BR2 Mixed Core Management

Bernard Ponsard, André Beeckmans
CEN.SCK, Boeretang 200, B-2400 Mol, Belgium

1. Introduction

The BR2 reactor is a high flux materials testing reactor, still using 93% enriched uranium in the form of aluminium cladded cylindrical plates. It is moderated by light water and beryllium. The reactor core is composed of beryllium hexagons with central irradiation channels of 200, 84, 50 or 33 mm diameter. The cooling water circuit is pressurized at 12 bar. The pressure vessel is localized in a pool filled with demineralized water. The operating power is routinely between 50 and 80 MWth so that unperturbed thermal neutron fluxes of 10^{15} n/cm².s can be achieved in the central channel of the core.

In order to optimize the utilization of the available HEU inventory, the CEN.SCK considers the possibility to elaborate a 'Mixed Core Strategy' based on the irradiation of standard 93% ^{235}U fuel elements together with 72% ^{235}U fuel elements using uranium recovered from the reprocessing of BR2 spent fuel. The exclusive use of 72% ^{235}U fuel elements has also been considered.

2. Core configuration requirements

The BR2 core configuration management has to satisfy the following aspects:

- the experimental programme,
- the safety criteria,
- the economical use.

The experimental programme requires specific irradiation conditions: available volume, thermal and fast neutron fluxes, gamma heating, temperatures, irradiation time, ...

The safety criteria are fulfilled by the cooling capability, the negative reactivity available in the control rods at any moment of the cycle (operation and shutdown), the regulation of the reactor, the hot spot on the fuel plates, ...

The main optimization parameters regarding the operating costs of the core are:

- the definition of a minimal core configuration satisfying the irradiation conditions,
- the location of the control rods in the core (efficiency taking into account the antireactivity of the experiments, the length of the cycle, ...),
- the choice of the right fuel element type (mass, density, burnable poisons, ...),
- the definition of the operating regime taking into account the irradiation programme, the ^{3}He poisoning level of the beryllium matrix, ...

3. Standard BR2 fuel elements

The standard cermet BR2 fuel elements of the type VIn G, presently manufactured by CERCA (France), consist of an assembly of 6 concentric cylindrical plates and are characterized by:

- total mass of ^{235}U: 400 g; enrichment in ^{235}U > 90%,
- thickness of the fuel meat: 0.51 mm; density of 0.060 g $^{235}U/cm^2$ or 1.31 g U_{tot}/cm^3,
- burnable poisons: 3.8 g B_{nat} in the form of B_4C and 1.4 g Sm_{nat} in the form of Sm_2O_3,
- thickness of the plates: 1.27 mm,
- water gap thickness between the fuel plates: 3 mm.

The BR2 core configurations used with the second beryllium matrix from 1980 till 1995 were often centred around the central channel H1. They were characterized by the loading of 28 to 39 fuel elements, 6 or 7 control rods, one regulating rod and have produced a total energy of 178 920 MWd.

The standard fuel elements allow a reactor operation at a power of about 60 MW during 21 days with 5 or 6 batches of fuel elements (fresh and partially burnt). The theoretical evaluation of the consumption of fresh fuel elements for the production of 1 000 MWd and a mean burnup of 50% at elimination is 6.2; the corresponding maximum burnup at mid-plane is about 62% or 1.6 e+21 fission/cm³. The experimental value for the exploitation of the second BR2 beryllium matrix gives a value of 5.7 fresh fuel elements loaded per 1 000 MWd for a mean burnup of 53% at elimination. This value depends on the operating regime, the configuration and the experimental loading.

4. AEA test fuel elements

In the frame of a 'Qualification Programme', 6 fuel elements were fabricated in 1994 by AEA-Technology (UK) with uranium recovered from the reprocessing of BR2 spent fuel at UKAEA-Dounreay. The programme had to:

- define the fuel specifications (^{235}U mass and density, burnable poisons, ...),
- define the technical specifications for fabrication,
- define the neutronic specifications (reactivity of the fuel element, ...),
- follow the recommendations of the 'Safety Advisory Committee',
- follow the QA/QC manufacture procedures,
- perform reactivity effects measurements of the fuel elements before each BR2 start-up,
- perform measurements during the irradiation (neutron fluxes, gamma heating, ...),
- analyse the final results.

The AEA test fuel elements of the type VIn E have the same geometry than the VIn G fuel elements and are characterized by:

- total mass of ^{235}U: 330 g; enrichment in ^{235}U = 72%,
- thickness of the fuel meat: 0.51 mm; density of 0.050 g $^{235}U/cm^2$ or 1.31 g U_{tot}/cm^3,
- burnable poisons: 1.8 g B_{nat} in the form of B_4C and 1.3 g Sm_{nat} in the form of Sm_2O_3.

They were irradiated during 5 cycles of 21 days in the BR2 reactor till a maximum mean burnup of 43% to 48% (about 1.3 e+21 fission/cm³), without release of fission products.

5. Comparison between VIn G and VIn E fuel elements

In the typical configuration 10U, illustrated in the figure 1, the standard **VIn G** fuel elements (93% ^{235}U) are routinely irradiated during 5 cycles of 21 days at a power of 60 MW, as follows:

- mean burnup of β=12% after 1 cycle in a C-channel,
- mean burnup of β=35% after 2 additional cycles in a A- or B-channel,
- mean burnup of β=45% after the fourth cycle in a D-channel,
- mean burnup of β=52% after a last cycle in a F- or G-channel.

