Chapter 1

BACKGROUND AND OVERVIEW

1.1. PROGRESS WITHIN THE PERIOD 1985 - 1998

1.1.1. Demonstration reactor operation

The outstanding success of the decade has undoubtedly been the reliable operation of the BN-600 plant at Belojarsk in Russia. It has been in operation since 1980, and has an overall lifetime load factor of 72 %. In 1992 it achieved a load factor of 83.5 %. The success was achieved in spite of a number of incidents including sodium fires. The effectiveness of the protective and remedial measures clearly demonstrates that a sodium-cooled fast reactor is capable of sustained reliable contribution to an electricity supply system.

In France the Super Phenix plant at Creys-Malville was successfully commissioned and operated, but not without difficulty. Three incidents marked the commissioning procedure and caused lengthy delays. In 1987 there was a sodium leak from the used fuel storage drum, in 1990 there was an air leak into an auxiliary circuit which caused extensive pollution of the primary sodium, and also in 1990 an exceptional snow fall caused the collapse of the roof of the turbine hall with extensive damage to the steam plant. Partly as a result of this experience the safety of the plant was thoroughly reviewed and modifications to improve the response to secondary sodium fires were made. A public enquiry on renewal of the operating license was held and reported positively, and in 1994 the plant was ready for restart. This was further delayed by a small leak of argon from the sealing bell surrounding one of the intermediate heat exchangers. Corrective action was taken and in the latter part of 1995 and through 1996 power was gradually raised to the full-power level. Later political changes called future operation into question and in February 1998 the French Government finally confirmed to discontinue its operation.

1.1.2. Prototype reactor operation

In Germany construction of SNR-300 was completed and commissioning was successfully taken to an advanced stage. A small leak in a ferritic steel sodium dump tank was found, and there was some pollution of the primary sodium by moisture released from shielding material. Effective technical provisions to meet the extensive criticism of the safety of the plant were successfully put into place, but the project was eventually terminated for political reasons.

The earlier problems of steam leaks in the evaporators of the PFR plant in Scotland were successfully solved, but in 1987 there was a large leak in one of the superheaters. This gave rise to a major review of the protection against large sodium-water reactions. In 1991 the primary sodium was polluted by oil from one of the sodium pumps. These technical problems were overcome successfully, and in addition in 1990 an operating license (which hitherto had not been a legal necessity) was obtained from the safety authority after a review against the same criteria applied to commercial thermal reactors. When it was finally shut down in 1994 PFR was operating with good reliability.

The BN-350 plant in Kazakhstan has operated for over 20 years, and a case for future operation has been made. Means of improving the protection of the plant against the effects of earthquakes have been identified. In 1989 there were failures in the two modular steam generators, which were repaired and returned to operation in 1993. These steam generators provide an important emergency decay heat rejection capability.

There are similarities between BN-350 and the Phenix plant in France, which is of a similar age. Phenix also has been operating for more than 20 years, and has been subject to a review of the requirements for future operation which has revealed the need to improve the ability of parts of the auxiliary systems to withstand seismic damage. There have been leaks on the secondary side of some of the intermediate heat exchangers and as a result they are all to be replaced. Inspection in the period 1991 - 1993 revealed cracks in some of the secondary circuit components made of 321 stainless steel, and repairs have been made. In 1989 and 1990 a series of fleeting negative reactivity transients were experienced, but in spite of intense investigation the cause has not been identified.

In Japan construction of the MONJU reactor was completed in 1991. Since then extensive start-up tests have been completed leading to criticality in 1994 and connection to the grid in 1995. Completion of commissioning has been delayed by a secondary sodium leak in December 1995.

1.1.3. Technical achievements

The period 1985 - 1998 has seen substantial technical advances. Chief among these has been the demonstration of reliable operation by the BN-600 plant, and the reliable operation of fuel at high burnup. In PFR large numbers of mixed-oxide fuel pins reached more than 15 % burnup without failure, and several reached 20 % burnup with an irradiation dose in excess of 130 displacements per atom (dpa) in the cladding. These results have been confirmed and surpassed by irradiations in Phenix to more than 160 dpa. The fuel cycle, based on mixed oxide fuel and PUREX reprocessing, has been closed in that plutonium from irradiated fuel has been separated, fabricated into new fuel and recycled to the reactor for further use. In the USA burnup of up to 20 % has been achieved in ternary alloy U - Pu - Zr metal fuel. The basic technology of the use of fast reactors to breed and recycle plutonium in a commercially acceptable manner has thus been demonstrated.

If a coolant loss occurs by boiling or gas intrusion, large LMFR cores show a significant reactivity increase. According to some experts, an increase of coolant temperature causes expansion of the absorber-rod guide structure, of fuel in the axial direction, and of the core grid plate in the radial direction, leading to negative reactivity coefficients that counteract a positive sodium-void coefficient in large LMFRs. Since cooling disruptions and sodium boiling may occur in a much shorter time than passive negative feedback, there was a strong incentive to reduce the positive sodium-void coefficient in large LMFRs. An IAEA/EC project assessed the capability of reducing the sodium-voiding feedback reactivity of the core by introducing a sodium plenum above the core in place of the upper axial blanket. The analysis showed that the overall void effect for the reference BN-800 MOX-fuel reactor might be close to zero. Further investigations were needed to determine differences in severe accident responses in order to estimate the improvement in overall safety that could be achieved from a reduction in the sodium-void value for a reactor core. It has been established by analyses done in various countries in the framework of the IAEA/EC 1994-1998 project that the upper sodium layer above the fissile core region instead of the upper axial blanket is quite an efficient design measure to prevent the net reactivity to approach prompt criticality in the severe reactor accidents.

