New directions in nuclear energy

by G. Tavernier*

Important differences of approach to the back-end of the nuclear fuel cycle between North America, and Europe and Japan, were evidenced at the Third European Nuclear Conference, held in Brussels from 26 to 30 April this year. About one thousand nuclear industry specialists from 25 countries attended the conference which dealt with new trends in the development of nuclear energy, with emphasis on the nuclear fuel cycle.

The differences of approach to the fuel cycle stem from the fact that North America has large indigenous energy resources, whereas Western Europe and Japan have next to none. This also explains the different political attitude of the USA towards the development of the fast breeder. Nevertheless, US representatives at the conference put forward a broad plan for FBR demonstration (including completion of the Clinch River Breeder Reactor) leading to a phase-in of the FBR between 2000 to 2010. In Canada also, strategic studies have led to the conclusion that advanced fuel cycles may not become economically attractive before 2010. Western Europe is already in the process of building industrial facilities for the treatment and storage of waste products, while North America is still at the preliminary stage.

It was reported at the conference that generally favourable operating experience has been gained in all 23 countries with civil nuclear power programmes. However, statistics on availability and operating costs show that improvements could be made in refuelling downtime, maintenance and test time, as well as in equipment and operator performance. Following the TMI accident, the Institute of Nuclear Power Operations (INPO) was set up in the USA to develop better standards for nuclear plant operation. Owners of nuclear plants from all countries could profit by joining INPO, thereby creating reciprocal international exchange of information on nuclear plant operating experience, including incidents and accidents.

Two options exist for the post-irradiation fuel cycle: final storage; or reprocessing, perhaps preceded by temporary storage. Both options were shown to be technically feasible; consequently choice of policy will be made on the basis of their comparative economics and energy conservation factors. If reprocessing is selected, the recovered plutonium can best be used in fast breeder reactors. As the La Hague reprocessing plant already operates reliably and other plants are scheduled to follow, excess plutonium will probably be available before fast reactors are put into commercial operation; this will lead to plutonium recycling in water reactors.

The fast reactor, which is expected to supply a large part of our future energy requirements, is now being demonstrated in several countries. In all cases the same basic options are used: sodium coolant; oxide fuel; and same reprocessing method as for LWRs. If the only criterion is competitiveness, the breeder might not be industrially deployed before the year 2000. But according to participants at the conference, economic criteria are not the only ones to be taken into account: commercial development of breeder in some industrialized European countries should not be further delayed for the following reasons: energy independence; risk of a shortage of cheap uranium; the time required for commercial penetration of the breeder is about 25 years, which will approximately correspond to the time available before uranium supplies are exhausted. Efforts must now be concentrated on improving the competitiveness of fast reactors, as compared with thermal reactors: for this purpose, international collaboration should be strengthened.

Nuclear fission is among the reasonable solutions to the problem of energy supply in most industrialized countries. However, future development of nuclear energy requires a more general public acceptance. The conference concluded that it is imperative to define coherent standards, without redundancies or unnecessary and misleading duplications; an endless cascade of superfluous safety measures should be avoided. As in the past, plant reliability and public safety, at reasonable investment cost, will be ensured through the application of proper standards. For non-proliferation reasons, nuclear activities throughout the world must remain under the scrutiny of IAEA: efforts will be devoted to reinforcing manpower, inspection equipment and the Agency's budget.

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Fuel supply and production

Stocks of natural and enriched uranium have increased following a reduction in the expected number of new nuclear power plants being put into operation. This situation, which will continue well after 1990, will be partly responsible for prolonging the depressed state of the uranium market. A similar problem to that of the natural uranium spot market could result in the enrichment-services market if electricity producers try to sell their oversupply. During the 1990s, commercialization of advanced isotope-separation techniques, such as laser excitation and uranium plasma, can be expected. In this context, the centrifuge enrichment method now in use in the United States could be considered as a temporary solution.

