operating experience with power reactors

A milestone in the use of nuclear power was reached in March with the initial operation of the one hundredth nuclear power reactor in a Member State of the IAEA. It took nearly 17 years, from the time when the first nuclear power reactor, APS, became operational in the USSR in May 1954 to the present day, to reach the first 100; the second 100 power reactors are expected to become operational within the next four years.

At the end of 1970 there were 98 nuclear power reactors with a total power output of about 20 000 MWe in operation in Member States (see Fig. 1), with cumulative experience totalling 685 power reactor-years. The cumulative output from nuclear power stations was then about 350×10^9 kWh, achieved with an outstanding safety record.

Experience gained in the operation of nuclear plants in the 1960s provided most valuable information for increasing the reliability, safety and dependability of new plants. There have been the inevitable teething troubles often associated with industrial plants incorporating new and advanced technology, especially because the average unit size has increased rapidly with the tendency to go to larger and larger units for economic reasons. Thus, experience gained with smaller units and components has had to be extrapolated by a considerable factor.

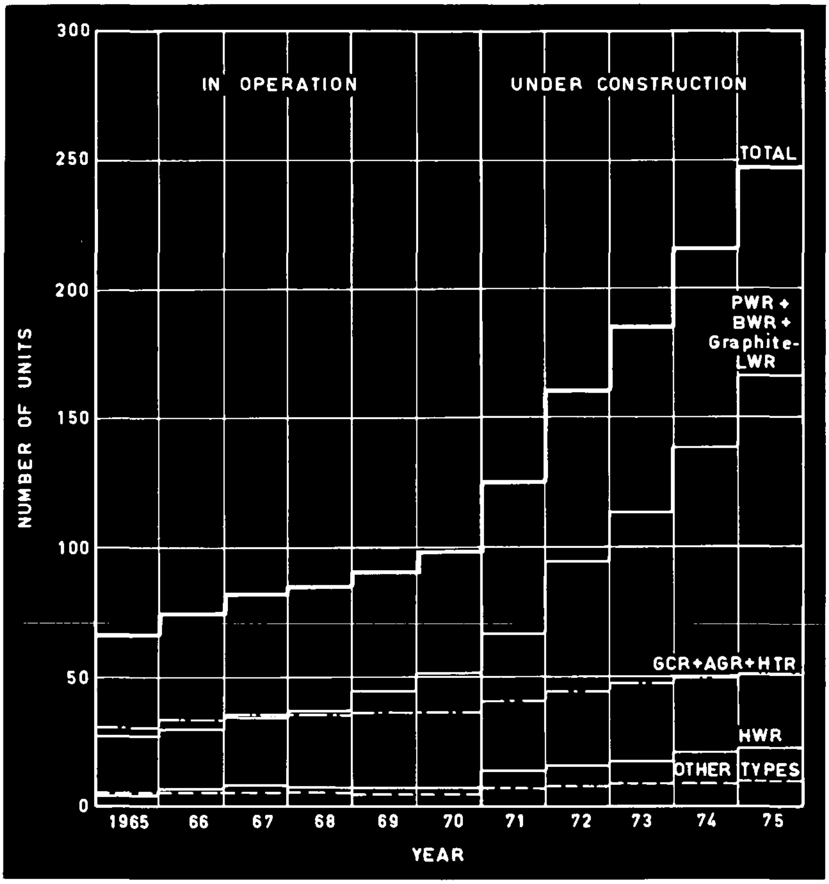

Fig. 1. Number of power reactor units operating or expected to be operating

A substantial number of large nuclear power stations (most of them with reactor units capable of generating between 500 and 1200 MWe) are expected to become operational by the mid-1970s. Many of these are to use duplicate designs, for which previous experience will be directly applicable, permitting greater economy and reliability to be achieved. This is opportune, since the utilities are insisting on high standards of performance. With the manufacturers no longer willing to offer low-priced turn-key bids and needing to satisfy increasing regulatory requirements, the pace of new orders for nuclear plants will depend upon many factors, including the performance of existing stations.