An important theme of the decade has been that of protection against sodium fires. The concern started with a non-nuclear event, a fire in a solar power facility at Almeria in Spain in 1986, in which structural steelwork suffered significant damage. Partly as a result of this experience, with detailed experimental support, extensive modifications were made to the Super Phenix secondary circuit cells to improve sodium leak detection, and to mitigate the consequences and secondary damage in the event of a major sodium leak. The fire protection systems at Phenix have also been improved.

There have been significant sodium leaks and fires from the BN-600 primary (1993) and secondary (1994) circuits. In both cases the protective systems were effective, the damage was not extensive and repairs were effected quickly. Nevertheless the protective systems have been improved. A secondary sodium leak and fire at the MONJU plant in late 1995 has caused a longer operational delay, and plant modifications will be made. The finding of cracks and defects in stainless steel components of older reactors such as PFR and Phenix has contributed to the general concern to provide adequate sodium fire protection measures.

Reactor safety experience has been good and sodium-cooled fast reactors have continued to give particularly low radiation doses to operating personnel and low releases of radioactive material to the environment, even in the cases of the sodium fires mentioned above. Safety has been examined closely by the licensing authorities in some countries, in all cases with satisfactory results. Super Phenix was subjected to a major public safety review, which made a positive recommendation. PFR was licensed to modern safety standards applicable to commercial thermal reactor plants. The EFR design has been reviewed and shown to meet safety standards comparable with those of future PWRs.

Good progress with the decommissioning of the Rapsodie reactor has been made, although the success was marred by a fatal accident. Decommissioning of PFR has also been started.

1.1.4. Design advances

Major steps towards commercial reactor designs have been made. In Western Europe the European Fast Reactor (EFR) design has been completed. This synthesises the extensive experience from France, Germany and the United Kingdom of large pool-type oxide-fuelled reactors. One of the outstanding achievements of the EFR programme has been to make firm and reliable cost estimates. Althought the construction of a reactor to the EFR design may not be commercially possible in the near future, but a well-validated way forward to commercial utilisation of fast reactors has been established.

Oxide fuel and sodium coolant have been chosen in several other countries. In Russia several designs for future power plants have been produced. These apply the experience from BN-350 and BN-600, together with modern safety and commercial standards, to a range of potential applications. In India the PFBR design is based on construction and commissioning experience with FBTR. The Japanese DFBR design follows a similar trend except that it utilises the loop layout of the primary circuit with separate vessels for the reactor, the primary pumps and the intermediate heat exchangers.

In the USA GE continue to follow a different line by making use of metal fuel in their ALMR design. This has good safety characteristics for many accident situations, and also allows use of the IFR integral pyrometallurgical reprocessing and waste handling technology. The

ALMR, in common with the Russian BMN-170 design, is a relatively low-power reactor which can be utilised either singly to meet small electrical loads in remote locations, or as one of several modules making up a large power station, depending on the economic circumstances.

1.2. CONTENTS OF THIS REPORT

Chapter 2 details operating experience from the world's prototype and demonstration fast reactors, BN-350 and BN-600 in the former Soviet Union, Phenix and Super Phenix in France, and PFR in the United Kingdom. Smaller test reactors such as FBTR, JOYO, BOR-60, EBR-II, FFTF and Rapsodie are not covered. Chapter 3 describes pre-operational testing of SNR-300 and MONJU. Between them these two chapters give a complete account of the decade's technical progress on fast reactors of greater than 250 MW(e) capacity.

Chapters 4 to 8 survey the areas where major technical advances have been made. Chapter 4 is an account of the neutron physics of large oxide-fuelled breeder cores, the calculation methods available for assessing the performance of these cores, and the state of validation of the methods. Chapter 5 is an account of new developments in reactor safety, with particular attention to design methods for the minimisation of risks, and to the question of the reliable removal of decay heat. Chapter 6 covers developments in instrumentation and inspection techniques, with particular reference to steam generators and to in-service inspection and repair. Ultrasonic and acoustic techniques are dealt with in some detail. Chapter 7 surveys advances in the understanding of the performance of fuel and core materials at high burnup and high radiation dose. Chapter 8 surveys some of the engineering fields in which there have been notable advances, particularly in thermal-hydraulics and the design of sodium pumps. It also covers the experience of decommissioning the Rapsodie reactor plant.

Chapters 9 and 10 look towards the future. Chapter 9 describes the substantial advances in reactor design which have been made, covering the EFR design, the Russian BN-1600M, BN-800, BN-600M and BMN-170 options, the American ALMR, the Japanese DFBR and the Indian PFBR (all of which are in the category of prototype or demonstration reactors), and concludes with an important account of the design of the smaller Chinese CEFR-25 test reactor. Finally Chapter 10 reviews the prospects for development of fast reactors in the future.