ADVANCED POWER REACTOR SYSTEMS

While the development of nuclear power during the next few years (some aspects of which are discussed in another article in this issue of the Bulletin) will be based largely on reactor types of proved design, the long-term prospects may also be associated with more fundamental advances in reactor technology. Studies and experiments are going ahead in a number of countries on some advanced reactor systems. These are still in a relatively early stage of development, but their potential value in economic power generation is already apparent.

Such advanced reactor systems comprised the subject of a Symposium on Power Reactor Experiments held by IAEA in Vienna from 23 to 27 October 1961. Nearly 200 reactor specialists from 25 countries participated, and 31 papers were presented.

Among the types discussed were high-temperature gas-cooled reactors, fast breeder reactors, homogeneous suspension and molten salt reactors, and nuclear superheat reactors.

High-temperature Gas-cooled and Homogeneous Reactors

In the discussion of high-temperature gas-cooled reactors, two papers were presented on the DRAGON reactor experiment being built as a co-operative project by the Member States of the European Nuclear Energy Agency at Winfrith, England. It was pointed out by P. Marien and G.E. Lockett, of ENEA, that this type of high-temperature gas-cooled reactor had a very good development potential since it brought within reach the possibility of achieving in one reactor a high power output per unit volume of core (making possible a smaller size plant), a high gas outlet temperature (making possible the use of efficient, modern turbines), and a high heat output per unit of fuel (reducing fuel cycle costs).

Another high-temperature gas-cooled reactor system discussed was the "pebble-bed" type, so named because its fuel is in the form of small balls through which gas coolant is circulated. Preparation of fuel in this form would eliminate some of the high fabrication costs usually associated with reactor fuel elements. A.P. Fraas (USA) described problems revealed by a series of conceptual design studies on pebble-bed reactors. Z. Zaric (Yugoslavia) presented the concept of a system in which the fuel balls would be regularly, rather than randomly, packed. Practical experiments to determine the amount and nature of fission products released from pebble-bed fuels under irradiation were described by C.B. von der Decken of the Federal Republic of Germany where a 15 MW pebble-bed reactor is under construction.

Czechoslovak and Netherlands scientists presented papers on homogeneous reactors, those in which the fuel and moderator are combined in a mixture. The Czechoslovak paper was presented by P. Novotny and related to experimental and design work on a reactor fueled by an aqueous suspension of uranium dioxide. J.J. Went said that the Netherlands was continuing to work on aqueous homogeneous suspension reactors, despite discouragement with similar types in other countries, because they seemed to answer the need for a high conversion ratio of fertile into fissile material and were likely to minimize or eliminate fuel element fabrication and fuel reprocessing costs.

A.L. Boch (USA) described a Molten Salt Reactor Experiment, now under construction, which is fueled by uranium and thorium fluorides dissolved in a mixture of lithium, beryllium and zirconium fluorides. As advantages of this type of reactor, Mr. Boch cited high temperature achieved with low pressure, the stability of the fuel solution under irradiation, the relatively simple method of fuel reprocessing, and the ease with which the system could be controlled. Disadvantages mentioned were the need to maintain the salts at all times at a temperature above their freezing point of 450°C., and the maintenance problems posed by the system's extreme radioactivity.

Fast Breeders

G. Drevon (France), Chairman of a session on fast breeder reactors, observed that fast breeders were indispensable to the long range development of nuclear power since, both by producing more fuel than they consumed and by being able to utilize the plutonium produced in reactors using thermal (slow) neutrons, they would greatly extend the life of nuclear fuel resources. J.L. Phillips (United Kingdom) pointed out in addition that fast reactors might well be able to compete economically with thermal reactors because of their small size (which reduces capital cost) and potentially low fuel costs. Mr. Phillips presented a paper on the Dounreay Fast Breeder Reactor Experiment in Scotland, the main purposes of which are to gain experience in the use of active sodium circuits and to perform test irradiations on experimental fast reactor fuels.

S.A. Hasnain (Pakistan) discussed fuel cycles in fast reactors. He pointed out that a major difficulty lay in achieving a high burn-up of fuel, a factor to which the fuel costs of fast reactors were particularly susceptible. Thus, he noted that fuel cycle costs for the Enrico Fermi fast breeder reactor, nearing completion in the United States, had been estimated at 7.2 mills per kWh with a burn-up of one per cent of the fuel, 3.5 mills with a burn-up of two per cent, and 1.0 mill with a burn-up of five per cent.

