SUMMARY

1. INTRODUCTION

The IAEA Technical Committee Meeting (TCM) on Absorber Materials, Control Rods and Designs of Backup Reactivity Shutdown Systems for Breakeven Cores and Burner Cores for Reducing Plutonium Stockpiles, was hosted by the Institute of Physics and Power Engineering (IPPE), Obninsk, Russian Federation, from 3 to 7 July 1995. This was the third IAEA meeting held on the subject of absorber materials and control rods for liquid metal fast reactors (LMFRs). The other two meetings were held in Dimitrovgrad (1973) and Obninsk (1983), in the Former Soviet Union.

Thirty-five specialists from France, Germany, India, Japan, the Republic of Kazakhsan, the Russian Federation and the Republic of Georgia (observer) attended the meeting.

The meeting had seven sessions. The sessions were chaired by B. Kryger (France), R. Babu (India), M. Edelman (Germany), K. Okada (Japan), T. Kaito (Japan), D. Favet (France), V. Risovany (Russian Federation), J.P. Truffert (France) and I. Bairamashvili (Republic of Georgia).

The main topics of discussions were:

- status of control rod designs for fast reactors and experience with operation,
- properties and behaviour of absorber materials for control rods; results of post-irradiation examination of absorber materials, and mechanisms affecting their properties and behaviour,
- design of a backup reactivity shutdown system utilizing passive mechanisms:
  - Curie point electromagnetic mechanism,
  - enhancement of thermal expansion of absorber rod drive lines,
  - hydraulically suspended control rods,
  - gas expansion modules in the core, and
  - the possibility of optimizing the reactivity coefficients and the efficiency of Pu burning by using absorber and moderator materials in the core.

A total of 23 papers were presented, and a technical tour of the IPPE also took place.

2. DISCUSSION AND CONCLUSIONS

2.1. Status of control rod designs for fast reactors and experience with operation

Significant experience, accumulated on absorber materials for fast reactor control rods, was presented at the meeting. Boron carbide of high enrichment (45-90% of ^{10}B) and vented absorber pins (with sodium bonding) have been successfully used in the Phénix, BN-350, BN-600 and Superphénix (SPX) reactors. The control rod lifetime for the BN-600 reactor is 500 effective days (e.d.); the lifetime predicted for the SPX reactor (based on the tests in the Phénix reactor) is 640 e.d. Boron carbide is the favoured absorber material. Europium oxide (Eu_2O_3) appeared to be an alternative to boron carbide of natural enrichment.

Investigation of the properties and behaviour of B_4C have been carried out in the BN-350, BN-600, BOP-60, Phénix and JOYO reactors for a broad range of conditions affecting its endurance. Data from these studies defined the behaviour of irradiated absorbing materials (both pins and the whole rods) provide the basis for improved control rod designs and extended control rod lifetimes.

Swelling of irradiated boron carbide is one of the main factors limiting the lifetime of the rods. The dependence of the boron carbide swelling rate (Δd/d%/B%) on the burn up was determined from post-radiation studies of control rods from the BN-600 reactor. After about 500 e.d. the boron burn up was ~18%. A minimum swelling rate of ~0.1% for enriched boron carbide and 0.2-0.4% for natural boron carbide was observed at a temperature of 500°C. At a working temperature of about 800°C, the swelling rate is ~1.0% per percent burnup for natural boron carbide and 0.6% per percent burnup of enriched boron. Some reserve remained since the gap between the absorber and cladding was not filled completely. Under these conditions mechanical interaction of the cladding was not observed, and the cladding material retained a sufficient reserve strength.

A series of tests were carried out in the Phénix reactor irradiating an enriched boron carbide rod for 240 e.d. These experiments showed that the in-pile residence time of the pin is limited by the mechanical interaction of boron carbide with the cladding, owing to absorber fragments entering the gap between the absorber and the cladding.

Irradiated boron carbide data (swelling rate and gas release on burnup) were also obtained in Japan in tests in the experimental fast reactor JOYO. Burn up of about 23% (230×10^{26} capt/m^2)[1] was achieved at a maximum temperature of 1400°C. The dependence of pellet swelling and gas release on burnup was measured. Japanese and French results of the absorber material behaviour under irradiation are in good agreement but differ in some cases from Russian results. It appears that the differences can be explained by differences in methods of obtaining enriched boron carbide. However, the results obtained are not contradictory, and they improve the understanding of the swelling and gas release processes.