The IAEA, as part of its activities in nuclear power, attaches great importance to the documenting of operating experience with nuclear power plants, and publishes an annual review of Operating Experience with Nuclear Power Stations in Member States. For this purpose, beside searching the literature, a system of officially-designated national correspondents, in which all the Member States having operating nuclear power stations are participating, is being used. The correspondents are expected to obtain the available data from their respective national sources and, wherever agreed, the utilities or other groups make information available directly to the IAEA.

The first formal annual review was of operating experience for the year 1969, published in the IAEA Technical Reports Series as IAEA-127. The review of operating experience with nuclear power stations in Member States for the year 1970 is now in preparation and is to be issued shortly. In addition, the IAEA encourages meetings to exchange experience and information. A Symposium on the Performance of Nuclear Power Plant Components was held in Prague in November, 1969; its proceedings have been issued.

The Agency report IAEA-127 reviews operating experience for each of the reactors which was operational in the 1960s. Highlights of the experience for each of the main reactor types are given in this article. The opinions expressed are those of the individual staff members who contributed to the report.

Light water reactors

The light water reactors (PWR, BWR and water-cooled graphite moderated reactor systems) developed rapidly in the 1960s and are expected to dominate the nuclear power programmes in the 1970s (Fig. 1). Fifty-one units were in operation by the end of 1970, and they had generated about 120×10^9 kWh of electricity. Another 125 units totalling about 75 000 MWe were under construction. The first generation of LWRs with unit sizes up to about 250 MWe, many of which were experimental and prototype units, have served to demonstrate the technical feasibility, safety and reliability of light water reactors and laid down the groundwork for size extrapolations and further developments of technology. Availability and capacity factors* for this group averaged 70 per cent, and 50 per cent respectively in the first few years. The plants had numerous troubles and extensive modifications were required in several cases. However, after the required changes had been made, the performance improved sharply. Dresden-1, Yankee and Novo Voronezh-1 are typical examples of LWRs now considered to be extremely reliable and having very low forced outage rates comparable to those of the conventional plants in their respective systems. Their load following characteristics (ability to respond to varying loads) are also excellent. Experience overall shows that there were far fewer problems on the *nuclear* side and the core and physics designs, and control and safety all proved to be generally reliable. Major problems were largely on the *conventional* side, reflecting inadequate engineering and design effort, insufficient quality control and limited understanding of materials behaviour. Much of the time the failures took place in the steam turbines operating under saturated conditions.

The initial operating record of the second generation LWR plants has been somewhat mixed. A sharp increase in size, incorporation of several innovations and lack of adequate engineering and quality control have contributed to problems. The trouble areas have included turbines, seals in the controlled leakage pumps, vibrations in the thermal shields,

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* The availability factor is the ratio between the length of time a station is on line in a given period and the length of that period; the capacity factor is the ratio between the average output of a station and its authorized output during a reference period.

control valves and other parts of the primary circuit, fires in cable trays, etc. Many of these difficulties resulted from "first of a kind" components or systems, and were speedily resolved. The availability factors for 1970 have been above 80 per cent.

The third generation of light water reactors (such as the 809 MWe Dresden-II and the 700 MWe H. B. Robinson) have recently started operation or are in various stages of commissioning; the initial reports are encouraging and indicate that the nuclear industry and the utilities have learned from their past experience with the earlier stations. During 1970, eight more light water reactors came on the line, and the utilities and the manufacturers will watch their progress with great keenness as they will have an important bearing on future LWR orders.