Papers on the "Rapsodie" fast breeder reactor to be built in the South of France were presented by C.P. Zaleski and L. Vautrey. The reactor will have a power rating of at least 10 MW(th), will use plutonium and uranium 235 as fuel, and will be employed as a test reactor for the development of future fast reactors. Criticality is foreseen for 1964.

Experience to date with the Soviet Union's fast reactor, BR-5, was described by I. Bondarenko. He noted that, although original design expectations were that the plutonium oxide fuel would achieve a burn-up of two per cent, five per cent burn-up had actually been achieved. Mr. Bondarenko concluded that the three years of experience with this 5 MW(th) test reactor appeared to confirm the possibility of building fast breeder power reactors on an industrial scale.

Nuclear Superheat Systems

Nuclear superheat, the achievement of high temperature steam by reheating lower temperature steam in a reactor, was the subject of papers from the Soviet Union, Sweden and the United States. The potential advantages foreseen for this feature, as noted by P.H. Margen (Sweden), include increased thermal efficiency, ability to use smaller turbines of standard design, higher power outputs for given reactor core sizes, and lowering of fuel costs. These advantages are not to be achieved without some costs in added complexity of construction, however, and it remains to be seen to what extent the economic benefits achieved in practice will overbalance the additional costs. On this matter, D.H. Imhoff (USA) stated that extensive economic studies conducted over the past three years "indicate an economic incentive for the successful development of nuclear superheat to be of the order of 0.4 to 0.5 mills per kWh as compared to the best boiling water nuclear plant that can be foreseen for the 1968-70 period".

Four approaches to nuclear superheating were described. W. R. Wallin gave an account of the BORAX V boiling water reactor in the United States which produces low temperature steam and then superheats it within a single reactor pressure vessel. Mr. Bondarenko presented a concept being developed in the Soviet Union which involves a graphite-moderated, pressure tube, boiling water reactor which transmits superheated steam directly from the reactor core to the turbine. Mr. Imhoff's paper described a plant being built in California in which steam produced either in an existing boiling water reactor or in an oil-fired boiler would be superheated in a second, "hook-on" reactor. Mr. Margen described a design study being conducted in Sweden of a possible 400 MW(e) boiling and superheating heavy water reactor. He said that the use of heavy water appeared to lower fuel cycle costs about 1 mill per kWh as compared to ordinary water, which seemed more than would be added to power costs because of higher capital costs.

Other Possibilities

P.E. Maldague (Belgium) discussed the design of a reactor which would produce 20 000 shaft horsepower for merchant ship propulsion. It would depend for control on variations of the temperature and composition of the moderator, which is a mixture of ordinary and heavy water, rather than on neutron absorbing control rods. (Rods would, however, be used for emergency shutdown of the reactor). Mr. Maldague cited studies which indicated that such a reactor would have lower capital and fuel costs than a usual type of pressurized light water reactor of the same output. Refueling of a ship would be required only once each three years.

Favorable experience with plutonium fuel in the Soviet Union's fast reactor, BR-5, and the intention to use plutonium in the French "Rapsodie" plant, have already been referred to. Several other papers also gave encouraging indications that plutonium, which is produced as a by-product of the fission process in uranium fueled power reactors, would itself prove an effective reactor fuel, thus greatly enhancing economic prospects for the nuclear power industry as a whole. M. McNelly (USA) described plans for a 10 MW(th) Experimental Fast Oxide Reactor which might use as fuel a mixture of plutonium and uranium oxides. J.K. Dawson (United Kingdom) described experiments in which the behavior under irradiation of uranium oxide slightly enriched with plutonium oxide was found to be not substantially different from that of uranium oxide alone. Finally, J.R. Triplett (USA) described favorable initial experience with the Plutonium Recycle Test Reactor, a heavy water-moderated and -cooled reactor which employs both uranium and plutonium as fuel.

In his concluding remarks to the participants, Pierre Balligand, the Agency's Deputy Director General for Technical Operations, observed that no comparison of the merits of different reactor types had been attempted at the symposium, since considerable advanced research was still required on most of them before definitive answers to technical and economic questions would be possible. Nevertheless, Mr. Balligand said, it was encouraging to note the extent to which the technology of nuclear reactors had advanced and how many new roads had been opened to the solution of outstanding problems.