This "theoretical" irradiation profile is in reality perturbed by the requirements of the experimental programmes. For example, the extension of the configuration 10 to satisfy the irradiation conditions of the LWR-CALLISTO loop required the loading of 3 additional fuel elements in G-channels, each for 1 or 2 more cycles; the mean burnup at elimination reached sometimes β=60%.

The **VIn E** test fuel elements underwent a typical irradiation profile of 5 cycles of 21 days at a power of about 60 MW in the 10U configuration, as follow:

- mean burnup of β=12% after 1 cycle in a C-channel,
- mean burnup of β=25% after a second cycle in a A- or B-channel,
- mean burnup of β=35% after the third cycle in a D-channel,
- mean burnup of β=48% after 2 additional cycles in a F- or G-channel.

The comparison of the measured reactivity curves of both types of fuel elements as a function of their mean burnup allows the definition of equivalences between 'batches of burnups':

BATCH	VIn G (93% ^{235}U)	VIn E (72% ^{235}U)
1	0 %	0 %
2	12 %	------
3	25 %	12 %
4	35 %	25 %
5	45 %	35 %
6 = β elimination	52 %	42 %

Three important conclusions can be drawn from the table above:

- there is no equivalence between a β=12% VIn G (93% ^{235}U) fuel element, characterized by the maximum of reactivity, and a VIn E (72% ^{235}U) fuel element; this creates an unbalanced inventory of the partially burnt fuel elements,
- the mean burnup at elimination is β=52% for the VIn G (93% ^{235}U) fuel elements and β=42% for the VIn E (72% ^{235}U),
- the inventory of VIn E (72% ^{235}U) fuel elements is limited to 4 'batches of burnups' in place of 5 for the VIn G (93% ^{235}U) fuel elements.

6. Mixed Core Management

The preliminary study made with the help of the calculation code GEXBR2-TRPT3-REAC2 showed the possibility to elaborate a strategy based on the **exclusive utilization** of VIn E (72% ^{235}U) fuel elements. Nevertheless this core management is not optimal because:

- the length of the cycle is mostly shorter than 21 full power days,
- the mean consumption of fresh fuel elements is about 9 fuel elements per 1 000 MWd,
- there is a build-up of β=35% fuel elements in the partially burnt fuel elements inventory; this results in a reduction of the mean burnup at elimination from β=42% to 35%<β<42%.

A further study showed that the **mixed utilization** of both types of fuel elements VIn G (93% ^{235}U) and VIn E (72% ^{235}U) can optimize the fuel utilization. Indeed this alternate strategy allows:

- a well balanced management of the irradiated fuel elements inventory,
- a mean consumption of 6.2 fresh fuel elements per 1 000 MWd,
- the possibility to alternate the loading of 6 VIn G (93% ^{235}U) fresh fuel elements for a cycle with 6 VIn E (72% ^{235}U) fresh fuel elements for the next cycle.

7. Conclusion

The BR2 fuel cycle management can be optimized by the fabrication and the irradiation of fuel elements with uranium recovered from the reprocessing of BR2 spent fuel. The VIn E fuel performances could be upgraded by increasing the amount of burnable poisons, the fuel mass, the fuel density, ... in order to obtain a higher reactivity effect at a burnup of about β=12% and a longer cycle duration. The preliminary results of the calculations need however to be confirmed by measurements on effective reactor loads.

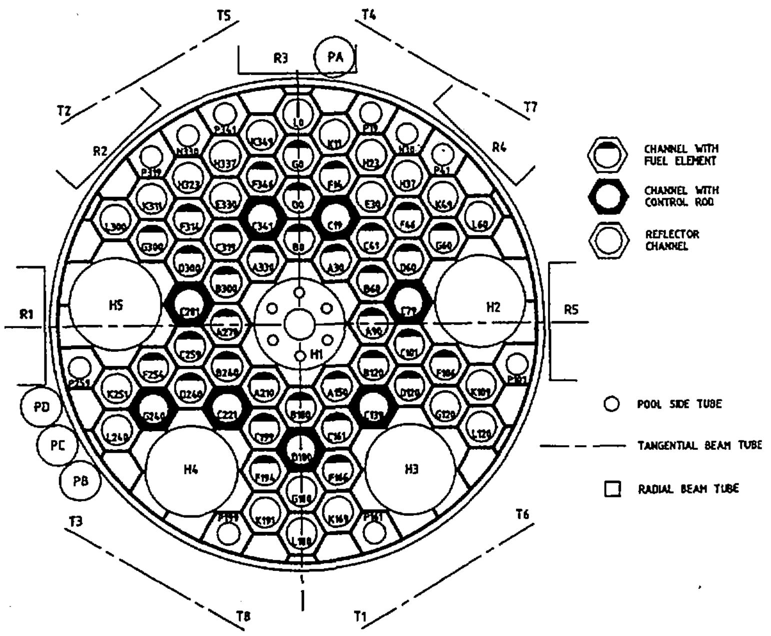

Figure 1 : Typical BR2 Configuration (10U)