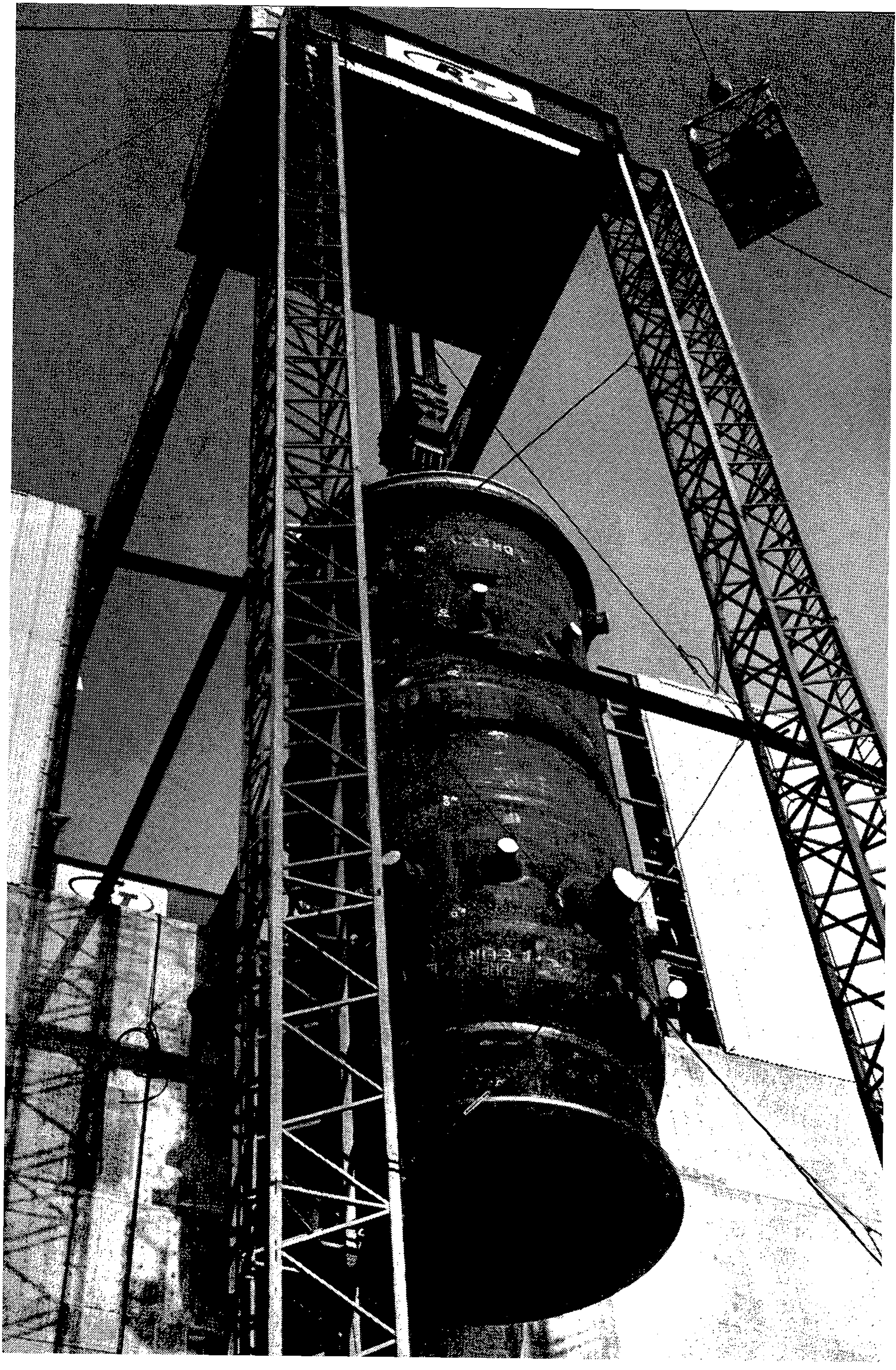
Heavy water reactors

At the end of 1970 there were seven heavy water moderated power reactors in operation. Another 15, totalling over 4500 MWe, were under construction. The plants represent several variants, namely, heavy-water cooled, natural uranium fuelled pressure tube and pressure vessel types, light water-cooled natural and enriched uranium fuelled pressure tube types, and a heavy water moderated, carbon dioxide-cooled type. Only one of these, the 208 MWe Douglas Point reactor, is a commercial unit. (The 508 MWe Pickering-1 unit went critical in March 1971.) Considering the small number of plants built so far and the distribution of efforts on the number of variants, the experience with individual types is relatively limited in comparison with LWR and GCR systems. However, the HWR technology is closely related to the LWR technology in materials and components and can benefit from the LWR experience.