Conference participants emphasized particularly that the manufacture of plutonium fuels for light-water reactors is of special interest, in view of the large amount of plutonium that will have to be stored in the coming years following spent fuel reprocessing in several European countries. Papers presented showed that experience acquired, especially in Belgium and F.R. Germany, demonstrates that plutonium fuel elements can be manufactured on an industrial scale; the total cost of plutonium fuel subassemblies is at present about the same as for those using enriched uranium; U-Pu mixed-oxide powders can be used as starting material. In F.R. Germany, such mixed-oxide powders are obtained by calcination of an intermediate product, UPuC obtained by carbonate precipitation from U-Pu nitrates. This process, already in use for the fabrication of enriched uranium fuel, has the advantages that the fuel is completely soluble in the nitric acid used in the first stage of reprocessing and that much less dust is produced during pellet fabrication. Other processes are still being developed: one example is the gelation technique for producing U-Pu oxide microspheres, reported by Swiss and Belgian speakers. Considerable experience has already been gained in the fabrication of fast reactor fuel elements.

Core management

Current practices in fuel management aim to prolong the operating cycle and improve repositioning patterns, thus achieving higher burn-up on unloading. These trends stem from the need to make the best use of the uranium supply and a wish to reduce the cost of producing electricity. In this way, it is also hoped to slow down the rate at which fuel is removed from reactors for interim storage so as to counterbalance the lack of reprocessing capacity that will prevail throughout the next decade.

It now seems that these objectives will be attained: indeed, the integrity of light-water reactor fuel rods is at the 99.9% level, and data are being gathered that demonstrate the acceptability of increased discharge burn-ups. In addition to improved fuel performance, the reliability of core components has been increased through improvements in fuel-assembly hardware and control rods. It is now acknowledged that fuel assemblies and control rods are among the most trouble-free components of present-day power plants and that the progressive implementation of higher burn-ups (up to an average of 40 MWd/kg) can take place.

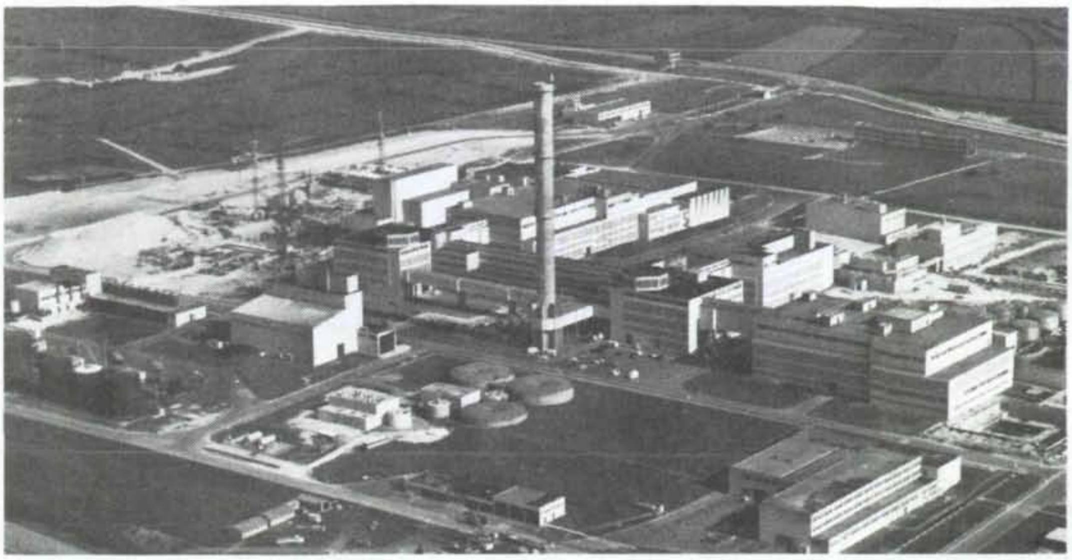
An increase in the length of the operating cycle implies the use of burnable poisons and the present state of knowledge of the subject was described at the conference. The burnable poison already in use in BWRs is gadolinium, in the form of Gd_2O_3 mixed with uranium. So far, commercial PWRs use burnable poisons (pyrex rods) only during the first cycle, and economic optimization has not been sought. Considerable effort is now being devoted to qualifying new burnable poisons for PWRs including gadolinium and B_4C. Qualification of gadolinium has reached an advanced stage: several fuel suppliers described the experience acquired with gadolinium-containing rods irradiated in power reactors. Much experimental data has been gathered and calculation methods are in the process of being checked. Use of gadolinium in PWR reloads is foreseen in the near future. The design of burnable poisons has also been considerably improved through the use of Zircaloy-clad $B_4C - Al_2O_3$ rods.

