laboratory, USA, on the dosimetry measurements carried out at Vinca, Yugoslavia, earlier this year has now been received by the Director General of the International Atomic Energy Agency.

The findings of the Oak Ridge team were discussed at a meeting on the Diagnosis and Treatment of Acute Radiation Injury organized by WHO and IAEA in Geneva, 17 - 22 October 1960. Some thirty of the world's leading specialists from France, India, Netherlands, Soviet Union, United Kingdom, United States and Yugoslavia and staff experts from the organizing agencies participated.

The Oak Ridge team, under the direction of Dr. K. Z. Morgan, was one of the main partners in the IAEA joint dosimetry project at Vinca which aimed at throwing light on the relationship between the exact doses received and the clinical effects observed immediately after the uncontrolled run of the Vinca reactor in October 1958 and in the period of treatment in Belgrade and at the Curie hospital in Paris of the six persons exposed to radiation.

Precise data on the relationship between levels of radiation and their effects on man are rare and the Vinca experiment was therefore unique in many respects. The results are considered to be of great value both for the scientific study of radiation effects and the development of methods of therapy.

The report from the Oak Ridge team reached the conclusion that the six exposed persons received total doses (gamma and neutron) varying from the low point of 207 rad units to the highest of 436 rad units (see