The Douglas Point station has been plagued with several unforeseen difficulties since its initial power generation in January 1967; however, since then several modifications have been made in the primary circuits and other systems which have improved the plant performance. In 1970 the station availability was 60 per cent. The on-load refuelling machines at NPD, Douglas Point, MZFR and SGHWR have posed varying degrees of problem. However, considerable experience has been gained and routine on-load refuelling is now being accomplished at NPD and at Douglas Point. The heavy water loss rate has been greatly reduced, both at NPD and Douglas Point. D_2O leakages have to be controlled not only for economic reasons but also because of the tritium hazard. It appears that D_2O loss in HWRs is not a major factor, and appears to be controllable.

To sum up, the heavy water reactors have had several problems with mechanical equipment and most of these have been solved. The next few years, during which the other three 508 MWe Pickering units and the four 750 MWe Bruce units and others will come into operation, will be very crucial in establishing the competitiveness of this system with respect to the LWR.

The reactor vessel for the third unit at the Dresden nuclear power station, Morris, Illinois, is hoisted to the roof of the reactor building after a 630-mile journey by barge from Mount Vernon, Indiana. Photo: Commonwealth Edison Company



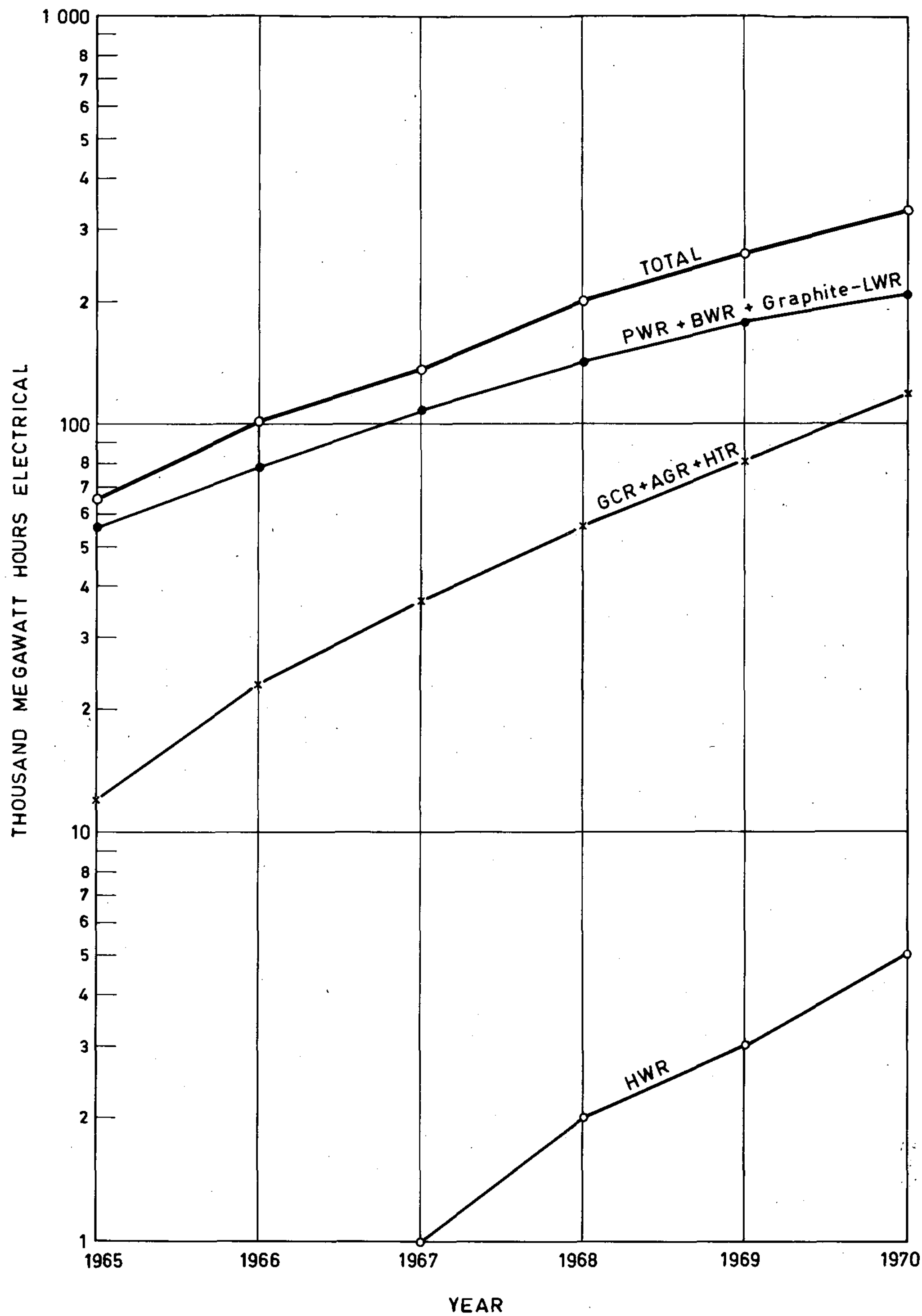


Fig. 2. Cumulative electrical energy produced by nuclear power reactors

Graphite-moderated gas-cooled reactors

This category includes the graphite-moderated CO_2-cooled natural uranium (GCR) and enriched uranium advanced gas-cooled reactors (AGR) and the helium-cooled high-temperature gas reactors (HTR). The 33 graphite-moderated CO_2-cooled natural uranium reactors had accumulated 263 reactor years of experience by the end of 1970, which is more than that of any other reactor system so far. Except for Calder Hall, Chapelcross and G-2/G-3, all these units were built as commercial stations, although Chinon-1, 2 and 3 have also had an experimental role, particularly in the development of more advanced types of fuel elements. Experience with these plants has indicated that, generally, they are capable of achieving high availability and capacity factors.

The main sources of trouble have been gas circulators, heat exchangers and fuel handling equipment. The problems with gas circulators and heat exchangers were resolved in most cases without great difficulty. On-load fuelling has an economic advantage, but the refuelling machines have taken a longer time to reach the designed steady state performance and this has led to a backlog of fuelling operations in many cases. Considerable improvements have been made in these machines.