Other trends are also apparent. These include the use of natural uranium-oxide axial blankets (10 to 15 cm thick) at both ends of the fuel assembly which are intended to decrease separative-work requirements and hence to reduce fuel cycle costs. Prototype subassemblies with axial blankets are currently undergoing irradiation in US power plants.

Some of the papers at the conference dealt with the performance of fast-breeder reactor fuel, mainly in the French reactors Rapsodie and Phenix: irradiation of 30 000 fuel pins with burn-ups of up to 25 per cent has been carried out in Rapsodie while more than 100 000 fuel pins have been irradiated in Phenix. Nearly 6% of the latter are experimental rods and a maximum burn-up of 12 per cent has been demonstrated. On the basis of these results, the Phenix fuel burn-up limit has been increased from the initial 5 to 10 per cent (maximum pellet burn-up).

Reprocessing policy

Participants at the conference stressed the importance of reprocessing irradiated fuel, not only as a means of making better use of the world's energy resources, but also in order to reduce the volume of high-activity waste to be stored. In the United States, the conference was told, the Reagan administration is favourable to reprocessing but the exact role of industry and the Federal Government in this matter still remains to be defined. The Barnwell plant for reprocessing light-water reactor fuels could be operational by 1987, although an additional US$ 730 million investment



The reprocessing plant at La Hague, France. Although the plutonium recovered from spent fuel by reprocessing can best be used in fast reactors it may be recycled in water reactors, according to some views at the conference.

must be made for waste treatment and the plutonium tail-end laboratory. A research programme on reprocessing breeder-reactor fuel is still in progress with the aim of developing a fully automatic reprocessing facility by 1990; special emphasis is being put on the development of remote-maintenance technology and on the use of salt-free reagents.

In France, the reprocessing of light-water reactor fuel has reached the commercial stage and industrial experience is now being aquired in reprocessing breeder-reactor fuel. This is illustrated by the following points: more than 11 t of fast-reactor fuel have already been reprocessed at the Marcoule and La Hague plants; for Rapsodie and Phenix, the fuel cycle is closed; and a plant with a reprocessing capacity of 130 t/yr for fast-reactor fuel is under investigation – it would be able to reprocess fuel from six plants of the Superphenix type, as well as fuel from Phenix and SNR 300. The F.R. German r&d programme on reprocessing is devoted to breeder-reactor fuel, whereas industrial programmes are restricted to LWR fuel. The first pilot unit for FBR fuel reprocessing is in operation at the Nuclear Research Centre at Karlsruhe and a conceptual study for a second unit with a capacity of 50 kg of heavy metal per day is being carried out.

If the Belgian Parliament decides to reopen it, the Eurochemic plant could be used to reprocess recycled fuel. Studies on adaptation of the flow sheet and equipment have shown that no fundamental changes will have to be made to the plant except in the head-end and plutonium tail-end areas. The Belgian utilities have clear views on the back-end of the fuel cycle: reprocessing is considered indispensable. This was illustrated at the conference by a description of the *Hermes* research

The prototype Fast Reactor at Dounreay, Scotland.

facility whose aim is to develop FBR oxide fuel reprocessing head-end.