New absorbing materials and new pin designs are required to achieve control rod lifetimes of 1000 e.d. Some measures to increase the control rods lifetime for existing reactors

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[1] The abbreviations capt. or cap. stand for capture

were proposed by the French. The first proposal was to reduce the capture rate in boron carbide by lowering the ^{10}B enrichment of the B_4C pellets in the lower part of the control rods pins. The second proposal was to prevent absorber fragment relocation by providing a thin stainless steel shroud to enclose the pellet stack.

Considerable progress has been made in the Russian Federation in the design and manufacture of rods containing absorbing (boron carbide) and moderating (zirconium) hybrid materials. Using this design with its lifetime of 450 e.d. would result in considerable saving of high cost enriched boron.

The participants agreed that the most efficient way to utilize high enrichment boron is to separate it from irradiated materials. The development of technology for reprocessing irradiated boron carbide, which provides complete removal of radionuclides from irradiated materials, was presented at the meeting. This permits repeated use of ^{10}B enriched B_4C in fast reactors.

It became clear after discussion that the French control rod calculation code REGAIN can analyse both steady state and transient pin behaviour and covers thermal, mechanical and some chemical characteristics. For boron carbide materials the code can deal with both sodium bonded and helium bonded design concepts.

The meeting participants concluded that the problems of reliable and effective control rods for sodium cooled fast reactors are being solved.

2.2. Optimizing core safety parameters for a plutonium burner reactor using absorber and moderator materials

It was noted that two approaches to optimize a fast reactor core for plutonium (or minor actinide) burning have been considered in France: the "dilution approach" (about two thirds of the pins are fissile pins, the remaining one third are fuel free) and the "poisoning approach" (the absorber B_4C is introduced in the diluent subassemblies). At present, the dilution approach is preferred since it allows better core safety parameters (mainly the Doppler constant). Data presented in the French paper indicated that the introduction of the moderator in the fuel bundle of the B_4C poisoned core strongly increases the Doppler constant (+60%) and reduces the sodium void reactivity worth (-20%). As a result the poisoned core option with $^{11}B_4C$ has similar plutonium burning characteristics and better safety parameters than the dilution option. Its main advantages result from the large diameter fuel pins which increase fuel lifetime using a standard fuel bundle. The use of $^{11}B_4C$ as filling material does not introduce additional technical problems.

It was concluded that the poisoned reactor option deserves further investigation.

2.3. Advanced passive reactor shutdown systems

The meeting participants noted that in classic core disruptions (unprotected loss of flow (ULOF) and unprotected transient overpower (UTOP), the reactor can be shut down only by inherent passive reactivity feedback mechanisms. Therefore, special measures to provide additional negative reactivity are needed.

The Russian Federation has developed a backup passive shutdown system based on hydraulically suspended absorber rods (HSAR) which drop into the core when the coolant flow rate in the core falls below 50%. Full scale HSARs for the BN-600 and BN-800 reactors have been tested. This system is capable of shutting the reactor down in a ULOF transient.

The German system for passive shutdown of the European Fast Reactor (EFR) uses enhanced thermal expansion of control rod drive lines (CRDL) to provide automatic scram. This system forces the control rods into the core when pre-set coolant temperatures are exceeded. This device uses a hydraulic expansion module and two individual (coaxially arranged) drive lines. The sodium has a larger thermal expansion coefficient than the container material. This system is capable of shutting the reactor down in ULOF and UTOP transients.

The demonstration fast breeder reactor (DFBR) in Japan includes the following passive backup shutdown systems:

- gas expansion modules (GEMS), and
- self-actuated shutdown systems (SASS) using a Curie point magnetic alloy.

In addition to GEMS and SASS, a feasibility study of the enhanced thermal expansion of CRDL is in progress.

The French presentation described and evaluated a third shutdown level for the EFR project which has been developed, implementing the following four new device systems:

- a system which terminates the power to the absorber electromagnets after a loss of primary pump electric power supply,
- a device for CRDL passively enhanced thermal expansion,
- a device which overcomes control rod jamming by motorized insertion of absorber rods, and
- a mechanical stroke limitation device which passively terminates the withdrawal of a faulted control rod.

The inclusion of these systems in the EFR project leads to a significant improvement of the shutdown function.

The shutdown system of the Indian prototype fast breeder reactor (PFBR) incorporates diverse and redundant features and includes the following systems:

- a system which terminates the power supply to the absorber electromagnets after a loss of pump power,
- a gas expansion module,
- a Curie point magnetic switch

It was concluded that with the introduction of these passive backup shutdown systems, future advanced LMFRs will have a very high degree of safety.