The most recent problem with carbon dioxide-cooled systems relates to the higher than expected corrosion rate of the carbon steel, (and the fact that in some cases the composition of the steel used was not precisely specified), especially the nuts, bolts and clamps above the core which are exposed to hot coolant. This had led to lowering of operating temperatures of several Magnox reactors in the UK by 10°C, which is equivalent to 13 per cent power reduction. Detailed investigations of the causes of this corrosion and means for its mitigation are being carried out.

The natural uranium carbon dioxide-cooled reactors, which have accumulated long experience, have generally settled down to routine operation; however, additional reactors of this type will not be built for economic reasons. Experience with the Windscale AGR prototype has been good, indicating high availability factors, but the start-up of the first large AGR is awaited to see how it operates. In the case of HTRs, the experimental plants, such as the 40 MWe Peach Bottom-1, the 14 MWe AVR and the 20 MWth Dragon have operated satisfactorily, and the expected start-up of the 330 MWe Fort St. Vrain plant in 1971 would be an important milestone for the development of this concept.

The overall view

Nuclear power plants, after varying periods of initial debugging and modifications, are now beginning to emerge as reliable power producers. In many cases the availability records are matching those of conventional thermal stations. However, if they are to achieve the full benefit from their low running expenses, nuclear plants should not merely be as good as fossil-fuelled stations, they must achieve higher capacity factors. The higher availability factors which are also necessary will require a vigorous programme of analysis and learning from existing experience, and continuing programmes of research and development. The need for an exchange of operating experience with nuclear power stations is widely recognized, and the atomic energy authorities, reactor manufacturers and electric power utilities are showing keen interest.

The current level of commitments for nuclear power plants exceeds five to six thousand million dollars a year, and it is expected that this will double by the end of the decade. The very size of this investment underlines the necessity for closer communications between all interested groups with respect to the performance of nuclear plants, particularly in regard to service continuity and safety. The role of an international organization such as the IAEA is to supplement the efforts made at national and regional levels, and to encourage the world-wide exchange of operating experience, so that nuclear plant owners and manufacturers can benefit promptly from the valuable lessons learned in various countries. The Agency plans to continue and expand its activity collecting and disseminating information on operating experience with power reactors in Member States.

Determining trace element concentrations in specimens of human hair: here, a research worker at Aldermaston, in the UK, loads irradiated samples into an automatic gamma spectrometer.
Photo: United Kingdom Atomic Energy Authority