All reprocessing operations reported at the conference are based on the *Purex* process, except for one paper from the CMEA* countries which described a new technique for reprocessing breeder fuels. This process, which uses melting of the pin cladding followed by fluorination in the gaseous phase, is soon to be tested in a reprocessing campaign on spent fuel from BOR-60.

Spent fuel storage

The interim storage of spent fuel is presently an essential part of spent-fuel management as a result of reprocessing delays and the lack of a well-defined policy with regard to the back-end of the fuel cycle. For some years now, a considerable effort has been devoted to the optimization of storage solutions. Though spent-fuel storage under water is a proven technology in general use at power and reprocessing plants, dry storage techniques can provide significant technical and economical advantages with respect to passive cooling systems, modular design, etc. Wet storage is feasible and safe for several decades at least; a preliminary heat-decay period in wet storage may be required before long-term dry storage. An away-from-reactor storage facility is a more economical option than new storage basins on reactor sites, except for sites with six or more reactors. In Sweden, for example, an underground intermediate storage facility with a storage capacity of 3000 tons of uranium with possible future extension to 9000 tons is under construction. Fuel-rod consolidation can lead to reductions of 50% both in the required storage area and in transport-cask handling operations. Extended fuel burn-up has a favourable impact on spent fuel storage as it reduces the latter's volume; in addition, it is not expected to affect fuel behaviour during storage under water. The final storage of spent fuel without reprocessing is technically feasible but still requires demonstration.

Waste management

The Federal Republic of Germany's policy on waste management includes reprocessing as a compulsory step. However, the state of Lower Saxony has asked for an analysis of the alternative option: spent fuel storage. In the meantime, a large storage pond for spent fuel is being built at Gorleben and three more possible reprocessing sites are being evaluated. Studies have shown rock salt to be the most attractive medium for waste disposal. In Belgium, management of radioactive waste is directed towards achieving maximum volume reduction, stabilization of the concentrates, selection of suitable media in which to dispose of these concentrates, and at achieving these at reasonable cost. Chemical and physical conditioning of radioactive waste has received particular attention. The bitumen waste-coating process and a concentration and immobilization process for reactor effluents are already in use.

The UK considers reprocessing an essential part of the global waste-management strategy and has continued with its planning of the THORP facility. In the meantime, a large storage pond has been constructed at Windscale. For low-level waste, ocean disposal is considered a good solution. Medium-level waste is stored in trenches from 30 to 40 m deep. For alpha and high-level waste, geological disposal is foreseen and the UK Government considers its feasibility has already been demonstrated so that further work in the field is unlikely in the near future.

In France, fuel is reprocessed. Low-level waste is stored at the La Manche facility, medium-level waste will be stored at a new site, and high-level waste in granite. Switzerland has examined very seriously the possibility of using granite formations to store high- and medium-level waste. In Denmark, feasibility studies have been performed regarding the storage of high- and medium-level waste in salt domes. The Commission of the European Communities has confirmed that it will continue to support a comprehensive r&d programme in the field of waste treatment and disposal.

High-level waste conditioning in glass is becoming the accepted practice. But progress was also reported in research on new matrix materials for retention of high-level waste during long-term deep geological disposal: nickel sulphide/graphite matrix, or synthetic rock containing minerals, may in the future constitute alternatives to the vitrification process.

Decommissioning of fuel cycle facilities

A review was made of all aspects related to the decommissioning of nuclear installations: techniques, safety analyses, regulations, cost, site cleaning and requirements for future r&d work. Illustrations of decontamination and decommissioning activities were given at the conference: decontamination, dismantling, and packaging, process-equipment contaminated with plutonium and enriched uranium at a US facility specialized in the fabrication of light-water reactor and fast-breeder reactor oxide and carbide fuels; and a 150 000 man-hour decontamination and partial decommissioning programme at Eurochemic's reprocessing plant in Belgium. Following decontamination access to all process cells and equipment became possible.

* Council for Mutual Economic Assistance.